TECHNOLOGY TRANSFER TO DEVELOPING COUNTRIES: THE CASE OF PHYSICAL ASSET MANAGEMENT IN SOUTH AFRICA

IAN BLAND HIPKIN

DOCTOR OF PHILOSOPHY

ASTON UNIVERSITY

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Bohlale ha bo phehwe ka pitsa e le nngwe.
E sa le lenyane, holo di sa tla.

Sotho proverb

Learning and knowledge know no bounds.
These are beginnings; more is yet to come.

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THESIS SUMMARY

This research investigates technology transfer (TT) to developing countries, with specific reference to South Africa. Particular attention is paid to physical asset management, which includes the maintenance of plant, equipment and facilities. The research is case based, comprising a main case study (the South African electricity utility, Eskom) and four mini-cases.

The primary interest is an understanding of the underlying mechanisms of TT, and an explanation of the events that occur, so an intensive research approach has been used. A preliminary survey was undertaken to establish important factors for managers in the context of TT.

A five level framework adapted from Salami and Reavill (1997) is used as the methodological basis for the formulation of the research questions. This deals with technology selection, and management issues including implementation and maintenance, and evaluation and modifications.

The findings suggest the Salami and Reavill (1997) framework is a useful guide for TT. The case organisations did not introduce technology for strategic advantage, but to achieve operational efficiencies through cost reduction, higher quality and the ability to meet customer demand. Acquirers favour standardised technologies with which they are familiar. Cost-benefit evaluations have limited use in technology acquisition decisions.

Users rely on supplier expertise to compensate for poor education and technical training in South Africa. The impact of political and economic factors is more evident in Eskom than in the mini-cases. Physical asset management follows traditional preventive maintenance practices, with limited use of new maintenance management thinking. Few modifications of the technology or R&D innovations take place. Little use is made of explicit knowledge from computerised maintenance management systems.

Low operating and maintenance skills are not conducive to the transfer of high-technology equipment. South African organisations acquire technology as items of plant, equipment and systems, but limited transfer of technology takes place. This suggests that operators and maintainers frequently do not understand the underlying technology, and like workers elsewhere, are not always inclined towards adopting technology in the workplace.

Keywords: case study, physical asset management, technology, technology transfer

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I would like to pay special tribute to Edith and the late John Moubray. They provided me with worldwide opportunities in maintenance and beyond; they encouraged me in many fields of endeavour; they offered invaluable and sustained friendship. It was a great privilege to work with John Moubray over the last 25 years.

My supervisor, Professor David Bennett, provided sustained support and an invaluable contribution throughout the research. His wisdom, insight and experience made the research enjoyable, and I have learnt so much else from him. I am most grateful for his encouragement both with this thesis and the conference work that has formed an important part of the research.

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GLOSSARY

BEE	Black economic empowerment (in South Africa)
BEEC	Black economic empowerment commission
BPR	Business process re-engineering
CMMS	Computerised maintenance management system
DC	Developing country
DSS	Decision support system
FDI	Foreign direct investment
FMEA	Failure mode and effects analysis
JIT	Just-in-time
JV	Joint venture
MIS	Management information system
MoT/MOT	Management of technology
OLAP	On-line analytical processing system
RCM	Reliability-centred maintenance
TPM	Total productive maintenance
TQM	Total quality management
TT	Technology transfer

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Sustainable growth in developing countries depends on the integration of politics, economics, technology and corporate governance. Technology evolves as a unifying force as innovations become the preserve of large vertically integrated organisations that can afford to capitalise on economies of scale. Technology developers in rich countries are able to retain control of technology until new inventions neutralise previous competitive advantage and remove formal and informal protective barriers. Developing countries are largely excluded from the technology revolution except where technology assists in exploiting natural resources and improving primary industries.

The role of technology in the growth of developing countries is complex and controversial. While developing countries are increasingly aware of the need to participate fully in world trade, they frequently lack the means to acquire the requisite competitive skills, technologies and infrastructure. Internationalisation of production and global competitiveness have established close linkages between technology and domestic capability development, but forces promoting global integration may conflict with the creation and sustaining of local autonomy. This struggle is not against globalisation; rather, efforts must be made to establish the terms under which participation in globalisation can take place (Marcus, 1992). Kahn (1995: 139) takes a sanguine view of the dominant and irreversible role of technology in the advancement of developing countries when he maintains, "it is an article of faith that the application of science and of industrial organisation would bring untold material benefits to the modern world". Kuper (1999: 210) provides further support "as civilisation advances, it will impose sacrifices. There is no guarantee that it will promote individual happiness or advance the common good ... but the capital of humanity increases".

The technological world is characterised by rapid changes in resource utilisation, increasing levels of decision complexity and intense competition (Sharif, 1997).

Organisations should recognise their dramatically changed circumstances, interpret them correctly, and manage the process of reconfiguration. Reduced development cycles and the pace of technological change place greater urgency on the need to adopt new technology if developing countries are to begin to compete globally (Jegathesan, et al, 1997), although they will not find it easy to beat the hard-won technological advantage of the developed world. The extent to which developing countries participate in the global economy will therefore depend on their ability to invest in and utilise technology. The management of knowledge and technical information, equipment and software (Wang, 1997) are areas of interest in technology transfer (TT) in general, and in this context Jelinek (1996: 810) notes that "new technology often creates advantages because it transcends the limitations of past practice: it offers capability to do what is impossible under older assumptions." In developing countries other issues assume even greater importance, such as human resources, skills and training, unique organisational issues, and "lore" (Adjibolosoo, 1994).

With this background, the chapter introduces the research topic and its context. Brief comments are made regarding the case study approach, and details are provided of the structure of the thesis.

1.2 THE RESEARCH CONTEXT

Each country has its own blend of history, politics, economic development and business practices. South Africa attracted the negative attention of the world during the apartheid era. A dramatic change in international opinion coincided with an equally profound transformation in the political dispensation of the country. Public opinion in the developed world soon tires of stability and non-events. While South Africans still experience turbulent times, commentators now report on the country's role as a leading developing country, and its position as the most powerful economy in Africa. A sound infrastructure, a relatively healthy and market-led economy, an abundance of raw materials, and the means to exploit them, make the country attractive for investment. Against this, crime is rife in a society where, on occasions, lawlessness seems the norm. HIV/Aids remains a formidable problem, despite recent government announcements that retroviral drugs will at last be available to sufferers, 600 of whom die each day.

Educational standards vary greatly, from world-renowned research institutions and universities, to schools where lessons are held under a tree without textbooks. There is a dire shortage of technically skilled people to service the technology that is vital to South Africa's future prosperity.

This research aims to contribute to an investigation and understanding of TT to South Africa. The study of TT in South Africa is a special case in that the TT literature between developed countries and from developed to developing countries is pertinent. The country's experiences can be useful to other countries at a similar level of economic and technological development.

This research adopts a case study approach. A main case study and four mini cases have been selected for analysis in order to widen the scope of the study, because extrapolation from the results of a single case would be limited from a theoretical and practical perspective. The main case organisation for this study is the South African electricity utility, Eskom[1], which was chosen for several reasons.

- Eskom, as the sixth largest electricity utility in the world, is a technology leader in South Africa and provides many of the country's industrial equipment standards.
- Eskom's generation, transmission and distribution installations use world-class technologies.
- The hierarchy of the organisation provides two distinct levels at which TT can be studied: a corporate head office, and an operational level. Power stations were selected for study as they contain a wide range of mechanical, electrical and instrumentation/control equipment.
- The company has been at the forefront of implementing the government's affirmative action and black economic empowerment policies, which are likely to affect and be affected by TT initiatives.

Eskom has recently changed its ownership and management structure following the publication of the South African government's white paper on energy policy. The

[1] Eskom is derived from the English *Electricity Supply Commission* and the Afrikaans *Elektrisiteits-voorsieningskommissie.*

electric power industry is undergoing worldwide restructuring in which electricity is traded as a commodity, constituting the largest commodity market in the United States. Eskom, like most other utilities, has occupied a monopoly position in generation, transmission and distribution. Restructuring has introduced greater competition by transforming wholesale and retail electricity markets, enabling both elements to choose their energy providers.

Changes in the electricity industry require revised management philosophies and new ways of operational thinking, many of which are unique to the energy sector. The questions impacting on the debate include: the reasons for, and the nature of, restructuring are still hotly contested, particularly following power failures in North America and Europe in 2003; the outcomes of restructuring are uncertain; commentators are unsure how new structures will differ from old in the longer term; it is unclear how restructuring will be achieved; evaluating the effectiveness of restructuring will be controversial.

Countries adopt different approaches to restructuring, but the concept contains a number of common elements. The aim is to provide a reliable electricity supply at the lowest cost to customers. Restructuring has commenced with the unbundling of vertically integrated utilities into generation, transmission and distribution, with competition at each level, and South Africa is moving in this direction. However, the former chairman of Eskom believes "big is beautiful ... in the electricity supply industry worldwide, we are seeing an unmistakable move to consolidation. Large energy companies are buying up others ... only the biggest will survive" (Cape Times, 2000). According to Shahidehpour and Alomoush (2002: 3) the intention is that the market and increased competition will reduce prices, and that

> "competitive forces will improve efficiency by further expanding the geographic horizon in the operation of interconnected generation and transmission systems ... restructuring will create new business opportunities where firms selling new products and services will appear, consumers will have alternatives in buying electricity services, and new technologies will develop".

In the more mature North American and UK markets, this has already occurred, but restructuring is still at an early stage of implementation in South Africa.

It was also decided to study a selection of mini cases that would differ in many respects from Eskom. They would be much smaller, with limited resources for technology acquisition. Decision-making would be simpler and not involve as many hierarchical levels. A private sector mentality may mean a different approach to TT. Details of the mini cases are given in Chapter 8. The choice of cases means that TT is being studied where the contribution of technology is to the process rather than directly to the product. Unlike the machine tool industry, say, where the extent of TT can be observed in the technological and operational capability and features of the finished product, in this study, new technology is embedded in the production process, and the product shows no direct evidence of the technology. Managers in the case organisations were challenged to make an assessment of how new technology had enhanced a process where success was ultimately measured in operational terms such as efficiency, production costs and plant availability.

1.3 THE RESEARCH APPROACH

The case study approach is useful for an explanatory study:

> "Explanatory research concentrates on identifying major causal mechanisms and the specific mediating conditions which resulted in their producing particular phenomena and outcomes in particular circumstances. Its usefulness in managerial and policy making contexts stems not from its predictive power so much as its capacity to specify critical processes and relations which could hinder or bring about desired outcomes" (Whitley, 1989: 21).

From a managerial perspective, explanations are essential for understanding a topic. In the final chapter this study goes one stage further by suggesting issues that need to be considered to improve TT. This approach exposes the risk that prescriptions may "create more complex problems than the ones they were supposed to solve" (De Cock, 1995: 2). While this may be the case, it was felt that where weaknesses were detected, some appropriate action should be proposed to mitigate these. This agrees with Alvesson and Deetz's (2000) contention that research should increase its relevance and interest for practitioners.

Cole (1934: 9-10)[2] provides pertinent points for management research:

> "We run the risk of assuming that precisely the questions Marx asked are the questions that need asking now, and that the answers will be merely modifications, or perhaps negations, of the answers which he found. But in fact the questions that it is important to ask may be different questions, and the answers may have to be stated in radically different terms.
>
> We shall doubtless find after all that many of his questions are our questions too, and derive from them answers of the same order as our own. But we must not, at our peril, assume in advance that this is so of any particular question, We must look closely at our own world, not only for the answers to our questions, but equally for the questions themselves. That is why, if Marx helps us at all, his method is likely to help us more than his conclusions. For a method of study is likely to remain valid for longer than any set of conclusions arrived at by its use.
>
> All livings things are subject to constant change, which arises partly from their environment and partly from within themselves. This is true of societies no less than of individuals; for societies are constantly changing collections of individual men and women. In order to understand any human society, we must study it not as something static, but as a continually changing thing, subject to an increasing process of development, growth and decay. It is intelligible only in relation to its entire past history, as well as its present condition, which is indeed only a cross-section of its history. Even if our aim is to understand the present, we have to think of the present as a constantly moving point; for even while we are making our analysis tomorrow is becoming today.
>
> It follows that, even if our aim were only to understand, and not to use our understanding as a basis for action, the method of static analysis could not, in the field of social studies, yield us satisfactory results. For if a thing is in constant motion, it is fatally misleading to analyse it on the assumption that it is standing still. For a thing which has change as the very essence of its nature will not stand still for the student's convenience: it can be grasped only in and through its changes, and by an understanding of its processes of change".

One of the first demands of this thesis is to establish which questions need to be asked. It cannot be assumed that the questions that others have asked are the correct questions, or that the answers will be modifications of others' answers. The methodology for this study needs to be analysed carefully. Both South Africa's history and its current situation should be taken into account when attempting to understand actions and

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[2] The fact that Cole's analysis is one of Marx is not significant: his open and questioning approach to social science research is appealing.

attitudes. Change is not only internal, so external influences may also be significant in understanding TT to South Africa.

The literature and a preliminary survey were used to determine the questions to be studied. The effect of formulating a research question should not be to prejudge the research approach, as would be the case, say, if a number of hypotheses were proposed for testing. The reason for formulating a research question is to guide the general direction of the research. The starting point is to establish the processes influencing TT from firms in developed countries to organisations in developing countries (and in particular, South Africa). A model of TT for developing countries developed by Salami and Reavill (1997) is used in conjunction with the preliminary research findings as the basis for the interviews. A revised model is presented in Chapter 10 suggesting a more appropriate structure for TT in South Africa.

Another important dimension to the thesis is physical asset management. Many publications and the author's research suggest a close linkage between maintenance management and TT, suggesting that maintenance is an under-researched management discipline (Amoako-Gyampah and Meredith, 1989), but this, in itself is insufficient reason to include physical asset management in this research. A fundamental tenet is that the purpose of maintenance is to ensure continued functionality of a system (Moubray, 2000). In simple terms technology is transferred if equipment operates and continues to do so as originally intended by the technology supplier, or as required by the technology acquirer. It will be seen that maintenance can provide a trajectory along which the accumulation of technology proceeds, suggesting many parallels between TT and maintenance.

1.4 STRUCTURE OF THE THESIS

The structure of the research is outlined in Figure 1.1. After Chapter 1 (Introduction), the TT and physical asset management literature is reviewed in Chapters 2 and 3, providing the theoretical base for the thesis. A general description of the South African economic and political situation is given in Chapter 4. Research methodology is presented in Chapter 5. Chapter 6 describes the preliminary research conducted to establish what was important for TT in South Africa. A sample of managers was asked to list and score items considered important in TT. An analysis of the interviews conducted in the main and mini case studies is given in Chapters 7 and 8. Details of interviews are included in the appendices. Chapter 9 analyses the findings, and Chapter 10 contains concluding comments, suggestions for improved TT, a discussion of the contribution and limitations of the study, and directions for further research.

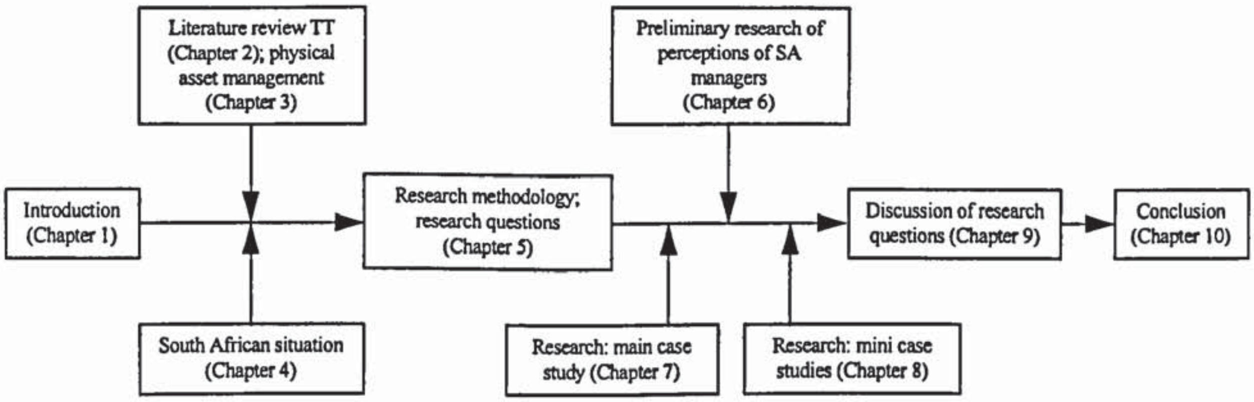

Figure 1.1 Structure of the research

CHAPTER 2

A REVIEW OF THE LITERATURE ON TECHNOLOGY TRANSFER

2.1 INTRODUCTION

Tayloristic work principles are being replaced by technology-based lean production, flexible work methods, and quality programmes that respond to customer requirements, with an emphasis on participation and empowerment (Bolden et al, 1997). While some recent initiatives are of passing interest, the TT researcher is presented with new challenges to discover and explain trends in technology management. Traditional problems of generalisability of case studies and limitations of survey research are exacerbated by the different approaches adopted by researchers who concentrate on technical matters, or on behaviourist issues, as explained by Bolden, et al (1997: 1115):

> "Such a gap between the two literatures is likely to lead members of any single academic discipline to the omission of certain themes and a failure to regard the domain of manufacturing as a whole ... the failure of 80-90% of IT investments is rarely caused by the technology itself; the heart of the problem is lack of attention given to the crucial role played by human and organizational factors in shaping outcomes".

This chapter introduces managerial, societal and technical issues relating to technology and TT in a production environment: the thinking behind the choice of technology, and discussions with potential suppliers; the acquisition, installation and commissioning by the technology owner[1]; mechanisms of transference of knowledge and expertise from the owner to the acquirer; contractual arrangements for subsequent support; and capacity building. These apply as much to the operation of new technology as they do to its maintenance, so maintenance of plant, equipment and systems forms an integral part of the study, and is examined in Chapter 3. In addition, contextual factors relating to adaptability, culture, the developing country environment, and so on, will also be considered. This chapter provides a brief review of methodologies used in the TT literature. Reference is made to the author's preliminary research of TT in South Africa

[1] Following the terminology of Bennett et al (1999), a technology supplier is interchangeably referred to as the 'owner' of the technology; the recipient is the technology 'acquirer'.

(discussed in detail in Chapter 6). Definitions of technology and TT provide direction for the literature review, which commences with discussions of globalisation and TT in developing countries. The discussion on technology policy and capability includes reasons for acquiring technology, strategy, and capabilities in a resource-based context. This leads to technology and operations integration, with reference to other developing countries. Mechanisms of TT, cultural issues, and management attitudes and actions are considered, and the chapter concludes with approaches for assessing TT.

The TT literature may be broadly categorised into two main areas. Firstly, studies relate to transfer between countries of equal technological development and expertise (normally this means developed country to developed country). The mechanisms whereby technology is supplied and acquired range from complete internal development, advancement through the use of consultants and technology suppliers, to turnkey installation projects managed by outside firms. Secondly, there is an extensive literature on TT to developing countries, although relatively few academic studies report on TT research in Africa[2]. A significant amount of literature on TT to developing economies relates to China. While the theoretical bases of research on China are widely applicable, generalisation of practical applications is limited as China presents a unique set of circumstances (as do most other countries). So, where reference is made to the literature on TT to China this generally cites theoretical issues rather than details of the practical outcome of such research.

Developing countries are less likely to benefit from factors that, in the developed world, typically lead to the increasing availability of technology from external sources: (1) rapid global growth in scientific and engineering knowledge; (2) availability of venture capital and the formation of numerous start-up companies; and (3) an expanding pool of displaced talent resulting from reengineering and corporate downsizing (Chatterji, 1996).

[2] Some have examined the poorest countries, such as the research by Voordijk (1999) in Ethiopia. Others have focused narrowly on certain sectors, such as Wilson's (1996) study of technology development in small Zimbabwean businesses, or Clarke's (2002) interest in rural development by funding agencies.

Figure 2.1 suggests that in the developed world political factors have little, if any, influence on TT. Economic issues have some influence on location, skills development and state assistance. The role of technology itself and mechanisms of transfer receive the most attention, indicated by the expanding arrow in Figure 2.1. The reverse applies in developing countries where the lower arrow narrows in the direction of technology: political factors play a significant role along with economic issues, while technology issues assume less importance.

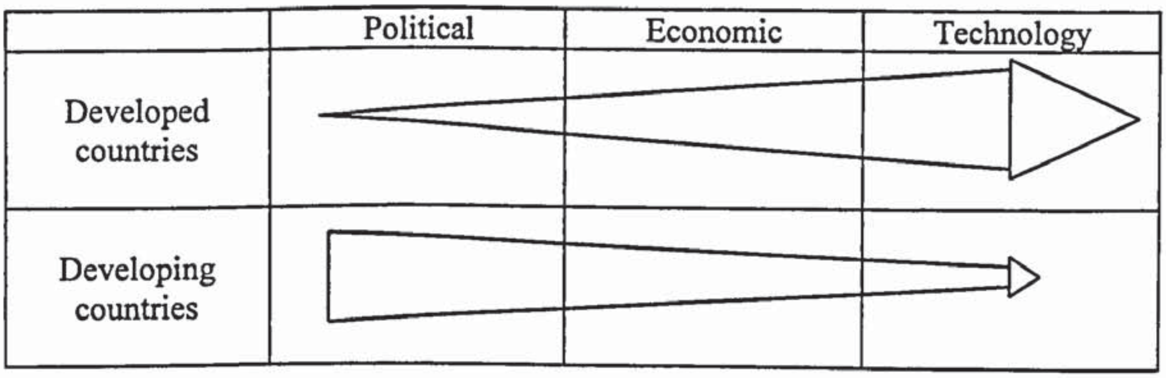

Figure 2.1 Differing TT emphasis in developed and developing countries

The difference in emphasis in TT to the developed world and to developing countries is described by Samli et al (1992: 1):

> "Managing technology in third world countries, unlike the common perception, is more related to the macro conditions prevailing in the society than micro conditions such as managerial skills and manpower resources. Among macro conditions, the power structure, openness of the culture and ability to prioritise options, are the three without which technology cannot be managed despite the appropriateness of the most micro conditions".

South Africa's politics and history present managers with unique challenges, as the country is highly developed in certain respects, but remains desperately poor in others. As part of the preliminary work for this research, a number of studies were undertaken to find some basis and direction for the main thrust of the research. These studies (see Hipkin and Bennett, 2001, 2002a, 2002b, 2002c, 2003) sought to establish factors that are important to managers in the context of TT, and to what extent managers are able to control these. These are discussed in Chapter 6.

2.2 A REVIEW OF METHODOLOGIES USED IN THE TECHNOLOGY TRANSFER LITERATURE

As a starting point for this review of the literature, it is instructive to examine the methodologies used in TT research. A random selection of papers was taken from the literature on TT in order to review the methodological approaches adopted by TT researchers. After analysing some 40 papers, conclusions suggested converging trends, and that further analysis would not significantly change or add to the findings summarised in Table 2.1. Appendix I contains brief comments on the papers, with a broad categorisation of the topics in each and an assessment of methodologies. These are categorised under four broad headings in Table 2.1, which shows the numbers of papers in each category: 16 are from conference proceedings and the remainder from refereed academic journals. While length constraints for conference papers may preclude in-depth studies with substantial methodological discourse, they do constitute a significant part of the literature on TT for developing countries.

Methodological category	No of papers	% of total
Research based – survey	12	30
Research based - case study	9	22
Conceptual	8	20
Pure description	11	28

Table 2.1 Summary of methodological categories

Of the papers selected 52% are survey or case based. Many case study findings and conclusions are derived from narrative interpretations of cases. It is possible to classify 20% of the papers as conceptual in that they contain substantial reference to the literature, and represent theory building. While not all papers in the conceptual category describe their methodology, they display academic rigour and provide an 'audit trail' to justify conclusions. The remaining 28% can best be portrayed as descriptive, with little or no methodological rigour. Prescriptive statements are made, such as: "the following factors must be taken into account ...", with no research or literature-based justification, and as such these represent little more than individual experience and conjecture.

Conclusions drawn in the descriptive category may appear intuitively sound, and concur with other literature, but these papers present the researcher with the problem of having to differentiate between 'good' research-based papers, with valid and reliable findings, and those largely containing authors' unsubstantiated opinions. Such remarks are not intended to represent a rejection of the validity of these papers. It could actually be argued that where a number of authors (independently) arrive at a set of factors which they claim to be significant in TT, then these opinions could in themselves be construed as useful research-based opinion. This literature review refers to all categories of paper, but tends to draw more substantive conclusions from research-based studies.

2.3 PRELIMINARY RESEARCH

The limited research on TT in South Africa necessitated an initial investigation of technology management in that country in the form of a preliminary survey (discussed in Chapter 6) of South African managers' perceptions of important factors in TT. The survey identified 78 items as being important for TT. These were grouped under 12 factor headings, shown in Table 2.2 with the number of items in each category.

	Factors	Number of items	% of total
1	Strategy	10	13
2	Maintenance	10	13
3	Technology	9	12
4	People and systems integration	9	12
5	Political and economic issues	8	10
6	Supply chain	8	10
7	Operations management	7	9
8	Knowledge	5	6
9	Contractual	4	5
10	High-technology issues	3	4
11	Finance	3	4
12	Resistance to change	2	2

Table 2.2 Factors influencing the management of technology

From Table 2.2 13% of the factors relate to strategy and 13% to maintenance. People and systems integration, and technology each account for 12% of the items, and so on. In addition to being asked which factors were important in TT, managers were requested to score the extent to which they believed they could control them. Political and economic issues were amongst the most important, yet managers had little control over them. This imbalance between importance and control causes frustration for managers.

Reference will be made to the TT literature in developing countries relating to cultural and economic issues, but it is not the intention to research anthropological or socio-developmental matters in detail. Some macro-economic aspects pertaining to South Africa are considered in Chapter 4.

2.4 DEFINING TECHNOLOGY AND TECHNOLOGY TRANSFER

Publications on technology and technology transfer frequently contain their own definitions of the terms.[3] The main themes emerging from a selection of definitions in publications on TT to developing countries are shown in Table 2.3[4].

Authors	Defining features
Technology	
Spann et al (1995),	Facilities
Moenart et al (1992), Afriyie (1988), Spann et al (1995), Al-Ghailani and Moor (1995), Adjibolosoo (1994)	Knowledge
Spann et al (1995), Adjibolosoo (1994)	Capabilities
Saren (1992)	Competencies
Afriyie (1988), Adjibolosoo (1994)	Technical support
Afriyie (1988)	Capital embodiment
Saren (1992), Al-Ghailani and Moor (1995)	Means of production
Tepstra and David (1985)	Cultural systems, environment and local conditions
Technology transfer	
Gee (1993),	Knowledge in technical ideas, information, data; and as skills, expertise
Kaynak (1985), Lall (1993), Al-Ghailani and Moor (1995), Spann et al (1995)	Transmission from one party (country/firm) to another of capital and technical know-how
Kaynak (1985)	Effective absorption and diffusion
Grant and Gregory (1997)	Transferability: adaptation, transmission, assimilation
Ostroff (1995)	Licensing of patents, IPR, provision of technical services

Table 2.3 Key words in definitions of technology and technology transfer

Significant ideas emerging from these definitions are:

[3] Many definitions of technology and technology transfer are grounded in economic theory (for example, Phillips et al (1994: 2) define technology as "new and better ways of achieving economic ends that contribute to economic development"). These are not discussed. Official definitions which enable technology to be classified as such in certain countries are also not included (see Bassolino and Tse, 1999).

[4] This study does not consider TT which takes place as a result of deliberate imitation, as discussed by Kogut (1995) where knowledge within a technology becomes known to competitors and is manifested as imitation typically through reverse engineering.

- Technology is the practical application of scientific or engineering knowledge (Moenaert et al, 1992).
- Technology is "a means of production" and "a set of competences" (Saren, 1992).
- Technology is "a cultural system concerned with the relationship between humans and their environment" (Tepstra and David, 1985: 148).
- From a systems perspective, technology encompasses (1) the basic (scientific) knowledge subsystem, (2) the technical support system (software), and (3) the capital-embodied technology (hardware) (Afriyie, 1988).
- TT is "the managed process of conveying a technology from one party to its adoption by another ... the process by which existing knowledge, facilities or capabilities developed (through) R&D are utilized to further public or private needs" (Spann et al, 1995: 19).
- TT is "the transmission of know-how to suit local conditions, with effective absorption and diffusion both within and from one country to another" (Kaynak, 1985: 155-156).
- TT combines the provision of capital with technical know-how, equipment, management, marketing and other skills. In its 'classic' form it also entails control over the operation by the foreign investor (Lall, 1993).
- The importance of transferability (rather than merely transfer) of technology is the innate ability of a technology to be adapted, transmitted and assimilated, independently of the recipient, within a reasonable time and with reasonable resources. Without being "transferable", there will be no technology transfer (Grant and Gregory, 1997).
- A more pragmatic view of TT is the assignment or licensing of patents or other intellectual property rights, the provision of technical services, and the sharing of know-how, which is provided in the form of drawings, technical data and technical specifications (Ostroff, 1995: 12).
- TT develops at three levels: level 1 is where the scientist makes available results of research by personal communication and publications; level 2 is a level of shared responsibilities between the owner and acquirer, whereby technology is utilised by

someone with adequate knowledge and capacity; level 3 represents profitable use of technology on a shared basis (Simango, 2000).

These definitions contain essential features of technology summarised in Table 2.3, such as knowledge, facilities and capability components. This is clearly broader than 'a machine' or 'a piece of software', so technology should encompass capability and knowledge in order to be of any use. Technical support and the embodiment of features build onto the knowledge based idea of technology. The definition of technology as a means of production (Saren, 1992) also embodies the notion of know-how. Several authors include a cultural and environmental dimension in defining technology.

These relatively broad definitions of technology take the TT process further by referring to absorption by, and diffusion within, the acquiring firm. Irwin et al (1998) state that individuals carry out all technology management and all TT occurs between people, so TT is less a task to be accomplished than a set of relationships to be nurtured. Also, by its nature TT involves communication, and incorporates a relationship management dimension. This view reinforces the assimilation element in Table 2.3. Transferring processes is more than the transfer of physical technology. Even though a process is fit for transfer, other 'softer' issues should be considered (Grant and Gregory, 1997).

Definitions of TT and technology by Kahen (1997) and Adjibolosoo (1994) incorporate features pertinent to the proposed research. Kahen (1997: 231) defines TT as

> "a continuous process involving planning, decision-making about technological options, and the choice of the most appropriate technology in the light of local characteristics and available resources, utilising and developing it with the aim of achieving particular goals and objectives at some time in the future."

The idea of 'foreign' technology is one of transference by a 'foreign' technology owner to a 'local' acquirer. Kahen (1997) sees utilisation of 'foreign' technology as a continuum from TT policy making, through TT planning, to TT implementation. Technology policy includes evaluation for selection purposes, followed by setting objectives and attributes (measures of performance and effectiveness). Technological planning should take into account socio-political factors, which are essentially an assessment of the feasibility and desirability of introducing a new technology, and consideration of the cost implications. In summary, Kahen (1997) maintains that TT should take into account four aspects: international political dimensions, commercial transactions, issues of operational relevance, and local conditions.

Adjibolosoo (1994: 1557) provides two definitions. He quotes:

> "technology is taken to mean the body of knowledge, skills, and lore that provides the capability to produce goods and services, to design and develop new ones when appropriate, to apply them to the specialized needs of the customer, and to install and service them" (Steele, 1979: 112).

Adjibolosoo's (1994: 1558) second quotation is:

> "Technology may be more usefully conceptualised as a quantum knowledge retained by individual teams of specialized personnel. This knowledge, resulting from their accumulated experience in design, production, and investment activities, is mostly tacit, that is, not made explicit in any collection of blueprints and manuals. It is acquired in problem-solving and trouble-shooting activities within the firm, remaining there in a substantially uncodified state" (Rosenberg and Frischtak, 1985: 172).

These definitions are useful as they contain many of the elements in Table 2.3, but they are by no means exhaustive. Spann et al (1995) comment on the incompleteness of models that view TT solely from the perspective of technology-source organisations (such as technology emanating from state funded institutions and those with political undertones) and suggest that greater emphasis must be placed on technology-acquiring organisations and measures of TT effectiveness. This dual approach to TT looks at technology-push, derived from technology capabilities and marketed by the owner, and technology-pull where transfer is concentrated on the potential acquirer on a needs-motivated basis. 'Push-pull' theory is most likely to occur "when a need and a means to resolve that need are simultaneously recognized" (Zmud, 1984: 727). From a strategic perspective market conditions frequently specify the need, and at an operational level new technology provides the means to produce it. Technology-push strategies include state funded technologies, politically motivated TT, and technologies devised without directly responding to market needs, but that provide opportunistic cost-benefits for the technology owner.

Lynskey (1999: 16) takes a different view on the concept of TT and claims that the term TT is an oxymoron: "technology as an abstraction cannot move - things and people are transferred". He continues that this is particularly the case with the tacit knowledge component[5] of technology (discussed in Section 2.8), which must be transferred through intimate human interaction due to its non-codifiable nature.[6] In not acknowledging the concept of TT, Lynskey (1999) distinguishes between 'technology agreements' involving resources (exchange of technical know-how in return for fees or royalties) and exchange of 'competencies' which involve information-based invisible assets. Both of these would be included under the heading of technology in Table 2.3.

From this discussion, the essential features of TT seem to be conveying technology, as represented by knowledge, capability and competency from owner to acquirer, to ensure absorption and diffusion in the local context. Before considering these in some detail, the influences of globalisation and TT in developing countries are discussed.

2.5 GLOBALISATION AND TECHNOLOGY TRANSFER IN DEVELOPING COUNTRIES

The internationalisation of business and the growing significance of trade are advanced by technologically driven change, technology flows, domestic capability development, international competitiveness, investment, and government policies. TT provides a more immediate stimulation of technological advancement and economic development than longer-term investments in education and R&D (Williams, 1996). Phillips et al (1994) reinforce several findings in the TT literature: TT between developed countries relies predominantly on strategic orientations; TT between developed and developing countries has the added dimension of cultural compatibility, where neither the process nor the package being transferred is necessarily homogeneous; cultural affinity has a significant and positive influence on technology acceptance through perceived ease of adoption. When established demand for a product exists and new technology is both

[5] Lynskey (1999: 3) uses the terms technology and knowledge somewhat interchangeably: he frequently refers to "technology/knowledge" or "technology and know-how".

[6] Yet, despite his emphasis on tacit knowledge, the examples given by Lynskey (1999) are transfer of explicit knowledge: documentation, training, demonstrations, and to a lesser extent, collaborative technical work.

necessary and available, priorities are formed in an effort to justify the adoption decision. This section discusses topics affecting such decisions.

Globalisation

Loveridge and Pitt (1990: 11) capture several broad issues in claiming that "the mechanisms by which organisations adapt their operations to changes in strategic context and vice versa – that is, the means by which firms create and invent changes that impact on their external context – are central to an understanding of changes in the wider sphere of the economy and society as a whole". Despite the concentration of innovation in a handful of countries and companies, technology policy at political and corporate levels is frequently based on global considerations (Lall, 1993). Much empirical work on TT in the literature concentrates on large firms in industrialised countries (an exception is China, where extensive studies have been done). Burgess et al (1998) suggest two reasons that weaken extrapolation from existing studies in developing countries: industrialising countries lag the mature economies, and firms in these countries tend to be smaller than those in the developed world.

The importance of technological innovation for competitiveness in industrialised countries is well documented in the literature (see, for example, Loveridge and Pitt, 1992; Wang and Zhou, 1999), but the nature and pattern of TT in developing countries differs markedly. Developing countries are increasingly aware of the need to participate fully in world trade, and are dependent on externally sourced technologies (Irwin et al, 1998). The way in which this is done will depend on the competitive advantages gained by past investments in technology, and the dynamic advantages created by policies relating to incentives, skills, technologies, infrastructure, research and education.

Globalisation renders firms in developing economies particularly susceptible to the intensity of competitive forces. Despite criticism in some quarters of the role and intentions of multinational corporations (MNCs) (Gergen and Whitney, 1996), they have been a significant driving force in globalisation, and governments of developing countries have frequently been eager to accommodate more MNCs. Local firms are then obliged to reposition themselves in a new business context as a result of structural and political events influencing the flow of technology to developing countries. When monopolies previously protected by legislation are deregulated or privatised, they are subject to competition from international companies with higher levels of technology, greater access to resources, and the ability to choose specific market segments. A deregulated monopoly is likely to have older technology, and a monopoly company culture, although it may potentially have the advantage of competitive intelligence and a better understanding of the capabilities, strategies and requirements of the stakeholders in that market (Evaristo, 1998).

Fleury (1999) describes three stages of globalisation: deregulation of financial markets (financial globalisation), removal or reduction of trade barriers (commercial globalisation), and organising production systems (productive globalisation). In South Africa, productive globalisation came first, and was followed by commercial and financial globalisation. The introduction of technology in developing countries occurs at the third stage, showing "a complex picture involving simultaneous interactions and outcomes of technological, economic, institutional, and individual considerations" (Alcorta, 1999: 163). The choice of new technology extends beyond adopting cost-efficient production processes for manufacturing quality goods. The emphasis becomes one of acquiring capacity for future productivity improvements, and assessing how adaptation can lead to innovation through knowledge acquisition (Smit and Pistorius, 1998). Kumar and Jain (2003) claim that a technology 'anchor' should be established and remain within a country to propagate further technological development. It is possible to identify some technological bases in countries such as Brazil, India and South Africa, but these have yet to develop into a broad improvement in technology and operations (Hipkin and Bennett, 2003).

Prochno and Corrêa (1995) claim that turbulent environments in some developing countries call for different approaches to business expansion from those in stable, developed countries. Firms seek political and economic stability, and domestic and international growth potential. For example, long-term planning in Brazil has been aggravated by high interest rates, high, unstable levels of inflation, and frequently changing government industrial policies, where "six months is long-term planning in Brazil" (Prochno and Corrêa, 1995).

One feature of globalisation is the emergence of inter-company relationships. Typically these take place in three areas (see Fleury, 1999: 556):

- manufacturing strategy (decisions about investments and capacities, technology, supplier networks, products and processes)
- organisational architecture (scope and responsibility for owner and acquirer input)
- management control systems (performance indicators, management information systems).

Much TT relies on imported equipment, using information, copying and reverse engineering, depending on the complexity of the technology. Formal technology acquisition is the likely mechanism for sophisticated technology. This means that some technology can be absorbed only by importing the equipment and obtaining licences. Too passive a dependence on imported technology, and excessively close relations with the technology owner can stifle the development of more advanced (possibly local) technological capabilities, and new products and processes (Fohrbeck and Wiesand, 1981; Narayanan, 1998). Dependence may remain an expensive option. When an organisation's level of development and the technological environment in which it operates are more advanced, the choice of technology may be between local and imported technology, taking into account the level of support which each offers. International suppliers of technology are more likely to be in the forefront of new developments and adaptive activity. Their policy is generally to transfer the results of R&D rather than the innovation process itself (Lall, 1993). This may be less satisfactory for acquirers confronted with the continuing need to adapt to 'foreign' technology.

Economic and political factors

Government policies on social and economic development and employment relations have a significant impact on technological and organisational choice (Williams, 1996). As a result of privatisation and economic liberalisation, high-technology international companies with substantial resources compete with previously protected monopolies in developing countries. Multinational companies are able to dictate to local governments and domestic firms through their ability to move technology, intellectual capital and knowledge assets across boundaries. Many multinationals use their technology-based expertise to provide better quality and service, and gain an even greater competitive lead through their global activities (Nagabhushana and Shah, 1999). Fleury and Fleury (2002) comment that some new market entrants offer little technology, and demonstrate no commitment to technological issues, but establish their presence through service innovations. New arrivals often choose specific attractive market segments, leaving the local deregulated firm, encumbered by old technology and a monopoly company culture and working practices, to serve the remaining, less profitable parts of the markets.

In economic terms, technology adoption is a function of income, savings, investment, productivity, availability of capital and education. Technology can fuel economic growth and increase productivity (Hirschcowitz et al, 2001; Phillips et al, 1994; Samli et al, 1985). The economic relationship between the state, business and management is illustrated in Figure 2.2 (Nicholson, 1999: 539). While this model is somewhat simplistic in that it implicitly assumes a common understanding of working practices and mutually acceptable goals, it does present some linkages pertinent to TT to developing countries. Technological advances may be encouraged at all levels: state policies determine taxation, state financial incentives, and education programmes; at a business (corporate governance) level these may take the form of investment decisions to incorporate new technology; at local management level, decisions are made of how new technology will be managed.

The processes in the model are not linear, but occur in clusters of interaction and integration necessitating a confluence of technology and corporate strategy (Xu et al, 1998: 384). Technical change should be accompanied by R&D-induced changes in organisational structures. Developing countries are constrained by financial limitations for new technology introduction and the poor education of many workers. As a result, technology imported into high-technology industries is not easily assimilated or diffused. These restrictions lead Voss and Blackmon (1996) to suggest that one of the main challenges faced by technology owners is the development of the workforce in developing countries.

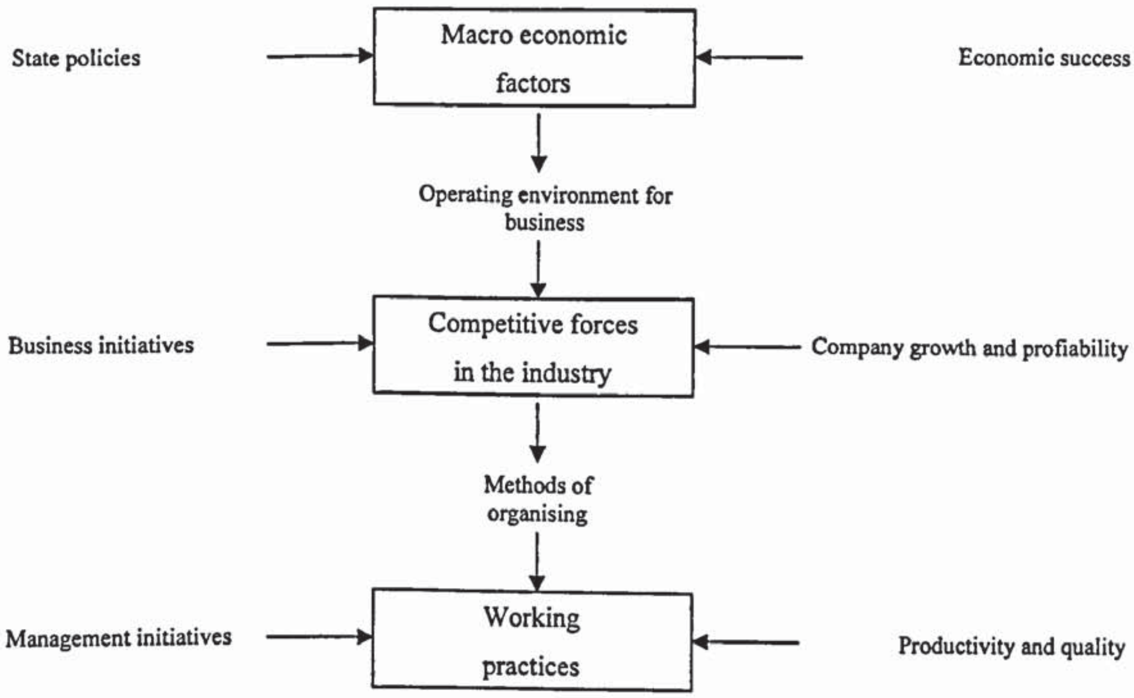

Figure 2.2 Economic relationships: state-business-management

TT is enhanced by appropriate training, especially where suitably trainable people are scarce (Voordijk, 1999). In developing countries the owners of technology frequently use their own expatriate workers. This has merit from a technical point of view, and enables the technology owner to protect its market position by limiting the diffusion of its know-how. Yet, this is seldom a permanent solution and owners must remain adept at solving acquirers' problems in a foreign environment (Olayan, 1999).

Skills development

Characteristics that are conducive to continuous improvement and innovation include: strategic managerial vision, labour markets with good levels of general education and skills, work organisation allowing employees to control and co-ordinate production activities, training and development that support learning, and management integration of strategic direction and adaptation to external and internal changes (Williams, 1996). Assimilating technology transferred from a supplier involves organisational learning through acquiring relevant skills. Baranson (1969) argues that the most challenging aspect transferring technical know-how from industrially advanced to developing countries is upgrading acquirers' human resource skills to enable them to utilise new technology. Immediate exposure to international competition may kill a technology before all systems and capabilities are in place (Lall, 1993). The extent to which technological development can proceed with such exposure depends on current skills and the complexity of the technology. Statutory protection may be offered to emerging industries to moderate the effects of full international competition, but the permanence of such intervention may have deleterious effects on competitiveness.

Firms in developed countries have expanded manufacturing operations to other parts of the world to meet global challenges, such as cost reduction and easier access to developing country markets. This requires adaptation of advanced technical know-how to local customs and conditions in developing countries. Some of the strategic questions that raise considerable debate are (De Meyer, 1992): To what extent should research, development and engineering be internationalised? Can competitive positions be strengthened through labour cost reduction? How easy is it to access different sources of technological knowledge in developing countries? Does closer physical proximity lead to attractive markets and innovative customer segments?

Lall (1993) contends that many 'implicit' elements in technology need a long period of learning to be mastered. These are a function of experience, but are enhanced by investment in training by the technology owner and acquirer, the search for new technical and knowledge solutions, and developing organisational capacities to create, communicate and diffuse knowledge internally. While infrastructure, and many activities and systems are quite routine in technologically advanced countries and organisations, these cannot be taken for granted in developing economies. Here, specific steps may be required, for example, to establish a quality culture, set up maintenance systems, and seek process optimisation.

Skills transfer and training are becoming contractual issues because inadequate operating and maintenance expertise in developing countries represents a formidable challenge to technology owners and acquirers. Knowledge creation commences with an understanding of products and processes. If knowledge remains embodied in a machine whose operation the acquirer does not understand, a technology policy aimed at knowledge creation may fail. Owners are reluctant to reveal all about a technology, whereas acquirers want as much understanding as possible. The result is an uncompromising paradox between resistance and accommodation (Marcus, 1992). A sophisticated acquirer will increasingly demand greater access to codified knowledge and insist that the owner makes tacit knowledge more explicit. Acquiring technology by developing countries rests on a firm's capacity to enhance its technological capabilities through learning. This begins with learning how to use the technology, and gain greater self-sufficiency through developing it, and possibly selling it to new customers[7].

Competency, absorption and diffusion in applying technology are essential components in this research. Several authors (for example, see Lall, 1993) see the transfer of technology (in the sense of supplying the equipment, and providing instructions and blueprints) as being different to its effective mastery (absorption, deployment and subsequent upgrading). They contend that the distinction between transfer and mastery is important as the same technology may be used at different levels of proficiency and efficiency in different plants. The reasons may lie in the technological and structural capabilities of the acquirer, but whether or not it is necessary to see TT and mastery as two different things depends on the boundaries of the definition of the term TT.

This section has considered global, economic and political, and skills-related factors in TT. Importing new technology and developing local capabilities involve building new organisational and technical skills, an ability to generate and access information, development of specialised competences relative to other firms, and establishing links with suppliers, buyers and institutions. Assimilation, adaptation and development of

[7] Eskom provides two examples. (1) Water shortages in South Africa forced Eskom to investigate dry cooling systems. This technology was initially obtained from the US in the 1970s, but Eskom developed this technology and now has the largest dry cooling power stations in the world, and shares this technology with other utilities. This example represents progression to higher levels in Leonard-Barton's (1995) technology capability ladder. (2) In conjunction with British Nuclear Fuels, Eskom is developing a 160MW pebble bed modular reactor (PBMR) whereby heat from a nuclear reaction is transferred to

imported knowledge are partly dependent on technology policy in organisations, and usually require new capabilities that do not exist in developing countries (Lall, 1993). Technology policy and capabilities are discussed in the next section.

2.6 TECHNOLOGY POLICY AND CAPABILITY IN DEVELOPING COUNTRIES

TT has the best chance of success if it leads to competitive advantage through fostering the commitment of all employees through co-ordination at strategic level and alignment with corporate goals and internal capabilities (Leonard-Barton and Deschamps, 1988; Martinsons and Schindler, 1995). Of course, there are instances where the purpose behind a new technology is essentially operational (such as lower production costs), and the strategic dimension is not directly applicable. Technology policy in an operations context requires a balanced assessment of product complexity (for value maximisation) and process complexity (for cost minimisation) (Sharif, 1997). These are a function of the relevant performance or design characteristics and quality requirements of the product or service. Technology specifications for new facilities include these parameters in the decision-making process, but resources, and financial and competency-based constraints restrict developing countries in technology selection.

Motivations for acquiring new technology

There are a number of reasons for acquiring new technology (Baines et al, 1999; Bennett et al, 1999; Barlett and Ghosal, 1989):

- Technology assists in retaining a business focus by developing a core competence or defending a unique manufacturing capability. It allows the company to concentrate on key activities and retain a competitive edge, while not being distracted by having to develop its own technology.
- A broader view looks beyond financial considerations in TT to technical and strategic objectives that are not mutually exclusive, but rely on short- and long-term compatibility between the technology owner and the potential acquirer.

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helium gas that drives a series of turbines. The intention is for Eskom to install these reactors in a number of South African locations, and sell them internationally.

- Technology supports an existing manufacturing technology or service by enhancing productive operations and continuous improvement.
- The acquirer introduces new technology to achieve operational benefits: increased output, improved reliability, lower costs, greater overall profits, shorter times to acquire the technology, and immediate quality advantages.

Lennon (1997) discusses the need for continuous updating of equipment and processes, and the relevance for developing countries to attain technological parity with international competitors. When technology is transferred to developing countries, owners and acquirers need to determine appropriate levels of technology that can be applied to suit the level of development in the acquiring country (Plenert, 1994). Technology owners can no longer dump obsolete technology on a developing country, or deliver technology designed to produce low value added items (Moor, 1994).

Strategy and capability

The relationship between strategy and the development of technological capabilities and core technologies in developing countries is widely discussed (Barbosa and Vaidya, 1997; Husain and Sushil, 1997; Kim, 1998; Virasa and Tang, 1999). Important issues emerging from an evaluation of reasons for adopting technology are the strength and capabilities of the technology owner and acquirer, and attributes of the technology (Bennett et al, 1999). Authors debate whether product technology is the main motivation, with Xu et al (1998) providing evidence that process, rather than product innovation is more important in the early stages of TT. This supports Hayes and Wheelwright (1984) that manufacturing's most proactive role in overall strategy attainment occurs when equal attention is paid to product *and* process technology, but contrasts with Abernathy and Utterback (1976) who expound the 'classical' pattern of product innovation preceding process innovation. Zhang et al (2001: 186) contend that transferring product technology constitutes a limited form of TT in that it does not "enable the technology acquirer to capture the most important aspects of capability, those of product and process innovation".

Leonard-Barton (1995: 218) sees technology activity between countries as a flow of technological capabilities, with an emphasis on the desire of the technology acquirer to establish "knowledge-creating activities". At a basic level technological capability flow becomes "a process of converting or transferring scientific or technological knowledge directly into the satisfaction of a customer need; the product then becomes merely the carrier of the technology and the form it takes is only defined after the technology and the need have been clearly matched" (Twiss, 1986: 4). The flow of technological capability is a continuum from sale of equipment by the owner to the acquirer, to total absorption which gives the acquirer equal partnership with the owner. Along this continuum Leonard-Barton (1995: 221) identifies four levels in a "technology capability ladder": (1) assembly or turnkey operations, (2) adaptation and localisation of components, (3) product redesign, and (4) independent design of products.

In developing countries the first two levels are most likely to predominate, although process redesign based on acquired technology may take place. Initially, technology is transferred as a total system or in the form of self-contained machines (essentially constituting a financial transaction). High levels of automation are presented as an entire capability, or as the solution to an acquirer's inability to operate sophisticated technology. Deskilling has been competitively disadvantageous where markets favour firms that can make frequent and intricate changes to production processes for customisation (Williams, 1996).

While automation may obviate the need for skilled operators and ensure consistently high quality, it is not always possible to capture all activities in procedures. Appropriate proceduralisation and automation depend on the level of knowledge of a process. Bohn's (1994) depiction of this is illustrated in Figure 2.3 which suggests that complete automation is only effective and efficient with complete knowledge of a process. Where firms have very low levels of knowledge automation should not be attempted.

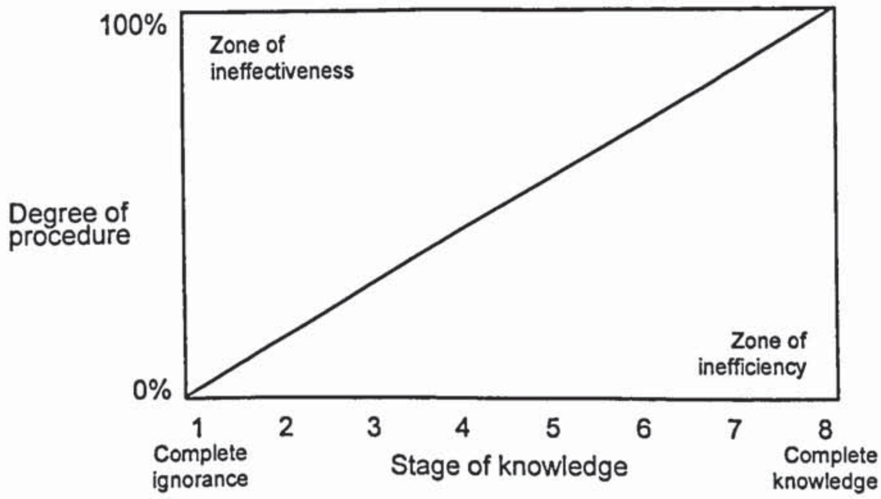

Figure 2.3 Degree of procedure and stages of knowledge

Among the reasons for inadequate knowledge is a firm's over-optimism about the knowledge of its own processes, and its inability to build, debug and operate new processes (Bohn, 1994: 70): "the automation of large complex, poorly understood, conventional processes result in large, complex, poorly understood, unreliable, expensive automated processes. New technology installations have often been counterproductive." If personnel do not understand a process, they are unable to handle unanticipated situations, and today's knowledge quickly becomes obsolete. Making high technology 'foolproof' for a developing country environment may be unnecessarily extravagant, and introduce levels of complexity that ultimately render the process unworkable or worthless as intricate operational procedures cannot be followed or breakdowns become irreparable. While performance may be affected by complexity, reliability is also influenced by the way in which a machine is operated (Bennett and Jenney, 1980). A technology policy which claims that the purchase of a new machine will simply give the recipient 'a new technology' is misguided, as this makes unrealistic assumptions of "self-sufficiency, flexibility, and endless reliability on equipment design" (Leonard-Barton, 1995: 225).

The challenge at Leonard-Barton's second level is to identify appropriate technology that can be absorbed in, or adapted to, local situations (Blumentritt and Johnson, 1999).

Much technology requires processing and modification (Platt and Wilson, 1999) and should be viewed from a pluralistic perspective including strategy and organisation (Riis and Sun, 1994). New surroundings are frequently incompatible with originally intended functionality. Problems of technical interfacing arise when attempts are made to integrate the owner's process with the acquirer's system without making allowance for different operating contexts. Adoption of new technology at higher levels (in Leonard-Barton's terms) is not necessarily easier as more sophisticated acquirers become more demanding, and more dependent on the owner's knowledge base (Bohn, 1994). At higher levels, capability transfer shifts from physical equipment and technological systems to managerial systems and values (Leonard-Barton, 1995).

The resource-based view relating to technology

The resource-based view (RBV) considers the contribution of capabilities to competitive advantage. Barney (1991) categorises resources as physical capital resources (equipment, inventory, and intangibles such as brand name, goodwill), human capital resources (education, experience, relationships, skills), and organisational capital resources (corporate culture, structure, procedures, guidelines, information systems, external relationships). Capabilities may be viewed along four dimensions: (1) employee knowledge, education, experience, skills, (2) values and norms, corporate culture, structure, procedures, relationships with stakeholders, (3) managerial systems and ways of creating knowledge, and (4) physical and technical systems (Barney, 1991; Zhang et al, 2001). The possession of resources is of no immediate advantage, but the use of a combination of organisational resources, learning, and dynamic capabilities can explain the difference in success between firms (Peteraf, 1993).

The RBV highlights the importance of a firm's internal attributes in providing sustainable competitive advantage and superior performance through developing a competitively distinct set of resources. The RBV is of interest in TT because it includes the use of resources, capabilities and management competence. Grant (2002: 124) sees resources as inputs to capabilities, which he defines "as what the firm can do more effectively than its rivals as a result of the configuration of resources". The possession of resources is of no immediate advantage, as firms are heterogeneous in their ownership of resources, and resources are subject to mobility barriers that reinforce heterogeneity among industry participants (Spanos and Liouskas, 2001).

The RBV is criticised by Collis and Montgomery (1995) because of the difficulty of objectively identifying and evaluating resources. Tests should ideally consider the strength of resources relative to the competition, but it is difficult to benchmark inimitability and substitutability, and to value intangible resources. Prahalad and Hamel (1990) take the view that competences are built through their very application and sharing among units and teams, implying that resource competences can be developed, rather than having to be a prerequisite at the outset. Spanos and Liouskas (2001) point to the ability to acquire competences through intangible resources such as knowledge and organisational learning.

Zhang et al (2001: 188) see capabilities "as part of an organisation's taken-for-granted reality", and as such are institutionalised as high-level routines. The authors build on Clark's (2000) argument that routines are a link between resources and capabilities: routines are the rules for resource utilisation (at corporate level), or a network of relationships that draw together otherwise disparate resources (at an operational level). Zhang et al (2001) comment further that while evidence of the existence of routines may be not identified, capabilities are recognised, if only by the control they require and their effects. Organisational resources enhance capabilities by combining with routines, learning and dynamic capabilities (which Teece et al (1997) define as the ability to integrate and reconfigure external and internal resources in a changing environment).

Zhang et al (2001) have combined resources, capabilities and routines into a model depicting the relationship between the three concepts, shown in Figure 2.4. The model introduces several vital components for TT. Physical, human and organisational resources combine with capabilities (skills, managerial systems), and together with technical systems, values and norms, these ultimately lead to competitive advantage.

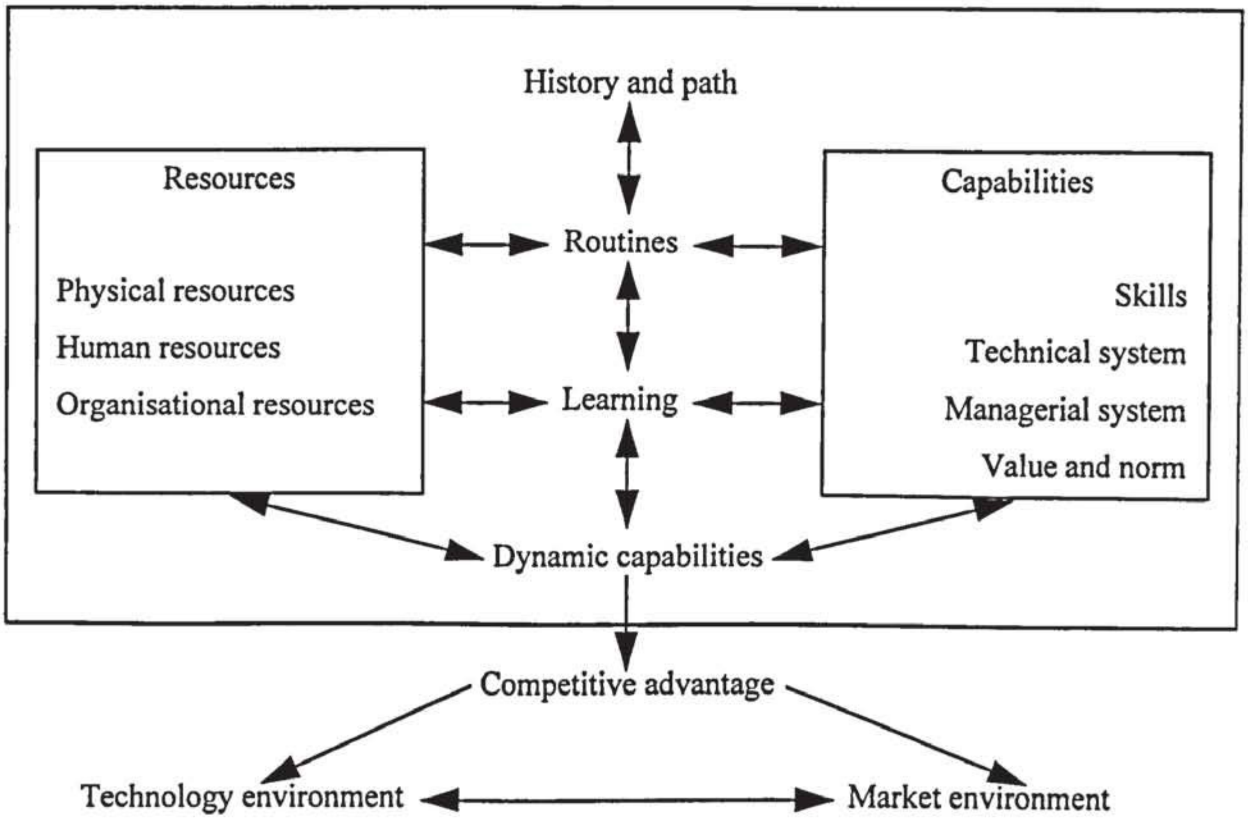

Figure 2.4 Construct of resources, capabilities and routines

Price and quality

Another strategic dimension is the price-quality relationship, shown in Figure 2.5.

Aston University

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Figure 2.5 Price and quality positioning (D'Aveni, 1994)

This plays a significant role in assessing the role of technology in the competitive environment. The dotted vertical line reflects pure price competition for products with no apparent quality attributes. The line L-C-D represents strategic alternatives that offer greater value, as a function of price and quality.

Figure 2.6 illustrates a strategic move towards the point of ultimate value (UV), which makes all other positions in a segment unviable. Common technology among competitors hastens the movement to UV. High quality-low price becomes necessary for survival, and price-quality positioning no longer creates competitive advantage, so the relentless drive for lower costs is at best a temporary solution. The competitive challenge is to assess if a firm benefits by speeding up the move to UV, and if so, how best to do this. While firms may deliberately adopt a follower strategy, they need to be aware of who and what is setting the pace of escalation in their industry. Once the point of UV is reached, the question is how quality should be redefined to restart the cycle.

Figure 2.6 The point of ultimate value (D'Aveni, 1994)

Figure 2.7 suggests various possibilities, which eventually require the strategic use of technology to take a firm beyond the price-quality competition circle to a new arena of technological competition.

Figure 2.7 Moving beyond price-quality through technology (D'Aveni, 1994)

2.7 INTEGRATION OF TECHNOLOGY AND OPERATIONS

A significant challenge when introducing new technology is managing the interface between technology and operations. Technology strategy shapes operations in terms of assimilation and relationships with technology suppliers, while the operating context determines technology adaptation, training and maintenance. The process develops through incremental enhancements, innovations and evolutionary replication (Niosi and Godin, 1999). Kumar and Siddharthan (1994) suggest that technology is truly transferred when the acquirer uses the technology to produce new product innovations, corresponding to Leonard-Barton's (1995) fourth capability level.

Configuration and coordination

Fleury (1999) emphasises the interdependency between configuration (spatial distribution of activities and resources), and coordination (functioning of productive facilities). Narayanan (1998) describes integration as progression through a framework consisting of a technological paradigm (to determine the nature of technology adoption) and a series of technological trajectories (problem-solving techniques to diffuse technology and establish manufacturing systems and procedures). In order to remain competitive, firms change the technological paradigm by shifting from one technology to another, and adopt a variety of trajectories. As a result of deregulation, technological paradigm shifts enable firms "to operate on a different technology frontier through which they can produce new and differentiated products" (Narayanan, 1998: 220).

External technology partners can facilitate technology integration through modifications and assimilation, yet even with similar technology, trajectories vary. Narayanan (1998) attributes differences in the technology paradigm and varying technological trajectories of firms in the same sector to firm specific issues, and country and cultural differences. Countries import technology when they lack the capabilities to "create frontier technologies or innovations which require a well-developed R&D infrastructure ... the correct mix of foreign and indigenous technology is necessary to raise the level of indigenous technology capability" (Kharbanda and Jain, 1997: 440).

It is argued that integration of systems and people issues should receive as much attention as those relating directly to technology itself (Burcher et al, 1999; Grant and Gregory, 1997). Gergen and Whitney (1996: 333) recognise the importance of the human dimension and new forms of social construction that are increasingly required to adopt "alien beliefs, values and practices ... undermining of traditions ... colonisation of perceptions, attitudes and actions" by the dominant party in a business relationship. They see this as coming about through the "tyrannical effects of globalising organisations. As an organisation (the owner, in the case of TT) increases its internal capabilities, its potential for transforming and subjugating its constituents is also enhanced ... this is noteworthy as it represents a major shift from a physical to a human resource" (Gergen and Whitney, 1996: 336).

Steps in the process

Whatever the theoretical constructs in determining how technology is transferred and integrated with operations, it is appropriate for configuration and coordination, and the progression through the technological paradigm and trajectories to take place as a sequence of events. Salami and Reavill (1997) suggest a number of 'steps', presented as a framework for TT: this starts at a macro-level (Step 1), through surveys of technology (Step 2), technology selection (Step 3), detailed implementation and maintenance (Step 4), and ends with evaluation and modification (Step 5). The first three steps emphasise the decision-making and selection process, and consider the relationships between technology supplier and acquirer, with particular stress on human resource aspects. The fourth and fifth steps are concerned with management and implementational issues, and evaluation and modifications.

The first step in the Salami and Reavill framework (Decisions for selecting technology) assesses the agreement between the technology owner and acquirer, in identifying needs and demands of the acquiring country, its capabilities, and macro and micro human resource issues, in relation to the acquirer's goals and objectives. The second step (analysis and survey of technology) concerns formulation and identification of appropriate technologies to meet the acquirer's needs, cost-benefit analyses, and evaluation of technology in relation to the acquirer's resources. The third step (selecting technology) details the final selection for technology adoption, considering human factors required for the technology, final evaluation of costs and benefits, and evaluating alternative suppliers. The fourth step (implementation and maintenance) looks at actions required of the supplier and acquirer, in terms of guidelines for human resource and general management issues, alternative technologies, and criteria for appropriate adaptation of new technology. The fifth step (evaluation and modification) re-evaluates factors pertaining to performance criteria, modifications, and innovative ways of developing the technology further. The framework, included as Appendix II, provides a description of the TT process, and will be referred to again in Chapter 5 as the structure for analysing TT in the case organisations.

2.8 MECHANISMS FOR TECHNOLOGY TRANSFER

One component of this research is understanding how technology is transferred between industrialised and developing countries. This section discusses mechanisms and structures for TT in organisations that acquire equipment and systems for production purposes. Onward sale of acquired technology or its subsequent outputs is not considered.

Internalised and externalised TT

Lall (1993) differentiates between internalised and externalised TT. Internalised TT implies that control remains with the foreign partner and becomes the mechanism for transferring highly complex and novel technology. This is likely to be the case when technology is subject to rapid changes, when R&D is tightly controlled and structured, and when technology is product-directed (since technical product details are initially seldom in the public domain). Externalised TT involves a more complex arrangement with a foreign firm contributing technical expertise, finance and industrial processing, possibly as part of an equity contribution to a joint venture (JV) or formal alliance[8] (including licensing, subcontracting, turnkey projects, management contracts, specialised engineering and consultancy services, and sales of equipment).

Large suppliers of technology frequently opt for internalised TT, as their international structures are set up to manage this. A competent acquirer is less likely to accept internalised TT as the perception is one of exploitation or domination by the technology owner. Lall (1993) has found that government intervention in developing countries is changing from insistence on externalised TT to the acceptance of a more market-oriented, internalised approach. Internalised TT involves a packaged form of TT, including capital, skills and brand names. There is greater recognition that when the acquirer lacks complementary skills, internalisation is the preferred mode of TT, whereas the more technologically proficient the acquirer, the greater will be the externalisation of the TT.

With internalised TT, the owner grants access to technology, possibly on a global scale, but retains a significant financial interest. Clearly some TT will have both internalised

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[8] A substantial body of literature addresses TT through collaborative agreements or JVs (see for example, Harrigan and Newman, 1990; Katz, 1996; Teece, 1986). Gammeltoft (2003) provides a comprehensive list of TT channels: foreign direct investment, joint ventures, purchase of turn-key plants, machine imports, licensing (patents and know-how), original equipment manufacturing, own design manufacturing, subcontracting, and so on. As these are not applicable to the case studies, this aspect of TT is not discussed.

and externalised attributes. The internal/external model, in concentrating on control, addresses only an initial step in TT from a contractual point of view, and lays a necessary foundation for negotiations between owner and acquirer, but is not sufficient to constitute TT in its broadest sense. Acquisition of new technology by a utility represents a direct purchase, sometimes with financial arrangements, specialised engineering, installation and operational agreements, and to this extent represents externalised TT. However, there are seldom JV arrangements or retentions of a financial interest by the owner in the acquiring firm. Even with high-technology projects with an internalised dimension, the owner only controls and structures the technology through a longer-term contractual agreement, but as use of the technology passes to the acquirer, control of it no longer remains with the owner.

As a technology becomes more standardised and diffused, and where local technology infrastructure is good, the acquirer has less direct need for internalised or externalised TT. Local sourcing of technology through supplier networks may be possible, although domestic providers may themselves be subject to contractual arrangements with an original owner. An example is the supply of electric motors to South African industry.[9] From the acquirer's (end user) point of view, all conventional, single speed motors from fractional horsepower to 15MW motors can be manufactured locally. The end user is not part of any TT that takes place from the technology owner in, say, Europe or the US. Only in the case of specialised motors (such as variable speed motors), manufactured abroad, will the acquirer, as an end user, be part of the technology supply chain, particularly if no local supplier is present in the country. Large acquiring organisations are in a better position to absorb new technologies, as they have the facilities to research, modify, or pay where necessary for the use of services of the technology provider. Lall (1993) claims that when sourcing locally, smaller companies suffer because of the lack of infrastructural services found in developed countries.

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[9] This information was obtained during interviews with Eskom's motor specialists and representatives from GEC Machines in Johannesburg.

Alliances and agreements

The literature on joint ventures and alliances concentrates on strategic and management issues (frequently described in broad terms as barriers and promoters), with little systematic evidence of precise technologies, and the dynamics of technology and knowledge transfer (Harrigan, 1988; Haspelagh and Jemison, 1991). An important issue when evaluating a JV in manufacturing organisations is sharing of the product-process core technology, which extends through designs, production engineering, layouts, inventory policy, quality and testing procedures, maintenance, and so on. In an alliance one partner, who may or may not emerge as a champion, will have expertise in areas where the other partner's knowledge is lacking (Katz, et al, 1996). In the case organisations, there is no JV in a contractually bound alliance sense, but owners and acquirers form close technology partnering relationships.

In general terms, the emphasis by Leonard-Barton (1995) on 'knowledge-creating activities' as mechanisms of TT is supported by Borys and Jemison (1989) who present a continuum of modes of knowledge transfer. These may be between two divisions of the same firm, through alliances, joint ventures and licensing agreements, or represent a pure market transaction (purchase) between two independent firms. To these, Inkpen (1998) adds distribution and supply agreements, R&D partnerships and technical exchanges. Mergers and acquisitions provide a further mechanism for technology and knowledge transfer. Since organic growth is deemed costly and too time-consuming, acquisition is an appealing way of increasing a firm's technology base in a reasonably short period of time. Knowledge transfer through alliances and joint ventures can be justified from an "organisational learning perspective for organisationally embedded knowledge which cannot be blueprinted or packaged through licensing or market transactions" (Kogut, 1988: 319).

Alternative ways of attaining global advantage through TT include collaborative agreements or JVs with partners already established in targeted countries or market regions. These apply to capital-intensive processes involving large investments to achieve economies of scale, and are attractive when competition is intense or where worldwide capacity exceeds international demand (Harrigan and Newman, 1990;

Teece, 1986). JVs occur in areas of cooperative mutual interest, although collaborating companies may remain competitors in other domains. Information and technology transfers develop more easily across the more permeable boundaries created by structured JVs (Katz, et al, 1996). The transformation of collaborative agreements into productive and strategically effective relationships will be the real challenge of strategic alliance management in the 21st century (Irwin et al, 1998).

Projects

The way in which technology is transferred is a function of the technology, the strategy of the owner and the capabilities of the acquirer. This is a more useful approach for understanding TT than treating it as a project, with project management principles being used for implementation of a new technology. TT is sometimes treated synonymously with project management, with TT being described in typical project life cycle terms: planning and description of TT as a project, feasibility study, negotiation and contracting, financing, implementation, operation and transfer of technology (see, for example, Kahen (1997)). Steenhuis (2000) details phases in TT set out by Dahlman and Westphal (1981), Chantramonklasri (1990), Behrman and Wallender (1976), and others as a prescriptive approach of treating TT as a project. This may be applicable in a practical situation (new equipment and systems are installed as 'projects'), but it is not particularly helpful in understanding the TT process.

Appropriateness, robustness and transferability

The choice of technology, and the extent of process adaptation, training, and acquirer requirements are determined by technology appropriateness, robustness and transferability. These should fit local conditions, and match the country characteristics and capabilities of the acquiring firm (Grant and Gregory, 1997).

Appropriateness pertains to the suitability of the acquirer's capabilities in being able to accommodate new technology. If the technology is not appropriate for the needs and conditions prevailing in the acquiring country, then no matter how superior or efficient, that technology will be unsuccessful. Katz et al (1996) propose co-ordinating or bridging mechanisms to assist in addressing problems of appropriateness for TT. The first category, the procedural bridge, involves joint planning and staffing, but also requires management of the know-how being transferred. The second bridge is the human one which relies on establishing direct interaction between people from different organisations. Thirdly, organisational bridges use specially constituted transfer teams and processes to formalise TT[10]. The three bridges proposed by Katz et al (1996) create a structure and a common context for effective TT. If Bohn's (1994) claim is accepted that the management of know-how in a first world context is not well understood, this is likely to be far more problematic in a developing country.

Robustness describes a process that can be transferred to any environment without adaptation and that fits local conditions: robustness is "recipient-independent" (Grant and Gregory, 1997). Transferability of a technology is a necessary condition for TT. Provided technology is appropriate (and this is not easy to ensure), there are four possibilities when judging situations in terms of robustness and transferability (Grant and Gregory, 1997):

- robust and transferable: the ideal process
- transferable but non-robust: the process can easily be transmitted, but requires adaptation to fit the acquirer's local conditions
- robust but non-transferable: the process is suitable for the acquirer's application, but cannot easily be transmitted and diffused
- non-robust and non-transferable: this is the most difficult process to transfer.

Lall (1993) contends that one reason for the technological advantage held by large acquiring organisations over their smaller counterparts is that they are better positioned to absorb new technologies with their facilities to research, modify, or pay, where necessary, for the use of services of the technology owner.

[10] As an example, Eskom's 1 900MW nuclear power station was acquired on a turnkey basis from France. The transfer of nuclear technology illustrates these categories. Considerable joint planning at managerial levels was followed by extensive training (the human bridge) in France of South Africa technical, operations and maintenance staff. Organisational bridges are maintained by close contact between the technology owners in France and on-going training and updating of operational and safety standards.

Grant and Gregory (1997) suggest that a less transferable process with poor appropriateness will require greater self-contained or 'embodied' knowledge, and a more intensive transfer method. Alternatively, the greater the acquirer's organisational, adaptive and assimilative abilities, the more non-robust and non-transferable the process that can be transferred. While more embodied knowledge has the advantage of being transferable, difficulties arise when adaptation or maintenance of that system is required at a later stage. Transferring technology may take place with or without modification (Grant and Gregory, 1997). The latter provides commonality on a global scale and obviates the need for any form of re-engineering, but this demands a robustness to the acquirer's local conditions, as opposed to adaptation which may facilitate the transfer process.

The suitability of the technology for adaptation to local conditions also includes non-technical issues: macro-economic factors such as the level of technology which optimises the output/employment balance, the market and its customers and suppliers, environmental and regulatory issues, infrastructure, societal issues and culture. As an illustration of this, Grant and Gregory (1997: 2) point to the apparently seductive appeal of Japanese operating techniques such as lean manufacturing to developing countries, because of their low capital requirements and simplicity. These authors proceed to illustrate why Japanese techniques "are perhaps not appropriate for less developed countries, requiring adaptation of the methods, extensive training, and infrastructure and capability building at the host site". Their reasons extend from an acquirer's lack of housekeeping and quality ethic to low educational level, unionisation, and difficulties with purchaser-supplier relationships.

Knowledge

Difficulties arise in TT because the success of technologies depends to a large degree on the cumulative experiences of key personnel. Explicit knowledge which is documented and accessible may well form only a small part of the sum of knowledge which needs to be shared (Nonaka and Takeuchi, 1995). Processes that are dependent on technological subsystems are subject to minor modifications to enable them to work effectively within an overall system. This requires subtle skills and knowledge which are often difficult to codify (Von Hippel, 1994). Despite comprising apparently identical equipment, individual manufacturing lines may reflect a remarkable uniqueness, through the accrual of "a plethora of incremental fixes and adjustments ... (requiring) individual line optimizations" (Katz et al, 1996: 98-99). The overall technological characteristics are the easiest to transfer (explicit issues), while fine-tuning presents the greatest challenges for operation and maintenance.

Collinson (1999) proposes three "domains" relating to technology and knowledge: technology-as-hardware (products, machinery), the knowledge-base (systems, suppliers, customers, environment), and routines (to develop and apply the knowledge-base of the firm). Routines are observable and transferable, and are a major focus of restructuring and change as firms improve their performance or respond to new conditions. While it is appealing to study a routine as a relatively stable knowledge construct, the forces of routinisation can be disrupted by events that raise new issues and require re-examination of old problems. This emphasises the importance of studying the dynamics of inter-organisational processes (Judge and Ryman, 2001).

From a knowledge perspective, procedures, practices and hardware are generally characterised as explicit knowledge. Difficulties in transfer are exacerbated by extensive tacit knowledge requirements. Although procedures and practices appear 'clinical', the implementation of these involve tacit knowledge transfer, and it is expected that in the maintenance context, the lack of (explicit) plant history will place demands on maintainers' tacit knowledge, even if only based on related experience.

Bresman et al (1999) add a further dimension to TT in this context: the smoothness of transfer. This relates to the transfer of best practices both as tacit knowledge transfer and more articulated explicit knowledge. Even where explicit knowledge is in the form of procedures and practices, from the owner's perspective, a firm must develop information processing and control capabilities to co-ordinate activities across diverse environments. This requires the development of skills of tuning into, and interpreting, strategic signals specific to a foreign environment (Barkema et al, 1997). Although managers should take a lead in the process by offering a firmly defined implementational methodology, they also need to be sufficiently flexible in engaging creatively in the emerging meanings associated with the dynamic unfolding of concrete interactions resulting from the technology. This implies a rethinking of other organisational processes that affect or are affected by the technology (Hart and Schlesinger, 1991; Sitkin et al, 1994; Tuckman, 1994).

A resource-based view of knowledge management recognises that distinct capabilities and knowledge form the basis of differential firm performance. Helfat and Raubitschek (2000: 961) speak of the "*coevolution* of knowledge, capabilities and products" which incorporate the vertical chain and the products which it supports. Supply chain management and the degree of vertical integration become vital components in technology policy. Where technology is a strategic resource, core knowledge will form the foundation for a variety of products, integrating different activities, capabilities and products in one or more vertical chains. This places unique demands on the acquiring company's co-ordinating abilities and control mechanisms in implementing strategic technology policies.

Creation and transfer of knowledge are treated as one concept by Zander (1991) who mentions that since acquirers of knowledge or technology have to devote substantial resources to assimilate, adapt and improve on original technology, their likely modification and development of original technology are components of the transfer of the technology. Transfer is visualised by Bresman et al (1999) as a two-way flow, from owner to acquirer and vice versa, with transfer requiring communication and absorptive capacity in order to achieve a supportive environment or "social community": more communication means more effective communication-intensive transfer, particularly when knowledge is tacit.

Champions

Since new technologies do not automatically sell themselves, Irwin et al (1998) see proactive individuals, boundary spanners or technology champions as the key to advancing TT through innovative ideas. This requires working within carefully designed and well-managed organisational structures. Through communication, personal actions confer a 'style' to the TT they are championing. Irwin et al (1998) consider this to be a special challenge now that international TT involves not only the well-known difficulties of communicating with diverse techno-cultures of scientists and engineers on one hand and business entrepreneurs and managers on the other, but also those of inter-cultural communication in an increasingly culturally diverse global economy. "Serendipity may play a larger role in effective TT than most would like to admit" (Irwin et al, 1998: 5).

As management of the supply chain becomes part of technology policy, local adaptation of technology invariably means greater involvement with local networks and local sourcing at second or third tiers in the vertical supply chain, and this soon necessitates building a network of capabilities, rather than networks of facilities (Leonard-Barton, 1995: 242). While the acquisition of technology in the case organisations is likely to be fairly conventional, an important feature will be how technology-based relationships are established contractually and how these emerge between design, commissioning, operational and maintenance staff.

2.9 CULTURE

A number of authors point to the influence on TT of infrastructure, operating methods, organisational arrangements, and to the importance of overcoming cultural and functional boundaries (Eldred and McGrath, 1997; Gupta et al, 1997; Tyre, 1991). The context of research influences the generalisability of its findings. For example, in a study of TT between US, German and Japanese companies, Katz et al (1996) found that success rates in a number of TT projects were the highest when TT involved the transfer of procedures and practices, whereas transfer of technology hardware showed the lowest success rates. The reasons put forward for these findings are that with hardware it is difficult to change and adapt from one environment to another, particularly if different functionality is required. Hardware implementation involves delays for many reasons (capital availability, staffing compatibility, access to plant during shutdowns, knowledge requirements).

Katz et al (1996: 103) suggest "practices and procedures can be accomplished in a more timely and autonomous fashion", and despite intricate and delicate cultural interaction, "specific procedures involved in a very structured and consistent environment" pose little implementational difficulty. They recognise that further qualification, such as intensity of cultural issues, is required before definitive conclusions can be put forward, and that procedural, human and organisational bridges are necessary to enhance long-term effectiveness of TT. Bowmaker-Falconer et al (1998: 225) concur "... a failure to understand cultural and other differences can lead to misguided assumptions, poor working relations, under-performance and discrimination. Performance is partly a function of how people fit into, and are treated in, the work environment".

Implicit in a consideration of culture is the question of cultural barriers to TT. These relate to the owner's and the acquirer's culture and the impact these have on organisational effectiveness, in relation to the diffusion and management of TT. From a somewhat idealistic point of view, Hussain (1998: 2) asks what kind of culture is necessary to achieve success in TT? Or, what are the culture-related specifications essential to TT? He further speculates whether these specifications can be summed up, compared, modified or blended with those of the owner organisation.

From a more prescriptive point of view, Hussain (1998) seeks to establish whether prerequisites exist for achieving the relevant TT. He gives possibilities such as the necessity of a free-market culture for inculcating Japanese style management techniques, or how a state-protected culture will inhibit TT because of excessive bureaucracy. In investigating these topics, Hussain (1998) suggests that a service-oriented, market-driven culture is essential for TT. Some of this would be achieved by a strong CEO, the appointment of staff who are receptive to new technology, appropriate training and education, and a performance-based and quality-linked organisational structure. Flexibility in adapting to foreign culture by the acquirer will also affect the success of TT. Appealing as Hussain's ideas may be from a free-market perspective, they cannot fully represent conditions for successful TT. While they may apply to MNCs Hussain's contention would preclude TT to many parts of the developing world, including massive importers of technology, such as China where the market operates in a constrained environment, and a free-market cannot be a prerequisite for TT.

Hofstede (1980) defines four dimensions of culture: power distance (the extent to which the less powerful members of organisations and institutions expect and accept that power is distributed unequally; uncertainty avoidance (intolerance for uncertainty and ambiguity); individualism vs. collectivism (the extent to which individuals are integrated into groups); and masculinity and femininity (assertiveness and competitiveness vs. modesty and caring). He also considers the type of culture referred to: national culture or organisational (corporate) culture. Some authors do not directly differentiate between the two, although their research may study just one aspect. Hofstede (1998: 2) defines organisational culture as "collective programming of the mind which distinguishes the members of one organization from another". He divides organisational culture into subcultures, such as a professional subculture, an administrative subculture and a customer interface subculture. Organisational units are typically characterised by a number of dimensions: process oriented vs. results oriented; employee oriented vs. job oriented; parochial vs. professional; open system vs. closed system; loose vs. tight control; normative vs. pragmatic.

Appealing as these dimensions may be in analysing situations such as those pertaining to South Africa, Hofstede has been criticised on a number of counts. McSweeney (2002: 107) comments on Hofstede's methodological flaws in that

> "generalisations about national level culture from an analysis of sub-national populations necessarily relies on the unproven and unprovable supposition that within each nation there is a uniform national culture ... and that what Hofstede 'identified' is not national culture, but an averaging of situationally specific opinions from which dimensions or aspects of national culture are unjustifiably inferred".

Much of the TT literature that addresses culture is more concerned with national cultural differences. Thus, for example, Hussain (1998) identifies three models of TT across cultures. The first refers to the situation where TT through JVs or foreign direct investment (FDI) is facilitated in full. This is achieved with almost total cultural diffusion of foreign partners (including language). The necessary absorption capability of an acquiring firm is provided by a combination of work culture and science and technology. Economic and political stability, law and order, and good government determine to a large extent whether TT will be impeded (Hussain, 1998). The second situation is where there is little effort on the part of an organisation to change work culture. In such cases, attempts to facilitate TT are likely to meet with little success. This is exacerbated where education and literacy levels are low. In such instances, the absorptive capacity of the organisation cannot cope with technology diffusion. The third model lies between these two extremes. For example, literacy may be high, but the science and technology culture cannot fully absorb technologies. Partial TT may take place, and this situation will produce only short-term benefit to foreign partners.

In an African context Mbigi and Maree (1995: 106) state that in a context of "poverty and suffering ... cultural dimensions seem to have a significant impact on the management of transformation". Lessem (1998: 86) speaks of "crossing the north-side divide" and quotes from an *Interdependence and Transformation in Southern Africa* document that "the three interrelated facets of society, namely authority, economy and community, form an interrelated whole ... whereas the authority pole stands for the rationality of the north, and the community pole for the humanism of the south, the economy represents a force of pragmatic integration". Pursuing this theme, Koopman (1991), a South African entrepreneur whose business philosophy has attempted to create an understanding business climate, makes the following statement based on his business experiences:

> "The African work group regarded their fellows primarily in terms of 'southern' morals and emotions rather than in terms of their 'northern' roles and functions. Traditionally blacks have emerged through the spoken word. Wisdoms were carried forward in the form of metaphors and stories as opposed to the written word, which preserved information for western cultures. So 'southerners' will tend to think aurally and emotionally, which is why they would think aloud and use continuous discussion as the main part of their reasoning process. The traditional *indaba* (place of discourse) of such cultures had, as its base moreover, the removal of all dissent before the group could proceed".

The reaction of black managers to this statement (Hipkin and Bennett, 2001) was generally hostile, accusing it of being reactionary, stereotyping, patronising, *passé* and even racist. The general opinion was that this sentiment was certainly not appropriate in

TT. Some managers conceded that during technology implementation, there should be extensive consultations with the workforce. A study of cultural issues (Hipkin and Bennett, 2001b) revealed that managers did not score the factors raised by Gergen and Whitney (1996) to be of great importance, although they did claim a measure of control over some of them.

Cultural identities may be seen as competing (opposing each other in a quest for dominance (Oliver, 1998)), or supportive, in that "African modernity complements the European and the new world modernity yet it cannot be identified with it" (Matustik, 1998: 112). There is clearly a balance between totally ignoring culture and allowing the debate on technology management to be subsumed by it. Blum (1998: 30) accepts that culture has some influence in technology management when it "seeks a moral injunction which avoids ethno-centrism and an indifferent ignorance in one's view of other cultures". Kuper (1999: 212) also acknowledges "the fiction of cultural wholes has at last been abandoned as cultural boundaries are uncertain and subject to negotiation, and that all cultural fabrications are contested from within".

Kuper (1999: 220) contends that "knowledge is culturally constructed ... with an ideological purpose ... (which is) the dehumanising ideology of a capitalist, imperialist, and patriarchal class ... disguised as power plays and strategies for the imposition of one set of values on the whole world", but preliminary findings (Hipkin and Bennett, 2001a) did not support this contention. While cultural differences and integration processes between the parties play an important part in transfer (Bresman et al, 1999), Voss and Blackmon (1996) have found that the influence of a corporate parent may be even stronger than the effects of local conditions. Hussain (1998) suggests that TT in an 'open' organisational culture on the part of the acquirer will depend on the extent to which the owner 'lets go' of the technology. A less open acquirer culture may inhibit TT, and be aggravated by a hostile attitude by the owner towards the acquirer's culture. Alternatively, the owner may mitigate if there is potential for integration of cultures.

Martinsons and Schindler (1995: 16) claim "it is unlikely that a deep-rooted culture could or should be modified to accommodate a new technology ... new technology assimilation will be most successful if it conforms to prevailing organisational systems and structures". This is not borne out by other authors, who point out that adaptation to some cultural issues by the technology owner will be conducive to TT. For example, Barkema et al (1997) claim that cultural distance adversely affects international transfer by eroding the applicability of the parent's competencies, and action is required to reduce cultural gaps.

Inkpen (1998) downplays the cultural dimension somewhat when he states that a learning partnership between the technology owner and acquirer is the key to a successful alliance. As firms gain experience in using an alliance for mutual benefit, they become more adept at using alliances as the mechanism for learning and knowledge acquisition. Learning is particularly ineffectual when learning expectations are inconsistent with partner capabilities and alliance tasks. Culture will thus affect TT if it is not conducive to learning.

Cultural homogeneity reduces communication and language barriers, and therefore affects adoption: cultural affinity positively influences ease of adoption and subsequently technology adoption behaviour (Phillips et al, 1994). While cultural incompatibility may be difficult to overcome, culture plays an important role in technology adoption. The significance of cultural issues is determined by the scale of the transfer and cultural, environmental and economic differences between the originating and the employing society. Phillips et al (1994) believe compatibility of cultures rather than the cultures themselves affects TT: compatibility brings about better understanding and creates the behavioural structures upon which TT can be built.

It is not possible to dismiss the divergent findings of researchers, as contradictory conclusions can be ascribed to the different context in which research is conducted. Peppard (1996) claims that wide differences in opinion do not permit simple and definitive conclusions to be drawn. Change programmes are context dependent, so managers must recognise the irreducible social dimensions of TT, and the web of social and cultural relationships for adoption and diffusion (Peppard, 1996). This requires acceptance of the need for people involved in TT to develop self-reflective and meaning-creating skills if TT is to extend from a narrow interpretation of a complex technology (where it exists) to a broader acceptance of the conceptual issues. The success of interventions such as TQM and BPR can seldom be empirically proven, so it may be that technology brings about change, less through its inherent characteristics and more through the context in which it is applied (De Cock and Hipkin, 1997).

2.10 MANAGEMENT ATTITUDES AND ACTIONS

Like many authors Martinsons and Schindler (1995: 11) emphasise human and managerial dimensions in TT: "evangelizing, exploring, motivating, mediating, projecting, planning, problem-solving ... there is a critical need to examine and enhance organizational practices which are used to introduce, integrate and institutionalize". It is to be expected that with a sense of purpose, receptive and positive attitudes result from easier adoption of technology and because of its immediately perceived utility. This is similar to the claim by Martinsons and Schindler (1995) that collective enthusiasm reduces organisational resistance to change.

In addition to the relationships between owner and acquirer, management attitudes and actions are intuitively obvious factors affecting intervention outcomes, and pervade implementational issues in various guises, such as management commitment, leadership, setting up support systems and policies (De Bruyn, 1994; Saraph et al, 1991; Sitkin, et al, 1994, Swenson and Cassidy, 1991). Managers increasingly perceive their role as one of setting the process in motion, creating opportunities and providing facilities and training, but they see the implementation of a technology itself as something for others in the organisation (Leonard-Barton, 1987). Increasingly, management should encourage the process of knowledge acquisition, through "legitimizing familiarisation activities" (Dimnik and Johnston, 1993: 161). The degree to which implementation is successful goes beyond training and education (Peppard, 1996), to knowledge of products, processes and quality standards, and depends on the ability of the organisation to learn (Kasul and Motwani, 1995).

These are obvious observations, which are frequently quoted. The underlying reasons for a lack of consistent action at senior levels lie at a deeper level. In a maintenance context, Hipkin and De Cock (2000) suggest technology is a label signifying to organisational stakeholders both the goals which senior managers should pursue as well as the means by which the goals may be attained. In order to retain stakeholder support and maintain their legitimacy, senior managers must be seen to be using such techniques (concurring with the earlier statement of Bennett et al (1999) regarding non-quantifiable benefits of technology). This is not to say that managers do not care about operational and technical matters, but by virtue of their positions, senior managers will be more preoccupied with, and attuned to, institutional pressures. These may also operate at lower levels where managers implement technologies that are considered by the professional community to be up-to-date and effective, and which are seen to represent progressive management. This is analogous to the evolutionary approach of Nelson and Winter (1982) whereby competences are built through path-dependent knowledge bases, and hierarchical routines determine how firms operate. Zhang et al (2001) attribute the source of a firm's tacit knowledge endowment to its evolutionary path-dependence.

The issue is more one of perception (the institutional dimension where managers are seen to have introduced the technology) than of substance (the technical component relating to what they have derived). This view is reinforced by Meyer and Rowan (1977: 340):

> "Organizations are driven to incorporate the practices and procedures defined by prevailing rationalized concepts of organizational work and institutionalized in society. Organizations that do so increase their legitimacy and their survival prospects, independent of the immediate efficacy of the acquired practices and procedures".

2.11 ASSESSMENT OF TECHNOLOGY TRANSFER

The literature proposes a number of factors that contribute to successful TT, whatever the context, although additional factors intervene when considering TT to developing countries. Lado and Vozikis (1996) identify two broad categories: the acquiring country's level of economic development, and the absorptive capacity of local firms. Olayan (1999) suggests that the transfer of technology will generally be more intense as the technical level of the recipient rises. Absorptive capacity will differ depending on whether the technology is to be used as a promoter of entrepreneurship, or to support corporate undertakings. Lado and Vozikis (1996) suggest that receptivity of technology is largely a cultural issue in the corporate situation, whereas the propensity to take risks by promoting business through technology relates more to entrepreneurship. This is also a function of the relationship, such as a JV or alliance, between owner and acquirer.

Objectives set by technology owners and acquirers differ, so assessment addresses a variety of goals, and diverges during implementation. Appraising the multiple outcomes of TT as an inter-organisational process (Spann et al, 1995) means that cost-benefit analysis is only one option for measuring the success of TT. The value of TT lies in the merits, compatibility and features of the technology itself, precise production outputs achieved through the technology, and the technical and commercial effectiveness of the TT (Bennett et al, 1999: 511). Measures such as number of machines sold, royalties granted and licences agreed, indicate at best no more than a technology owner perspective of short term success, and say nothing of the extent to which technology has been transferred (Spann et al, 1995). Bennett et al (1999: 492) discuss quantifiable and non-quantifiable benefits of TT for owners and acquirers. Typically, non-quantifiable issues include "we ought to be in China" (on the part of the technology owner), or the acquirer's belief that "we must acquire CNC technology".

A specific user evaluation construct is needed to link technology to the demands it places on the organisation. Goodhue (1995) introduces the term task-technology fit (TTF), which views technology as a means by which a task is performed by equipment and goal-directed individuals. TTF focuses on the degree to which technology characteristics match user task needs and abilities. Appropriateness is a function of the characteristics of the underlying technology and "elicited beliefs or attitudes" (Goodhue, 1995: 1828). To assess these it is necessary to understand many different attributes such as functionality, usefulness and ease of use, impacts, and relative advantage. Goodhue (1995) suggests that because there are so many different constructs to understand, it is not possible to develop a suitable general theoretical basis for appropriateness, so he proposes an approach that can link underlying systems to their relevant impacts. If technologies are viewed as tools by which individuals carry out their tasks, then the TTF perspective creates a better fit between technology functionalities, task requirements and individual abilities, leading to better performance, as shown in Figure 2.8.

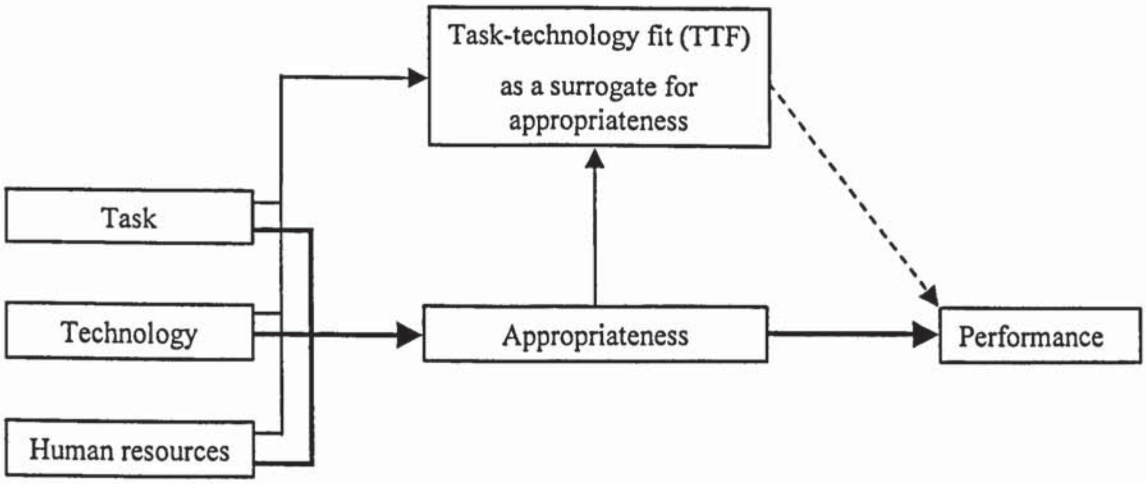

Figure 2.8 Task-technology fit as a surrogate for appropriateness

When measuring the effectiveness of TT several issues are important. The time dimension is technology specific, with successful TT being achieved almost instantaneously in some instances, or in other cases, requiring months or years to achieve reliable and meaningful results. The type of technology under consideration influences the nature of the transfer and the measures used to determine success or failure. Katz et al (1996) describe transfer as successful when technology has been incorporated into a system and has achieved full operational status. TT is unsuccessful when transfer does not meet expected performance standards, or the technology is abandoned.

Perceived utility and ease of application determine attitudes and behaviour intention in adopting technology (Phillips et al, 1994). Ease of adoption is the extent to which the acquirer expects the new technology to be "free of effort regarding its transfer and utilisation" (Phillips et al, 1994: 2). While measuring the construct in this way may take into account industrial and social conditions in the recipient country, it effectively places the onus on the suppliers in a context where they may have no control over many factors relating to transferring, adopting and using the new technology. For example, Phillips et al (1994) cite a study of TT to China where perceived ease of adoption positively affected the perceived utility of the technology, and both ease of adoption and perceived utility had a positive influence on the acquirer's attitude toward adoption of the technology.

The success of new interventions frequently turns to technical and financial measures such as costs, benefits, tangible improvements, and monetary savings (Hackman and Wageman, 1995; Wilkinson and Wilmot, 1995; Wilson, 1991). The literature bemoans the lack of recognition given to performance measurements (Clarke and Mia, 1993) and the neglect of internal systems that fail to meet the information needs generated by a new intervention (Deluzio, 1993; Swenson and Cassidy, 1991; Upton, 1998). There is, moreover, diversity of opinion of what constitutes success and how it should be measured (Safayeni et al, 1991). This arises because objectives are often ambiguous and the lack of established effectiveness measures renders evaluation difficult (Armistead et al, 1995; Dixon et al, 1994).

Managerial intuition is often the basis on which technology decisions are made, rather than through cost-benefit analyses (Alcorta, 1999). In some cases, governments recommend or prescribe a certain technology for political or economic reasons (Quinton, 2002). Sambasiva Rao and Deshmukh (1994) suggest that improved quality is frequently the primary reason that developing countries introduce new technology. Thereafter, new technology should reduce costs, provide flexibility, shorten response times, and increase productivity.

The lack of standardised methods for introducing technologies may present advantages, as this permits organisations to transfer new technology, evaluate it, and measure its outcomes in a number of ways. This has been the case with other management interventions such as TQM and BPR (Farrell, 1994; Grover et al, 1994; Guimaraes et al, 1996). In the TQM and BPR context, the attraction for managers is that these are fashionable yet somewhat indeterminate concepts, under whose guise almost any management intervention can be implemented, and to which credit can easily be attributed. It is ironic that concepts so openly and extensively in the public domain are ill-defined to the extent that managers can use them for their own ends, without fear of being challenged or contradicted (Clark and Salaman, 1996; Kerfoot and Knights, 1995; Knights and Morgan, 1991). The popular success of generic change approaches such as TQM and BPR may be explained by their inherent ambiguity (De Cock and Hipkin, 1997). They appeal to a wide audience because everyone can find something of value in the various approaches making up these constructs. However, popularity does not equate to operational success. A lack of formal definitions and implementation methodologies may even be helpful to obtain the commitment of various constituencies inside the organisation "in order to legitimize all sorts of measures and changes in the name of a self-evident good" (Wilson, 1991: 1). The literature on TT has not extensively addressed implementation in the light of the experiences of other management interventions, but research into these may provide pointers for TT, and for measuring its effectiveness. The array of definitions of TT may mean that wide interpretations thereof can result in similarly diverse assessments of its success.

Again looking at a broader picture of management interventions, while desired outcomes are stated in measurable terms, such as fewer defects, better service, cost savings, reductions in the workforce and higher operating efficiency (Hammer, 1990; Smith et al, 1994), actual outcomes may be nebulous and indeterminate. Customers expect quality and conformance to specifications, reliability and flexibility of supply, and confidence in the ability to provide long-term innovative capacity and to ensure financial viability (Barnes and Kaplinsky, 2000). Without specifying precise outputs, there is confusion as to what new technology is really about. Thus, the intervention may be perceived as the process, the training programmes, the meetings and the systems, and even the company publicity and progress reports; sight is frequently lost of what the end goal is (De Cock and Hipkin, 1997). Key participants in a process may have an interest in measuring certain things in certain ways (to make them look good). Managers cannot consider "measurement" as a purely technical, neutral concept. They should view measurement in the context of on-going struggles in the organisation, around control, power, authority and consent (Hipkin and De Cock, 2000).

An assessment of TT requires an analysis of the roles of the disseminators (who make people aware of new technology), sponsors (who provide financial and political support), implementers (who cultivate new customers and troubleshoot new technologies), and adopters (who incorporate new technologies in processes and products) (Spann et al, 1995). Clearly the different players will spend different amounts of time in the various TT activities. The contribution of these activities to the management of technology, and measuring its effectiveness will be studied in the case organisations.

2.12 CONCLUSION

This chapter has reviewed aspects of the literature relating to TT in developing countries. The impact of globalisation, and economic and political factors are seen to be of great importance in developing countries. Strategic issues are increasingly driving technology decisions, although developing countries are affected by a number of intervening constraints. Integration of technology, operations, physical asset management, and mechanisms for TT have elements in common with developed countries, but are influenced by local cultural and management factors. These will be discussed in detail when analysing the empirical evidence from the case studies.

Developing countries need to recognise the varying importance of politics, economics and technology (as depicted in Figure 2.1). As purchasers, first world consumers are not concerned with the afflictions of poorer nations. Developing countries must take painful political decisions and make bold economic moves to enhance the role of technology if they are to play a meaningful role in global business.

CHAPTER 3

A REVIEW OF THE PHYSICAL ASSET MANAGEMENT LITERATURE

3.1 INTRODUCTION

Organisations frequently seek new management interventions to improve their operations. Claims and counterclaims persist as to the effectiveness of the 'three-letter acronyms' (TQM, BPR, JIT and so on), with studies listing key success factors, and describing what was successful and unsuccessful in their implementation. Impressive accounts of cost reductions and improvements in output and quality are countered by scepticism and refutation. The number of failed initiatives should raise questions about the interventions and their implementation. Swanson (1999) comments that when introducing new technologies, organisations generally only consider the impact on the direct workforce, with insufficient consideration given to supporting structures. In particular, she calls for more research into the implications of new production technologies on the management of the maintenance function.

This chapter considers some of the revised thinking in physical asset management that assists in providing greater understanding of maintenance management systems and technologies. The following sections contain some general comments on maintenance, followed by consideration of a number of viewpoints on quantitative aspects of physical asset management, availability and reliability. Functionality is presented as the basis of maintenance, with associated functional failures, failure modes and effects. Underlying concepts of preventive maintenance, maintenance performance and measurement, and computerised maintenance management systems are presented. RCM and TPM are briefly discussed. The chapter concludes with some issues relating to risk and condition-based maintenance. Appendix III contains a selection of the many definitions found in the maintenance literature. In some instances there are contradictions between different authors' understanding of the terms, which inevitably lead to different interpretations of maintenance concepts. These are referred to in subsequent sections of this chapter, and again when discussing the relationship between physical asset management and technology transfer.

3.2 GENERAL COMMENTS ON PHYSICAL ASSET MANAGEMENT

Maintenance encompasses "all activities necessary to restore equipment to, or keep it in, a specified operating condition" (Pintelon and Gelders, 1992: 301). This illustrates a change in emphasis in maintenance management from more traditional approaches involving "repairs needed to make a failed machine operational" (Russell and Taylor, 1995: 727). The difference is important as it suggests a new starting point for determining maintenance requirements. The management of physical assets[1] is also affected by the profound changes taking place in the operations field.

Manufacturing organisations have been compelled to look at their physical asset management for several reasons. Safety and environmental disasters are increasingly attributable to equipment failure (Lofgren et al, 1992; Manion and Evan, 2002). Maintenance itself is changing, as a result of substantially different ways of understanding the nature of failure (Moubray, 2000). Technology is relied upon to increase output, improve quality, ensure more efficient energy use, and meet customer value resulting in a closer relationship between maintenance and product quality (Campbell, 1999). Automated facilities operating in a just-in-time regime require higher availability and reliability from plant and equipment (Nakajima, 1989).

Greater competition demands strict cost control, with maintenance accounting for an increasing share of operational costs (Paz and Leigh, 1994). A percentage point improvement in operations and maintenance expenditure can be worth tens of millions of dollars. The impact of poor operating and inappropriate maintenance on profitability

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[1] The term physical asset management is frequently used synonymously with maintenance management. 'Maintenance' evokes the notion of factory plant and equipment, predominantly related to mechanical and electrical rotating equipment. Physical asset management encompasses a broader range of activities and applications, incorporating the traditional maintenance spheres of activity, but also including buildings and structures, instrumentation, hardware and software, many of which have no relationship with production activities. It thus encompasses the proactive physical management of assets in an operational environment.

is even more dramatic when costs of poor quality and lost opportunity due to lack of equipment availability are taken into account. Willmott (1994) estimates that maintenance costs are some 5% of turnover in manufacturing industries although this varies from one industry to another. Figure 3.1 illustrates cost of maintenance as a percentage of total manufacturing costs for several UK industries (Willmott, 1994).

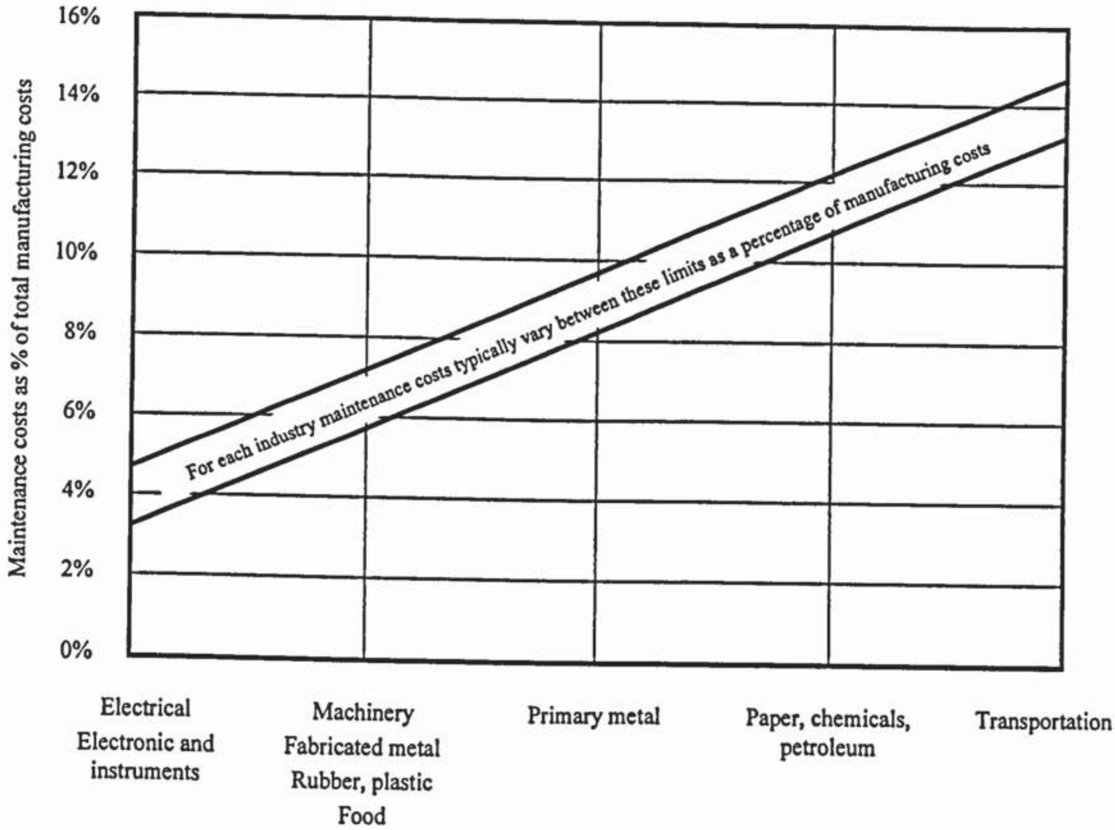

Figure 3.1 Range of maintenance costs by industry (UK) (from Willmott, 1994)

Operating and maintenance experience is frequently lacking when new technology and systems are introduced. Extensive data, information and knowledge contribute to a potentially fuller technical and operational understanding of plant, equipment and processes, so information technology is being called upon to assist in achieving a broad range of objectives in the management of physical assets. Equipment performance is increasingly dependent on knowledge of plant and procedures, and equipment failure data (Cleveland et al., 1989; Cohen and Levinthal, 1990; Huysman et al., 1994; Jaikumar, 1986; Leonard-Barton, 1995; Ramamurthy, 1995). The expectation that maintenance will provide desired availability and reliability through failure prevention is being replaced by new and broader approaches to the management of physical assets.

Physical asset management includes a range of engineering activities pertaining to maintenance, as well as the adoption of a variety of management approaches to maintenance, such as reliability-centred maintenance (RCM), total productive maintenance (TPM), multi-skilling, and hazard and operability studies. Implementation of RCM, TPM or computerised maintenance management systems (CMMS) is likely to be enhanced where managers set precise objectives for the interventions (Coetzee, 1999). Developments in CMMS have meant that traditional planning and scheduling of maintenance activities are being replaced by expert maintenance management information systems. Powerful proponents are selling RCM and TPM: the forceful persuasion behind RCM is frequently that "this is the way the airline industry does its maintenance" (Nowlan and Heap, 1978), while TPM is sold as the way Toyota and other successful Japanese companies do their maintenance (Willmott, 1994). These are illustrative of just two management interventions that companies look to in order to bring about improvements in their operations.

The above paragraphs suggest the management of physical assets requires consideration of the interaction of equipment, operating and maintenance staff, and the organisation itself (Pitz and Weber, 2001). Performance of equipment is directly affected by its operating context, design parameters, and maintenance policies applied to it. Operators and maintainers require training and skills as 'knowledge workers', functioning in designated or informal teams. Organisational structuring, value systems and functional requirements influence how individuals perform their tasks, and how equipment behaves. Swanson (1999) proposes a comparable set of capabilities: equipment failure response and prevention, communication and coordination, and technical expertise.

3.3 QUANTITATIVE ASPECTS OF PHYSICAL ASSET MANAGEMENT

The physical asset management context in which detailed consideration of technology transfer will be investigated offers the researcher a vast literature, much of which falls into the operations research (OR) domain. Mathematical approaches and OR applied to maintenance propose solutions to real life problems but necessarily impose "a plethora of boundary conditions and other factors that have to be taken into account and that limit the number of possible solutions" (Fortuin and Lootsma, 1985: 55). It is more likely that many modern systems are too complex for mathematical analysis (Banerjee and Flynn, 1987). Information required from sophisticated modelling is often not available in a usable form (Christer, 1984; Currie and Sneddon, 1992; Huber, 1984), and the relevance and credibility of the results emerging from these approaches are questioned (Turban, 1967).

Further, theoretical studies of maintenance problems may be regarded as "abstract versions of real-life problems ... (having) limited use for practitioners as they are frequently chosen to correspond with current modelling practice or are selected for computational convenience" (Flynn et al, 1990: 251). This introduces a "practicality gap" (Fortuin and Lootsma, 1985: 57) between the theoretician and the manager that is manifested in a number of ways:

- decision-makers are often not willing to accept quantitative analyses of management problems because they do not understand or believe the mathematical and computational manipulations. These appear not to address prevailing risks, uncertainties, technological developments and social factors. The danger in management research is avoiding divergent (human) problems by reducing them to convergent issues through mathematical reasoning
- where OR problems have ambitious solutions, specialist analysts are often isolated, do not appreciate written and unwritten rules of conduct, and are not perceived as having sufficient experience, intuition, knowledge, insight and understanding.

Barlow and Proschan (1965) suggest that mathematical maintenance models take one of two forms: two-state models (the system is either fully functional or in a state of total failure) and multi-state models (the system can be in more than two states, depending on the extent of deterioration). Gits's (1984) summary of the two- and multi-state models is presented in Figure 3.2.

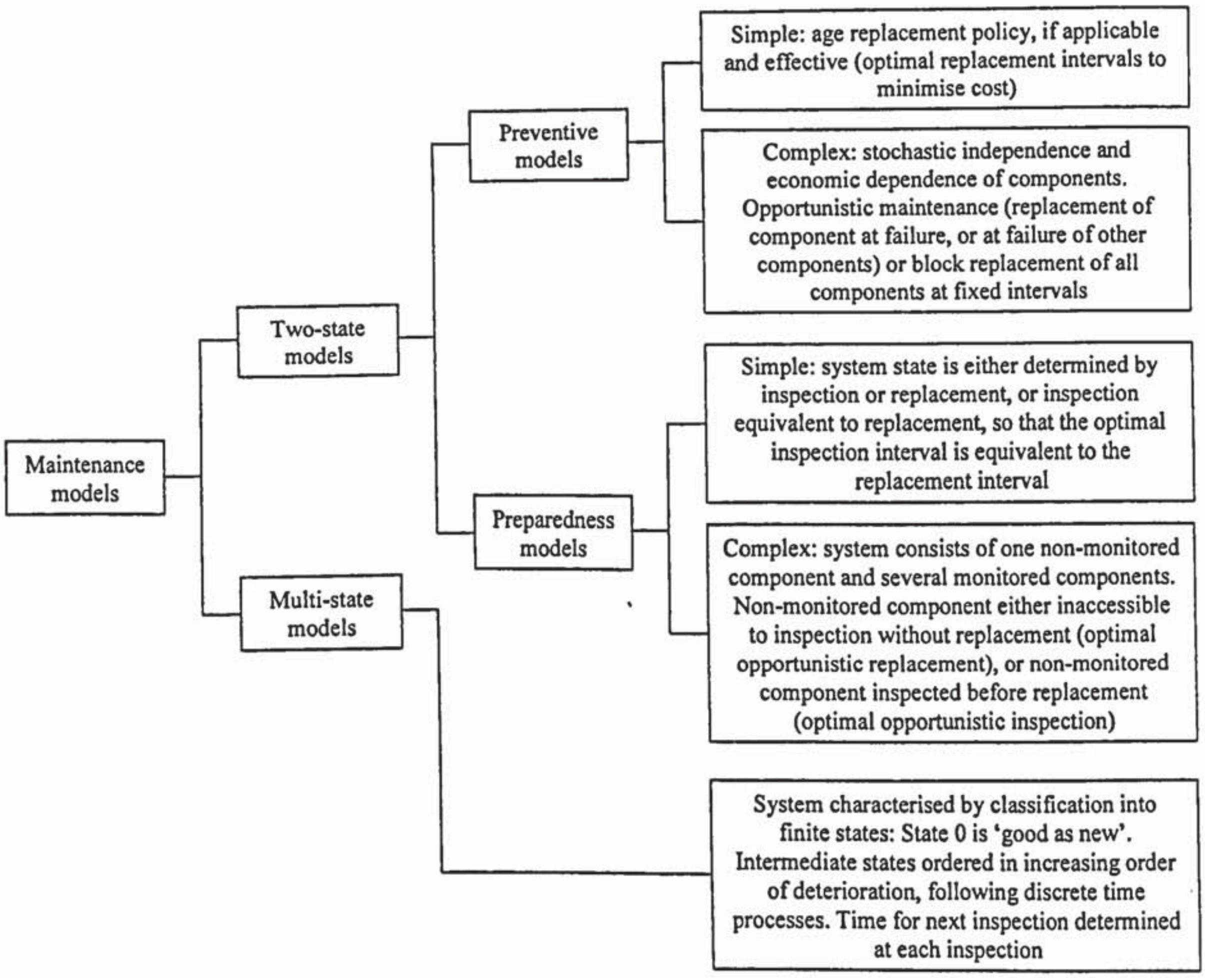

Figure 3.2 Classification of mathematical maintenance models

In preventive maintenance models, the underlying assumption is that the actual state of the system is always known with certainty. A relationship is assumed to exist between failure probability and age, which determines when maintenance should be performed. Alternatively, maintenance of an item is carried out when other components in the system fail, or when these are subjected to preventive maintenance. This is expressed in practical terms by saying that 'while A is being repaired and the machine is out of service, we might as well replace B'. In preparedness maintenance models the actual state of the system (or at least some of its components) is not known with certainty; failures are only detected when some definite maintenance action is taken, which is the basis for condition-based maintenance. In simple maintenance models, it is assumed that the system consists of only one component, whereas complex maintenance models consist of several components.

Taha and Wolf (1996: 57) refer to a number of mathematical optimisation, heuristics, dynamic and integer programming techniques in electricity generation systems aimed at minimising costs, determining minimum reserve capacities, reducing risks, computing effective capabilities, and forecasting load uncertainties. They generally reject these because "simplifying mathematical assumptions make them more suited to theoretical research than to practical application ... the planner may not be able to use these models in practice because of the difficulty of estimating the necessary cost parameters".

It would be irresponsible to question all the OR work done in the area of maintenance on the basis of simplistic assumptions, mathematical convenience, or whatever, but the above comments are made to emphasise the difficulties encountered when applying the quantitative techniques developed in the OR literature. The remaining sections of this chapter do not consider mathematical approaches to maintenance any further.

3.4 AVAILABILITY AND RELIABILITY

Availability and reliability are amongst the most frequently encountered concepts in maintenance theory and practice. A number of definitions appear in Appendix III. The first part of the definition of availability given by the US Nuclear Regulatory Commission is commonly encountered: the time a system is functional as a percentage of the time during which the system may be required. The second part, claiming that availability includes reliability, is not found elsewhere in the literature.

Smith (1993) proposes that two parameters should be controlled in order to improve availability: mean time between failures (MTBF) and mean time to repair (MTTR). Availability is then defined in the following terms:

$$Availability = \frac{MTBF}{MTBF + MTTR}$$

A large MTBF in relation to MTTR or a small MTTR results in high availability. Smith (1993: 205) suggests factors that increase MTBF or reduce MTTR (Figure 3.3). The specific tasks listed in Figure 3.3 suggest that efforts to improve availability include a broad range of activities, many of which are incorporated in definitions of maintenance and encountered in the RCM and TPM processes. The range of definitions of maintenance in Appendix III cover a number or perspectives varying from retaining the available state (Gits, 1984), to a process specifically including repairs, surveillance, diagnosis (US Nuclear Regulatory Committee, 1992), but they do not refer to training, spares and design issues.

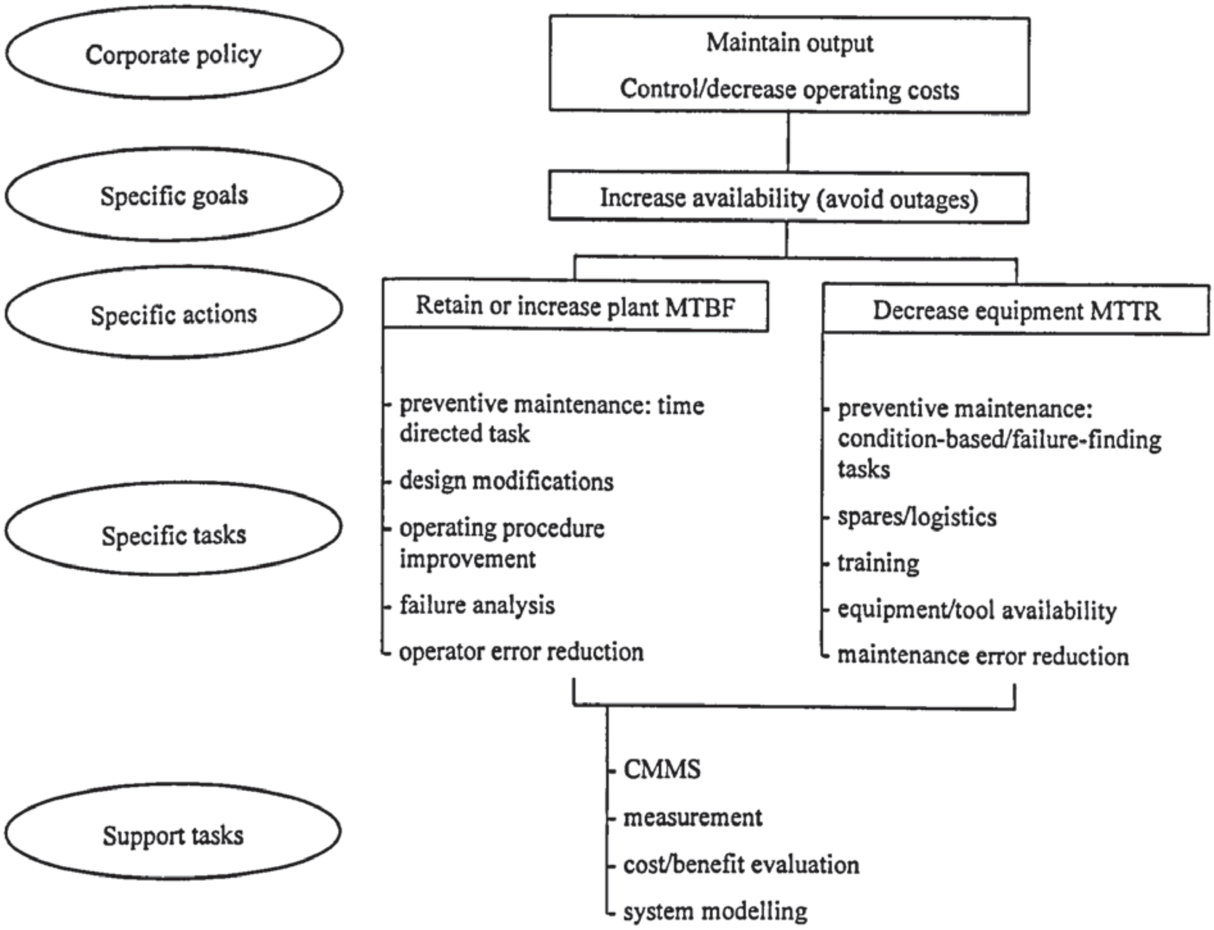

Figure 3.3 Factors to improve availability

Nikolaev and Gourinovich (1996) illustrate the impact of maintenance on equipment reliability in Figure 3.4. In the top part of this figure servicing renews functionality by restoring the condition of the equipment, but general degradation continues over time. Provided reliability does not drop below reliability control limits, a component remains 'functional' (able to fulfil its function). Where components are serviced and overhauled during, say, every fourth service (the bottom part of Figure 3.4), the rate of degradation is reduced. Clearly, this applies only to components that deteriorate over time.

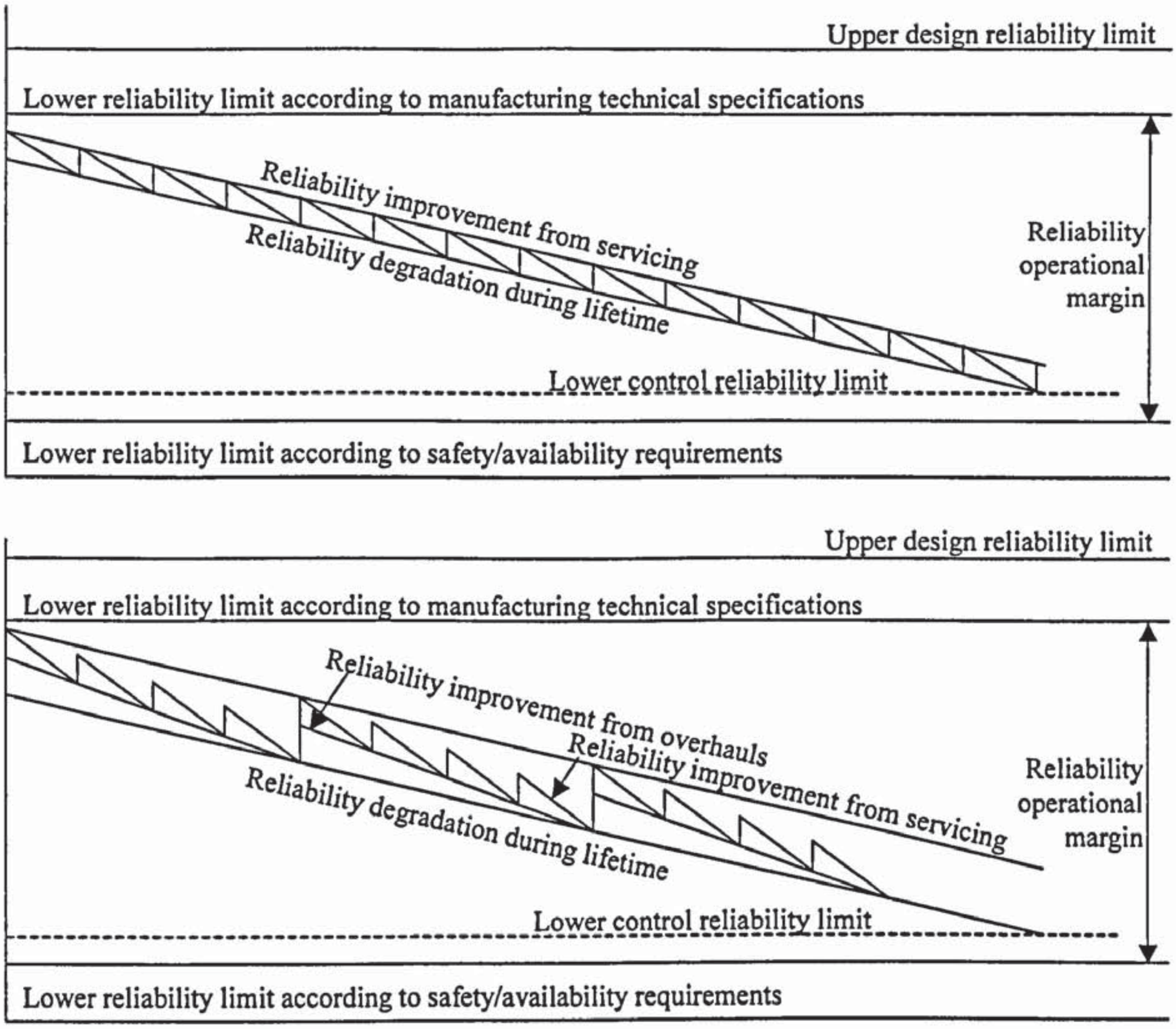

Figure 3.4 Impact of maintenance on equipment reliability over time

3.5 FUNCTIONS AND FAILURES

Competitive advantage is increasingly obtained through knowledge and the knowledge-based company (Leonard-Barton, 1995). This has a direct bearing on maintenance, as knowledge of machine capabilities, a thorough understanding of the production process, and a high level of production competence are essential before maintenance can be determined (Jaikumar, 1986; Cleveland et al, 1989; Ferdows and De Meyer, 1990). Nowlan and Heap (1978) commence their discussion of maintenance determination by establishing the intended functions of a system, machine, or item, and by quantifying desired performance standards. The next stage in maintenance determination is a failure mode and effect analysis, and a consequence evaluation (Swanson, 1999). Thereafter, appropriate maintenance intervention is determined.

This suggests that it is no longer appropriate to perceive maintenance solely as a discipline for preventing failures to achieve desired availability and reliability levels (Banerjee and Flynn, 1987). A common theme in the definitions of maintenance in Appendix III is that the task of maintenance is to ensure functionality. It follows that inability to sustain functionality constitutes a failed state. It is only possible to distinguish between functional and failed states if performance standards are quantified in the operating context under consideration (Moubray, 2000). The challenge for operators and maintainers of new technology is to acquire high levels of product, process and plant knowledge, as part of the TT process.

Gits (1984: 2) prefaces his definition of maintenance by defining a technical system as "a set of interrelated parts fulfilling a specifiable production function". He then defines maintenance of a technical system as "the total of activities aiming at retaining each part of the technical system in, or restoring it to, the physical state considered necessary for fulfilment of its function". These definitions apply to a production environment, but can be extended to include all aspects of physical asset management. Gits (1984) specifically excludes from his definition the replacement of the entire technical system, modifying it to design out maintenance, and the provision of the primary input of the production process. This is not to deny the necessity of replacing entire systems or including modifications, but suggests that engineering redesign is the task of another functional department. Other authors do not specifically divorce engineering and operational redesigns from the maintenance function (Willmott, 1994), as remedial action frequently requires a form of redesign.

The inability to satisfy functional requirements constitutes a functional failure. Moubray (2000) provides an illustration in Figure 3.5(a) indicating that deterioration from an initial capability is 'maintainable' until the desired performance is reached. Figure 3.5(b) shows the failed state in that desired performance is higher than initial capability. Maintenance cannot raise the functionality above its inherent design capability. If deterioration results in capability falling below desired performance, the solution lies in an engineering redesign, or changes in operating procedures.

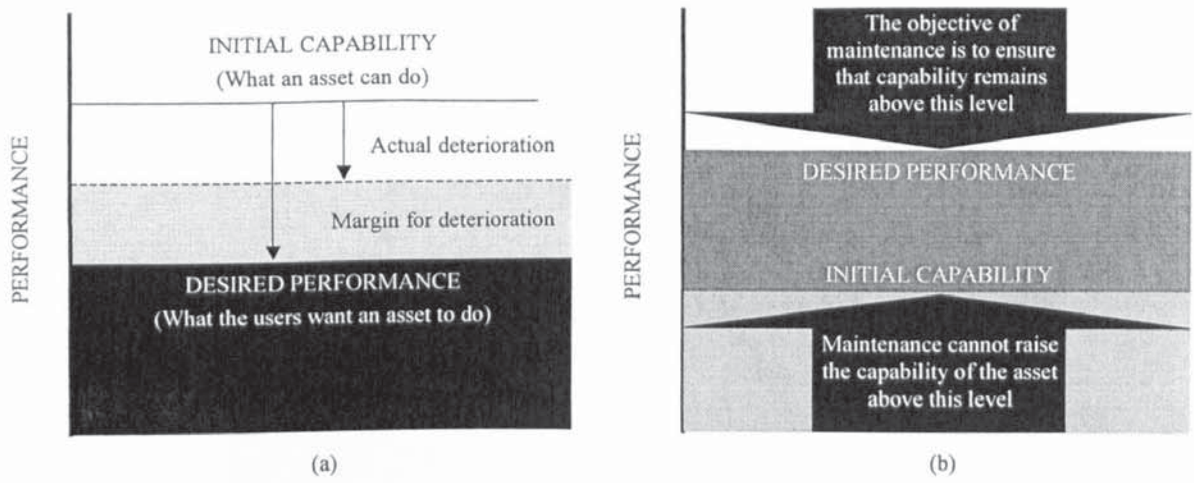

Figure 3.5 Initial capability and desired performance

Gits (1984) defines a failure as the transition of a component from an operable state (a state sufficient for fulfilment of its function) to an inoperable state (a state insufficient for fulfilment of its function). Failures can be absolute (total) failures (where the capability of the asset falls below the desired performance) or normative (partial) failures (which can be envisaged as partial deterioration).

Figure 3.6 shows the number of failures in a certain part of the nuclear power station, before and after the introduction of a CMMS in 1998, and its revision in 2000. Three types of failure are referred to by Kondo and Ichige (1991): potential failures (a component is still capable of fulfilling its intended function, but failure is imminent), partial failures (a component is only able to fulfil part of its intended function), and total failure of a component. Kondo and Ichige provide no explanation for the increase in failures during the year of implementation, but these failures can probably be ascribed to the difficulties of 'burn-in' encountered with the implementation of new systems, as the maintenance department changed over from one system to another (this is depicted by failure pattern F in Figure 3.7, discussed in the next section). It would be expected that the discovery of potential failures should decrease the number of functional (partial and total) failures. This is the case in 1999. The number of partial and total failures increased in 2000, the year in which the CMMS was revised. A dramatic drop in all failures is noted in 2001, when the system was fully operational.

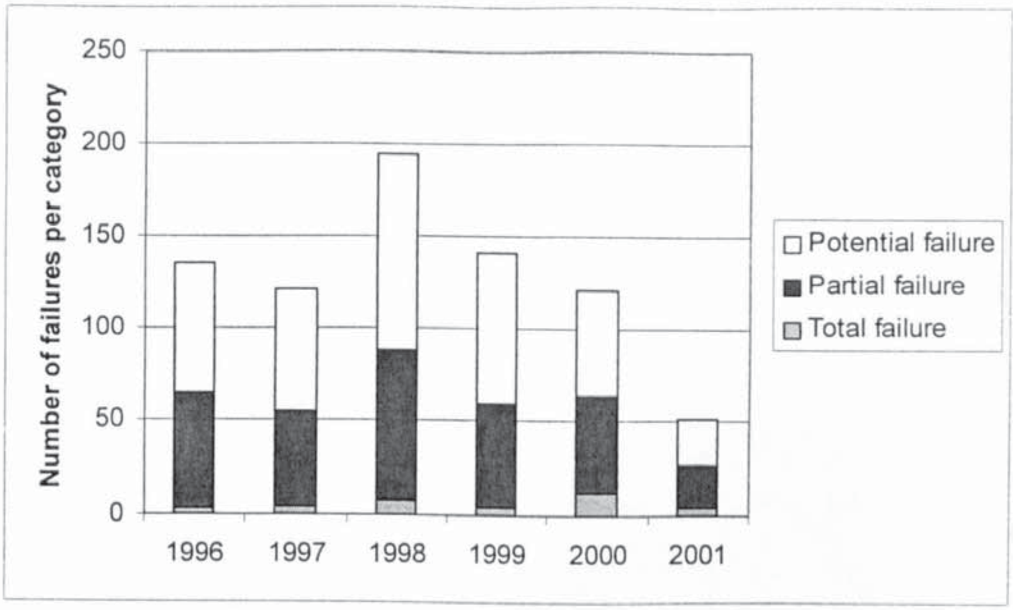

Figure 3.6 Illustration of potential, partial and total failures in a nuclear power station

Failure mode and effect analyses (FMEA) are widely used in maintenance management. In relation to an FMEA the US Army definition in Appendix III differentiates between failure causes and failure modes, but the terms are used interchangeably in the literature. Defining maintenance in terms of functionality would not support a maintenance approach that starts with an FMEA. Failure modes should be identified for each functional failure, and functional failures can only be determined if equipment functionality has been defined. Failure effects describe what happens when a failure occurs, and failure consequences are categorised as hidden, safety, environmental, operational and non-operational (Moubray, 2000). These in effect assess the severity of failures. In contrast, the US Army claims that a failure effect is a failure consequence. However, in its definition of an FMEA, the US Army implicitly acknowledges a distinction between failure effect, as the result of a failure, and failure consequence, which is a classification of the severity of failure.

Bloom (1995) proposes a system of component prioritisation for preventive maintenance, as illustrated in Table 3.1. This requires identifying component criticality at failure mode level. Determining maintenance requirements at this level without immediate reference to system functionality deviates from the views of Gits (1984), Moubray (2000), Smith (1993) and others who contend that maintenance intervention should be aimed at ensuring functionality, and failure criticality should be assessed through consequence evaluation.

Critical components	FMEA. Components to be subject to detailed analysis
Economically justified components	
Economically insignificant components	Possible use of FMEA Components are candidates for 'run-to-failure
Non-critical components	

Table 3.1 Component prioritisation for preventive maintenance

Ohta (1996) suggests factors to be taken into account when determining equipment priorities: normal or emergency use, whether supported by auxiliary equipment, possibility of maintenance or surveillance testing without shutdown, supplier guarantees, operating hours, operating environment, failure history and experience. Decisions are taken at equipment (rather than component) level, but even this higher level does not specifically consider functionality. Ohta (1996) does take the operating context into account, and makes oblique reference to failure consequences in so doing.

While some failures must be prevented (those with safety and environmental consequences), it may be more effective to permit other failures in certain circumstances. Functionality and operating context of a system determine which failures can be tolerated. For example, if dual 100% systems are installed, a suitable policy may be to keep one item in permanent operation and the second on permanent standby. The maintenance policy should permit the normally operating item to fail, while maintenance effort is directed at ensuring that the standby item will function when necessary. The frequency of maintenance intervention (failure-finding) of the protective function (the standby) is determined by the criticality of the system (and hence the desired availability) and the reliability of the item in normal operation (which will determine how often the standby item will be required) (Moubray, 2000).

Gits (1984) subdivides maintenance into breakdown maintenance (due to absolute failure), and shutdown maintenance (resulting from maintenance control decisions). He sees the purpose of maintenance as one of reducing failure consequences (rather than failure prevention), through corrective, preventive or detective maintenance (detective maintenance (failure-finding) is the effort to ensure functionality of a hidden function).

Consequence evaluation in a specific operating context is emphasised by Swanson (1999: 850): "increased integration with AMT means that equipment failures lead to more immediate and costly consequences". The need for uninterrupted equipment operation means that problem solving becomes more important (Schmenner, 1988), with a higher level of training and a broader set of skills (Gilbert and Finch, 1985). In an operating context with high work-in-progress inventories, the cost of downtime is low and maintenance tends to be reactive. Where there is little coordination between maintenance and production, adversarial relationships develop between production and maintenance (Swanson, 1999). Various authors have commented on maintainers' static knowledge levels of equipment functionality (Johnson 1990), and the need for updating maintainers' skills (Peele and Chapman, 1987).

3.6 UNDERLYING CONCEPTS OF PREVENTIVE MAINTENANCE

In seeking to maximise equipment availability and reliability, and minimise maintenance costs, preventive maintenance systems prescribe regular tasks at predetermined intervals. The validity of these intervals is often questionable and the frequency of maintenance intervention remains one of the most controversial issues in maintenance (Lihovd et al, 1998). Theoretical studies suggest optimal maintenance intervals to minimise costs (Cho and Parlar, 1991), but with greater acceptance that most failures are not age-related, practitioners recognise the limitations of theoretical studies to determine intervals (Block and Geitner, 1983; Wang and Lee, 2001).

Research by Nowlan and Heap (1978) into failures in passenger aircraft revealed six failure patterns, as shown in Figure 3.7, indicating the conditional probability of failure against time.

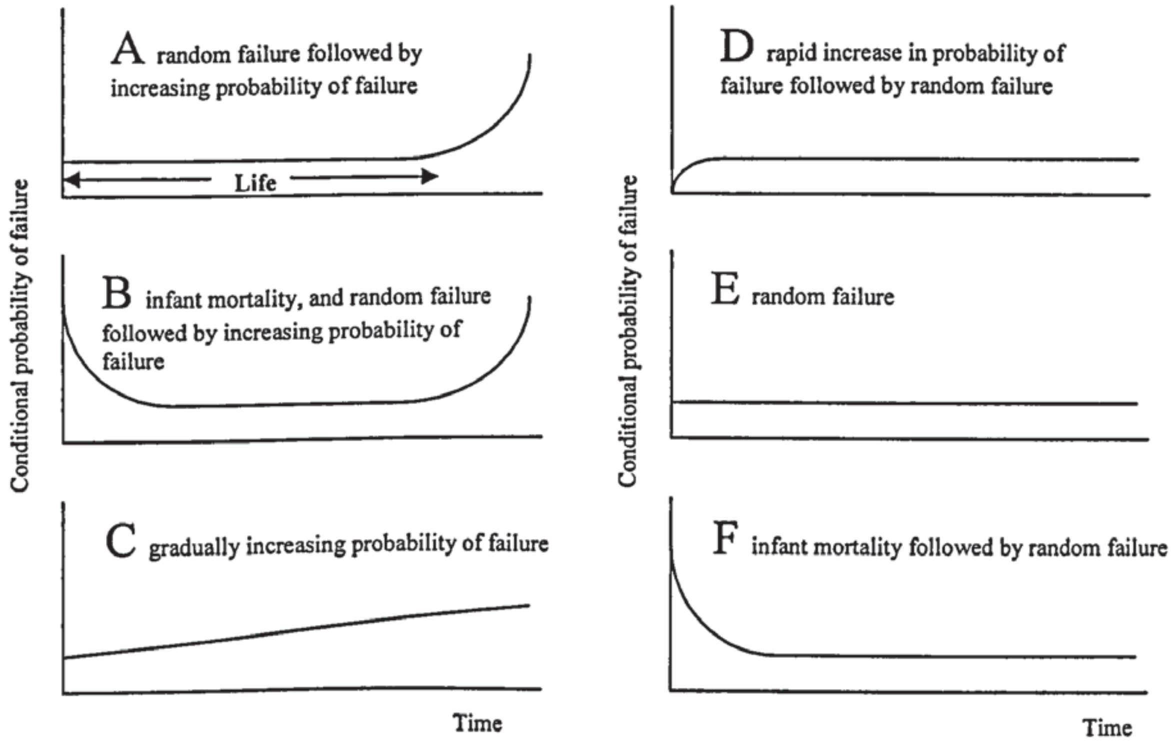

Figure 3.7 Failure patterns for failure modes in passenger aircraft (Nowlan and Heap, 1978)

Pattern A shows random failure until the 'life' of an item is reached, followed by a rapid increase in conditional probability of failure (2% of failure modes in civilian aircraft conform to this pattern). Pattern B is the traditional bathtub curve, indicating infant mortality (or burn-in), a period of random failure and a rapid increase in the probability of failure once the 'life' of the item is reached (4% of aircraft failure modes conform to this pattern). Pattern C illustrates a linear increase in conditional probability of failure with no specific point of failure (5% of aircraft failure modes conform to this pattern). Pattern D presents a small rapid increase in the probability of failure shortly after installation, followed by random failure (7% of aircraft failure modes conform to this pattern). Pattern E shows random failure with no relationship between component age and failure probability (14% of aircraft failure modes conform to this pattern). Pattern F indicates infant mortality (burn-in) followed by random failure (68% of aircraft failure modes conform to this pattern). Figure 3.7 shows that 11% of failure modes on passenger aircraft are age-related; of the remaining 89% that are not age-related, 68% of failures follow the pattern of infant mortality and random failure.

Establishing maintenance tasks is dependent on the applicability and effectiveness of the proposed intervention (Nowlan and Heap, 1978), and on the nature of the failure itself. Basic types of maintenance range from preventive, predictive and corrective to include detective maintenance[2]. Regular overhaul or replacement of components is only appropriate if there is a relationship between the age of the component and its probability of failure, and it must be possible to determine the component's 'life' (patterns A, B and C in Figure 3.7). The frequency of condition monitoring is governed not by the severity of the consequences of failure (as suggested, for example, by Pitz and Weber, 2001), but by the rate of deterioration (Sacks, 1996) (this is considered again later).

Nowlan and Heap (1978) emphasise the importance of justifying proactive maintenance. When consequences of failure are purely operational (such as production loss, poor quality and service), the cost of prevention (cost of maintenance intervention at appropriate intervals) should be less than the cost of the operational consequence (a function of the number of failures occurring at the MTBF of the component or machine, and possible secondary damage). Prevention of failures whose consequences are safety-related or that could infringe environmental regulations should be justified on the basis of risk assessment, and not by cost considerations. In many countries, government regulations prescribe the intervals for maintenance intervention or functional checking of safety-related equipment.

The US Defense Department Mil-Std (1996) presents five types of preventive maintenance:

a) Servicing tasks to replenish consumables expended during normal operation, such as lubrication, as required by the design of the equipment.

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[2] Preventive maintenance implies overhauls/rework or replacement at regular intervals; predictive maintenance refers to action to predict failure (also referred to as condition-based maintenance); proactive maintenance is a generic term encompassing predictive and preventive maintenance; corrective maintenance means repair once failure has occurred; detective maintenance (failure-finding) is a functional check, frequently of a protective system, to establish whether it is still working, or in a functional state.

b) On-condition tasks to detect potential failures before they can cause a functional failure. These include inspections for symptoms of failure, including calibration tasks for support equipment.
c) Hard-time rework and discard.
d) Combination of on-condition and hard-time tasks when safety consequences result from failure, and neither individually proves applicable and effective.
e) Failure-finding tasks are inspections or functional checks to prevent multiple failures or to detect hidden failures.

Mil-Std (1996) introduces the concept of safe life limits, which are imposed on an item whose failure may have safety consequences, and when there is no observable potential failure condition. In such instances, an item is removed at or before a specified maximum age. Mil-Std does not indicate how to determine such an age, other than suggesting that this may be obtained from the manufacturer, or through simulated testing, whereupon a conservative fraction of such a life will be used as the safe life limit. This reasoning assumes that the conditional probability of failure has an age relationship, such as patterns A, B or C in Figure 3.7, even though the 'life' is not known. If an applicable and effective on-condition task cannot be found it would be more prudent to modify the equipment, or to change the operating context to ensure that failures do not have safety or environmental consequences.

Economic life limits are based on the relationships between age and reliability, rather than some fraction of the average age at failure. While practising the safe life limit concept by definition prevents accumulating failure data because the item is not permitted to fail, economic life limits are justified by cost effectiveness. This requires knowledge of the failure rate in order to predict what will be the impact of the total number of scheduled removals of items at various age limits on task effectiveness.

3.7 MAINTENANCE PERFORMANCE, MEASUREMENT AND CONTROL

Management commitment, appropriate support systems and managing resistance to change are necessary for successful new initiatives (Doll and Vonderbremse, 1991; Padmanabhan and Souder, 1994) and apply as much to other management interventions as to maintenance. Formal monitoring and measurement of objectives require appropriate infrastructure (Geisler and Rubenstein, 1987; Huber, 1984). The maintenance function also suffers from inadequate performance reporting systems (Bouche et al, 1986; Currie and Sneddon, 1992; Drucker, 1990). Kutucuoglu et al (2002) and Swanson (1999) identify a number of performance indicators for a maintenance system, with typical performance indicators:

- equipment related: availability, reliability, utilisation
- task related: schedule completion
- cost related: preventive maintenance cost vs. breakdown cost, total maintenance cost
- immediate customer impact: number of delayed deliveries due to failures
- learning and growth: percentage of workforce that is multi-skilled
- percentage of equipment covered by preventive maintenance
- methods of inventory control for spares (mathematical techniques, inventory counts).

The International Atomic Energy Agency (1992) proposes several measures of maintenance effectiveness:

- Improving the preventive maintenance/corrective maintenance ratio
- Providing a systematic and structured process
- Optimising cost
- Using qualitative and quantitative maintenance history
- Ensuring visibility and traceability of actions and decisions.

Several other points relate to maintenance tasks and performance (Moubray, 2000):

- how often an item fails (suggesting its reliability, measured by the mean time between failures), or its failure rate
- how long an item lasts (the life of an item, or its durability)
- how long an item is out of service when it fails (affecting downtime or unavailability)
- how likely an item is to fail in the next period (the conditional probability of failure, or a measure of dependability)

- efficiency (a measure of output relative to input, or how well an item performs against how well it should be performing, or the consumption of maintenance consumables, such as lubricating oil, and process consumables, such as solvents and reagents).

From a survey of process industries Suzuki T (1994) provides an indication of the usage of maintenance performance measures (Figure 3.8).

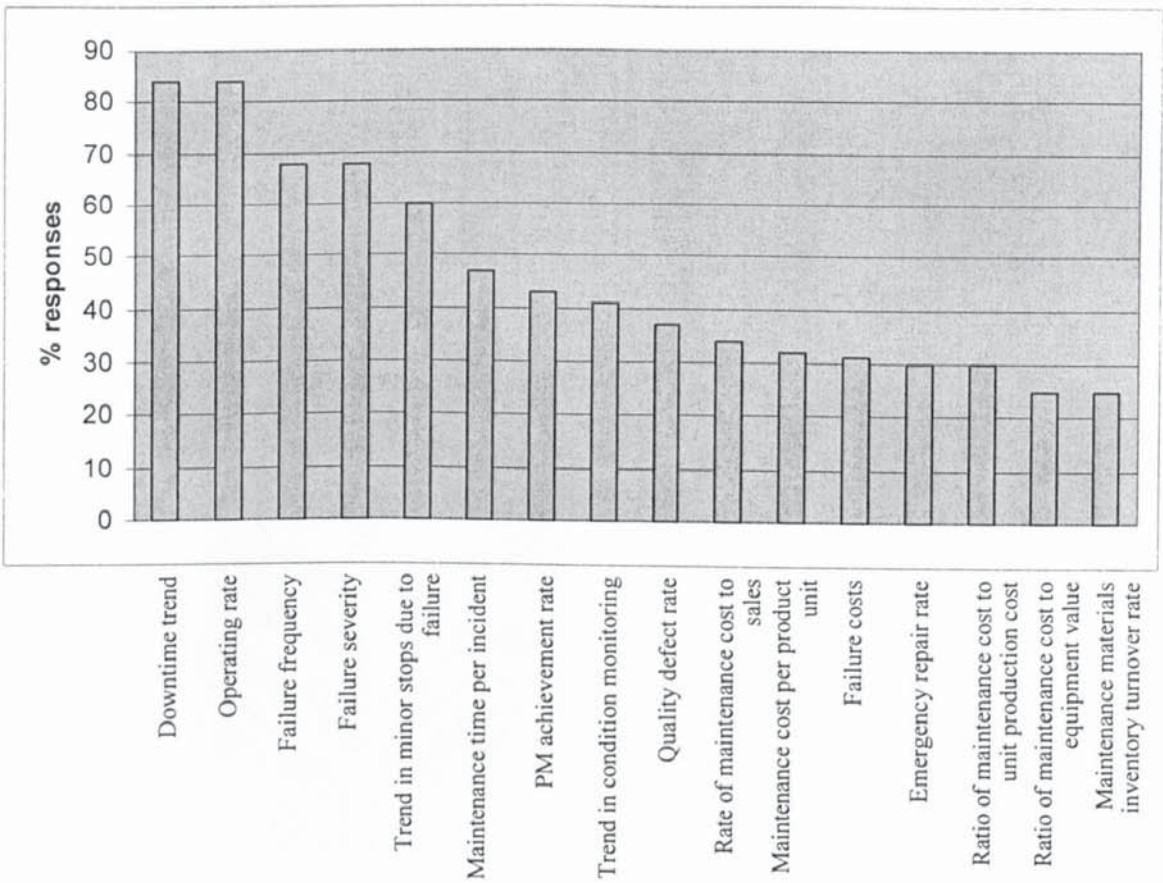


Figure 3.8 Maintenance performance measures in process industries

Two further issues are important in evaluating maintenance. Firstly, the level at which the assessment is made has significant implications for management. Moubray (2000) provides the following illustration. Maintenance can be viewed as ensuring functionality at system level: for example, a pump-motor set (the 'system'), delivering a certain rate of flow and pressure, can totally fail to deliver, or it can fail to deliver at the required rate. Different failure modes contribute to each functional failure (seized bearings, broken impeller for the total failure condition; worn impeller for the partial failure situation). Each may have different failure effects, and may require different maintenance. Measuring the availability of the pump-motor is useful in overall terms, but from a management perspective, the causes of each failure are important. Condition monitoring will not prevent the seizure of bearings, but may prevent the consequences of seized bearings (by filling the tank before replacing the bearings, to eliminate or reduce the effects on production of an empty tank). Again, monitoring flow (a form of condition-monitoring) will not prevent an impeller from breaking. This may require an upstream filter to prevent large particles from damaging the impeller. The worn impeller is a natural wear-and-tear development. A thorough assessment of maintenance effectiveness would measure downtime attributable to each failure mode, as different intervention is required in each case.

Secondly, evaluating the consequences of failure is relevant in assessing maintenance effectiveness. Where safety is compromised or environmental legislation is infringed, consequences are more severe than where equipment failure has no direct effect on operational capability (Smith, 1993). A high percentage of equipment covered by preventive maintenance is not necessarily a general indicator of good maintenance. Appropriate maintenance is determined by the operating context, the type of equipment and the way it fails, not by high levels of preventive maintenance.

Earlier discussions of functionality support the importance of learning and growth of knowledge, with multi-skilling being only one aspect of knowledge acquisition. Swanson (1999) suggests several measures of technical expertise that will improve the ability to perform skilled tasks and understanding processes and equipment: frequency of training, the percentage of craftworkers receiving training in the past year, hours of training received per craftsman. However, training is often insufficient to provide the requisite skills to master the operation and maintenance of a process (Leonard-Barton, 1987). Increasing complexity of equipment requires knowledge about the technologies in operation and additional maintenance skills. Eade (1997) points to the inadequacy of training only craftsmen in new technologies. Supervisors also need to be updated on the latest maintenance techniques. Both maintenance engineers and operators are required to assist with fault diagnosis and repair.

Restructuring departments, reducing supervisory levels and attempts to empower individuals have affected the location and management of the maintenance function in an organisation (Hipkin, 1997). Paz and Leigh (1994) suggest that the organisation of maintenance crews into decentralised units improves communication and relationships with production. This is significant as maintenance intervention is increasingly determined through coordination between production and technical departments to ensure that production schedules allow time for maintenance work, and that operators are part of the decision-making process. Swanson (1999) contends that control of the maintenance function requires sharing information such as production schedules, equipment condition, and repair time requirements.

Analysis and reporting of data and information are essential for knowledge-based maintenance management and for control purposes (Hipkin, 2001). In order to facilitate maintenance control, Gits (1984: 4) suggests a control structure consisting of decomposition and coordination. Decomposition is the "breaking down of a complex control problem into a number of separate, less complex, sub-problems". Coordination is "the problem of translating the overall objective of control into local objectives for each decision function … (so that) local objectives eventually result in realising the overall objective". Gits (1984) differentiates between long-term maintenance control (requiring substantial changes), mid-term maintenance control (ensuring that existing maintenance resources are adjusted within mid-term boundaries to achieve long-term objectives), and short-term maintenance control.

There are obviously many ways in which data can be presented, but to be of any use, it is reasonable to assume that meaningful management decisions can be taken, or policies formulated on the basis of the information. Two examples of failure and cost data representation are given to illustrate largely meaningless information that may well have been derived from sound data. These are shown in Figures 3.9 and 3.10, reflecting a breakdown of failures in a nuclear reactor (Kondo and Ichige, 1991).

Figure 3.9 is of some interest in that it identifies that 10% of failures are due to human factors, suggesting that human resource issues and training should be addressed to reduce the incidence of human error. While the 38% of failures attributable to fatigue or end of design life indicate that over a third of failures conform to failure patterns A, B or C (in Figure 3.7), the management implications are unclear. No overall maintenance policy can be formulated as it is not known which of the three failure patterns is applicable, nor what the life of individual components is. Figures indicating that 20% of failures are mechanical and 27% are electrical are of little use. Presumably these failures are not age-related, but as no indication is given of the consequences of these failures, policy decisions cannot even be made as to whether proactive maintenance, such as condition-based maintenance, may be applicable and effective. Maintenance policies can only be formulated at individual failure mode level.

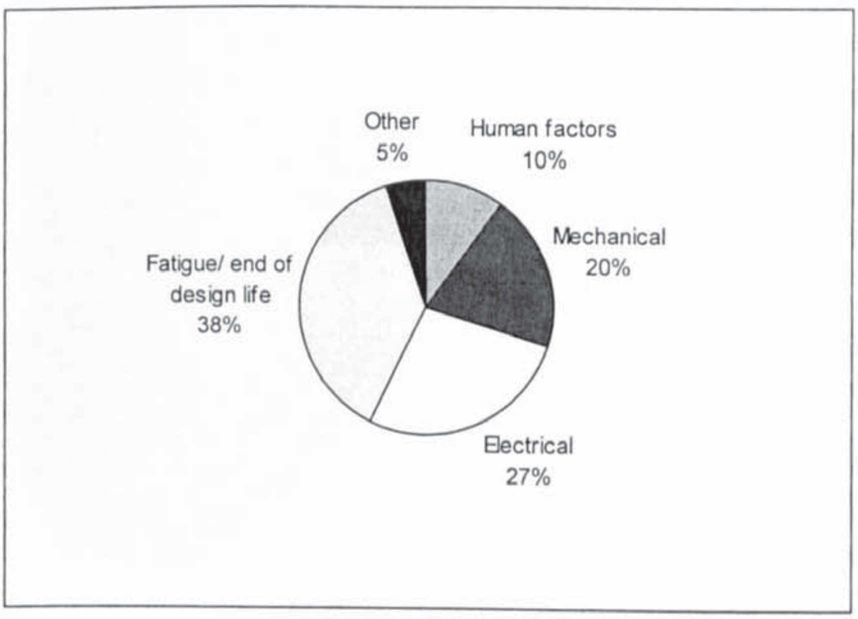
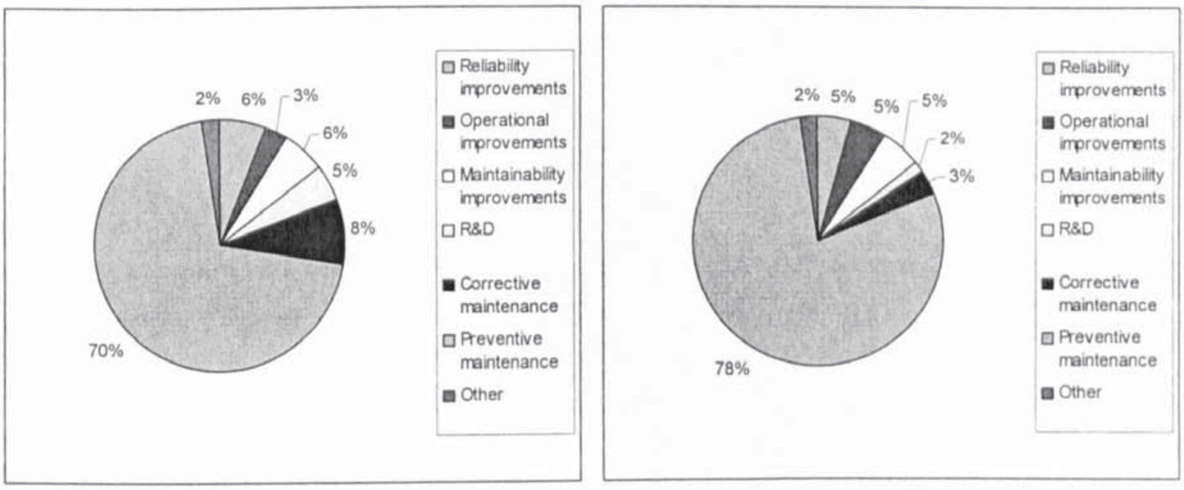


Figure 3.9 Breakdown of failures by failure category

In Figure 3.10 Kondo and Ichige (1991) show the percentage of total maintenance costs for a number of maintenance interventions in one part of a nuclear power station, before and after the implementation of a new computerised maintenance management system for the years 1998 (when the new programme was installed) and 1999. Reliability and maintainability studies were carried out in conjunction with the new CMMS and improvements in operator training were introduced.

Figure 3.10 shows that the costs of performing preventive maintenance costs have increased from 70% to 78%; corrective maintenance costs have decreased from 8% to 3%; R&D costs have decreased from 5% to 2%; the costs of maintainability improvements reduced from 6% to 5% of the budget after implementation of the

CMMS, and so on. The total budget is not given so it is not known whether preventive maintenance costs have increased or decreased in monetary terms. More preventive maintenance is not necessarily a 'better' solution to breakdowns, as corrective maintenance can be cheaper, depending on the consequences of failure. This therefore questions some of the performance indicators provided at the beginning of this section, such as the percentage of equipment covered by preventive maintenance, or improving the performance maintenance/corrective maintenance ratio. Spending a smaller proportion of the budget on R&D and maintainability improvement may be a cost-saving measure in the short term, but may spell higher longer-term costs.



(a) (b)

Figure 3.10 Percentage of total maintenance costs for a number of interventions

3.8 CMMS, INFORMATION AND EXPERIENCE

Limited research has been conducted on computerised maintenance management systems (CMMS)[3], so researchers in this field must extrapolate and synthesise the maintenance, operations management, and appropriate IS literature (Hipkin, 1996). Drives for improved efficiency and greater output have affected maintenance as much as other functional areas. This has resulted in considerable emphasis on performance measurement, which now increasingly makes use of information systems for the gathering and analysis of data. Information systems have been developed for maintenance applications for decades, and in many instances pre-dated inventory and

[3] Various terms are used for CMMS. MMIS (maintenance management information system) is also commonly encountered.

production control systems. They were predominantly record keeping and planning systems for scheduling maintenance tasks at what were considered appropriate intervals (Pintelon and van Wassenhove, 1990). Sets of data were interpreted manually, with planners and engineers determining maintenance tasks and intervals. Computers generated work instructions in the form of maintenance schedules. Despite years of data collection, many organisations lack useful historical data on their plant and equipment, suffering from data syndrome: "most enterprises have far more data than they can possibly use; yet, at the same time, they do not have the data they really need" (Levitan and Redman, 1998: 90).

Swanson (1997) suggests that CMMS are used to plan and schedule work orders, expedite despatching and control breakdown calls, automate predictive and preventive maintenance activities, and assist in inventory control. CMMS provide rapid access to information and allow for the analysis of maintenance-related information on equipment performance and maintenance resource utilisation (Callahan, 1997). Lihovd (1998) sees a further role for CMMS in condition monitoring. When a deviance in a component's condition is detected, a decision must be taken as to when the item should be repaired to ensure high availability of plant while preserving safety and environmental integrity. Integration of condition-based maintenance (CBM) with periodic and corrective maintenance should utilise opportunistic maintenance and dynamic scheduling of tasks. If one item in a maintainable unit requires immediate maintenance, the CMMS should guide the maintainer through information gathering about the maintenance history, plans and availability of resources (personnel, spares) within production constraints.

While these points describe an ideal situation, various authors suggest that practice is rather different. Pitz and Weber (2001: 225) refer to the problem of CMMS containing "disordered data ... protocols of inspections, reports of defects and failures". In a study of CMMS Hipkin (1997: 2438) found that

> "Managers who had introduced CMMS purely for reasons of direct technical and performance improvement were disappointed ... the benefits went far beyond performance improvements through better maintenance, which are seldom quantifiable with any great degree of accuracy ... most organisations are

not in a position to measure improvements in performance which could be directly or indirectly attributed to the CMMS".

One immediate difficulty with new technology is a lack of understanding of how it operates and how to maintain it. While owners recommend maintenance policies and spares, these seldom take into account the acquirer's operating context (Bouche et al, 1986). With new technology, the owner's experience and failure data should also be evaluated. Lack of historical failure data is perceived as a barrier to maintenance intervention, but the way in which failure data is used and the reason for collecting data must be clear. Moubray (2000: 252-3) comments on the widespread belief that without a large database, proactive maintenance cannot be undertaken:

> "an issue which bedevils the whole question of technical history is that if we are collecting data about failures, it must be because we are not preventing them ... successful preventive maintenance entails preventing the collection of the historical data which we think we need in order to decide what preventive maintenance we ought to be doing".

The emphasis should be one of gathering data for predicting failures and avoiding failure consequences. The quantity of data in a CMMS can be deceptive. Nowlan and Heap (1978: 66) doubt whether sufficient data exists to determine preventive maintenance intervals:

> "The development of an age-reliability relationship requires a considerable amount of data. When the failure is one which has serious consequences, this body of data will not exist, since preventive measures must of necessity be taken after the first failure. Thus actuarial analysis cannot be used to establish the age limits of greatest concern – those necessary to protect operating safety".

If a database contains large numbers of instances where replacements of items are recorded, this does not necessarily mean the items actually failed. If they did fail, then the interval is probably too short, and so the preventive maintenance system is not achieving what it should. If it is not recorded whether or not items have failed, the maintenance manager has no way of knowing whether maintenance is excessive. If the item was replaced as part of a preventive maintenance system, the user does not know the condition of the item, that is, the user knows that in general the item lasts at least as long as the current replacement interval, but has no idea of how much longer the item could have lasted. It is often engineering judgement and operational experience that provide the best insight into failure patterns (Hipkin and Lockett, 1995). A CMMS should go far beyond traditional data storage and schedule generating facilities. Requirements now include access for data entry and retrieval (often through computer terminals at the work place), facilities for data manipulation through on-line analytical processing (OLAP) systems that integrate MIS and DSS to introduce spreadsheet-type facilities and graphical presentation capabilities (Koutsoukis et al, 1999).

Further, CMMS fall into disrepute when they cannot show quantifiable results of improved maintenance (Hipkin and De Cock, 2000). Thus, production managers may feel maintenance intervention is unnecessary, whereas maintenance managers believe that they do not have sufficient access to machines to undertake the required maintenance. It is somehow hoped the CMMS will solve this intractable difference in opinion. The problem is often one of inappropriate maintenance: items with no identifiable age-related failure pattern are replaced at regular intervals; condition-based maintenance intervals are determined on a fundamentally incorrect premise. The main problem is not the maintenance task itself, but rather the frequency at which it is undertaken. A CMMS should be tailored and used to provide correct answers, in a user-appropriate manner (Hipkin, 1997). Even if there is an age-relationship, the literature does not fully address how maintenance frequencies should be determined.

3.9 RCM AND TPM

This section provides a brief description of these widely used approaches to maintenance. The intention is not to compare the two, but to present features of each that are useful in enhancing an understanding of maintenance management.

Reliability-centred maintenance

RCM, initially developed in the civil aviation industry, is a structured approach to determining maintenance requirements of physical assets in their operating context (Moubray, 2000). RCM establishes functional requirements and desired performance standards of plant and equipment. By relating these to design and inherent reliability parameters, functional failure characteristics are determined. For each of these, a failure mode and effects analysis (FMEA) is performed. The consequences of each failure fall into one of 5 categories: hidden, safety, environmental, operational, and non-operational consequences. Figure 3.11 contains the author's summary of RCM.

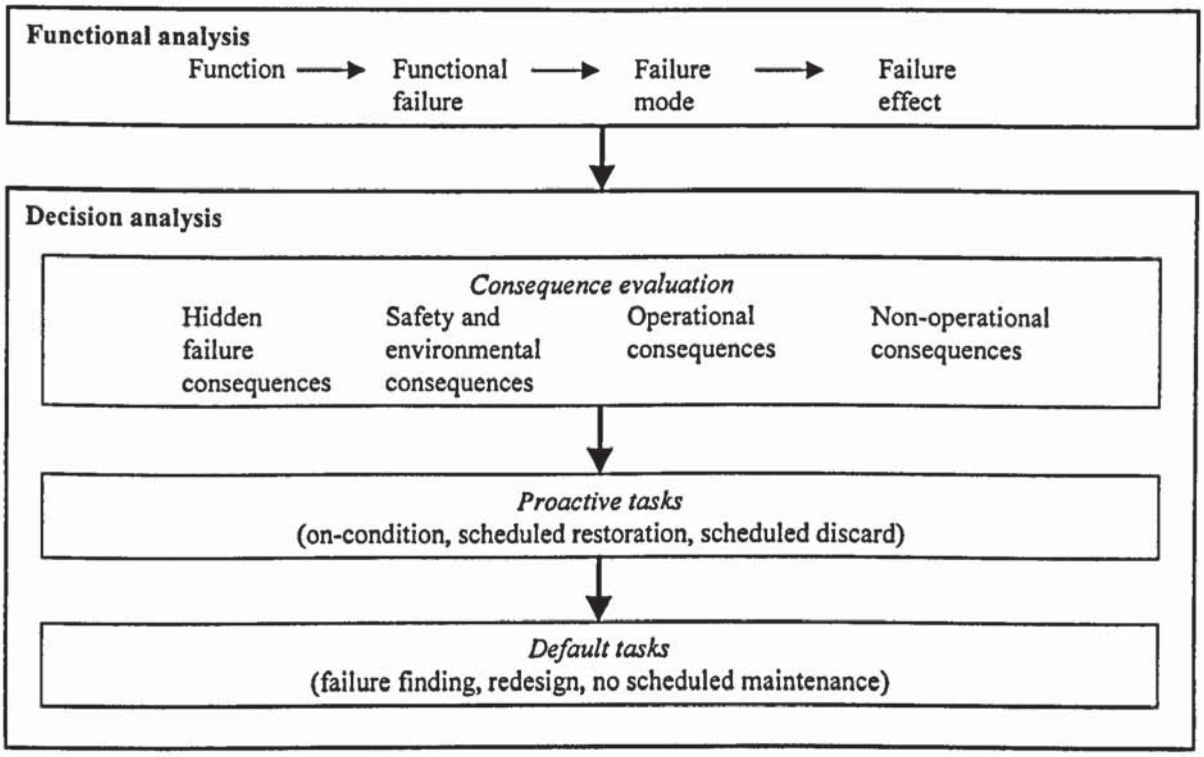


Figure 3.11 The RCM process

Following a process of decision logic (Gordon, 1982; Matteson, 1985; Smith, 1993), proactive intervention (on-condition tasks, scheduled restoration or discard) is considered which deals with failures according to strict applicability and effectiveness criteria. If criteria for proactive tasks are not fulfilled, default tasks include failure finding (for hidden consequences), redesigns of equipment, changes in operating, maintenance and training procedures, or no scheduled maintenance. The RCM task determination process is summarised in Figure 3.12 (adapted from Moubray, 2000).

The generic RCM developed by Nowlan and Heap (1978) gives no indication of how a maintenance programme should be developed. The human dimension is thus not part of their underlying philosophy. A group approach is suggested by several authors (Matteson, 1985; Moubray, 2000) with participants, trained in RCM and led by a facilitator, representing the production and maintenance functions, and where necessary, appropriate technical and process specialisms.

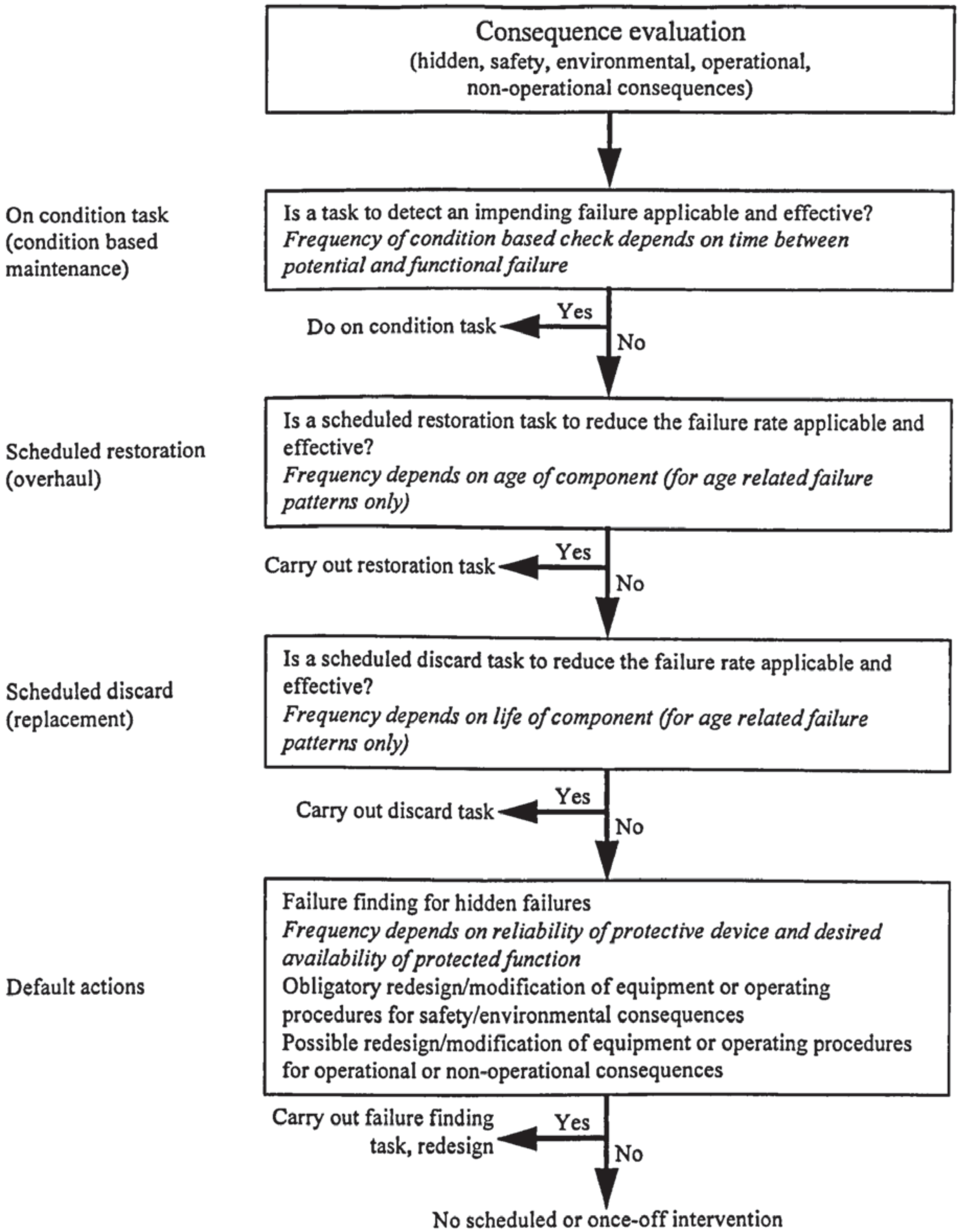


Figure 3.12 Maintenance task determination (adapted from Moubray, 2000)

Total productive maintenance

The literature presents TPM as a more amorphous concept than RCM, although five essential features are stipulated (Nakajima, 1989):

1. Maximising equipment effectiveness
2. Development of productive maintenance for the life of the equipment
3. Involvement of all disciplines (engineering, design, production, maintenance)
4. Active involvement of all employees
5. Promotion of TPM through motivation management: autonomous small group activities.

Nakajima (1989: 10) states that the first point is achieved by "the complete elimination of failures, defects and other negative phenomena" (which is, of course, central to the zero defects philosophy). He points to the fusing together of the traditional maintenance and production functions as acceptance that operators can perform simple maintenance tasks. The company-led small group activity, similar to the quality circle approach, is "consistent with Likert's participative management model". Overall efficiency, including economic efficiency, is achieved by "... minimizing costs of upkeep and maintaining optimal equipment conditions throughout the life of the equipment ... by minimizing life cycle cost" (Nakajima, 1989: 10).

With reference to their overall TPM framework shown in Figure 3.13, McKone et al (1999: 124) suggest that:

> "TPM provides a comprehensive company-wide approach to maintenance management ... in the short-term attention is focussed on an autonomous maintenance program ... a planned maintenance program ... and skill development for operations and maintenance personnel. In the long-term, efforts focus on new equipment design and elimination of sources of lost equipment time".

TPM establishes a maintenance plan for the entire life of equipment, by including maintenance prevention (MP: by which is understood maintenance-free design), preventive maintenance (PM) and maintainability improvement (MI: repair or modification to prevent failures). All encompassing is the notion of autonomous maintenance by operators. TPM seeks to eliminate 'six big losses': equipment failure, set-up and adjustment, idling and minor stoppages, reduced speed, process defects and reduced yield. Minor stoppages are reduced by lubrication, cleaning, performing adjustments and conducting inspections carried out by operators with maintenance staff performing periodic inspections and preventive repairs (Nakajima, 1989).

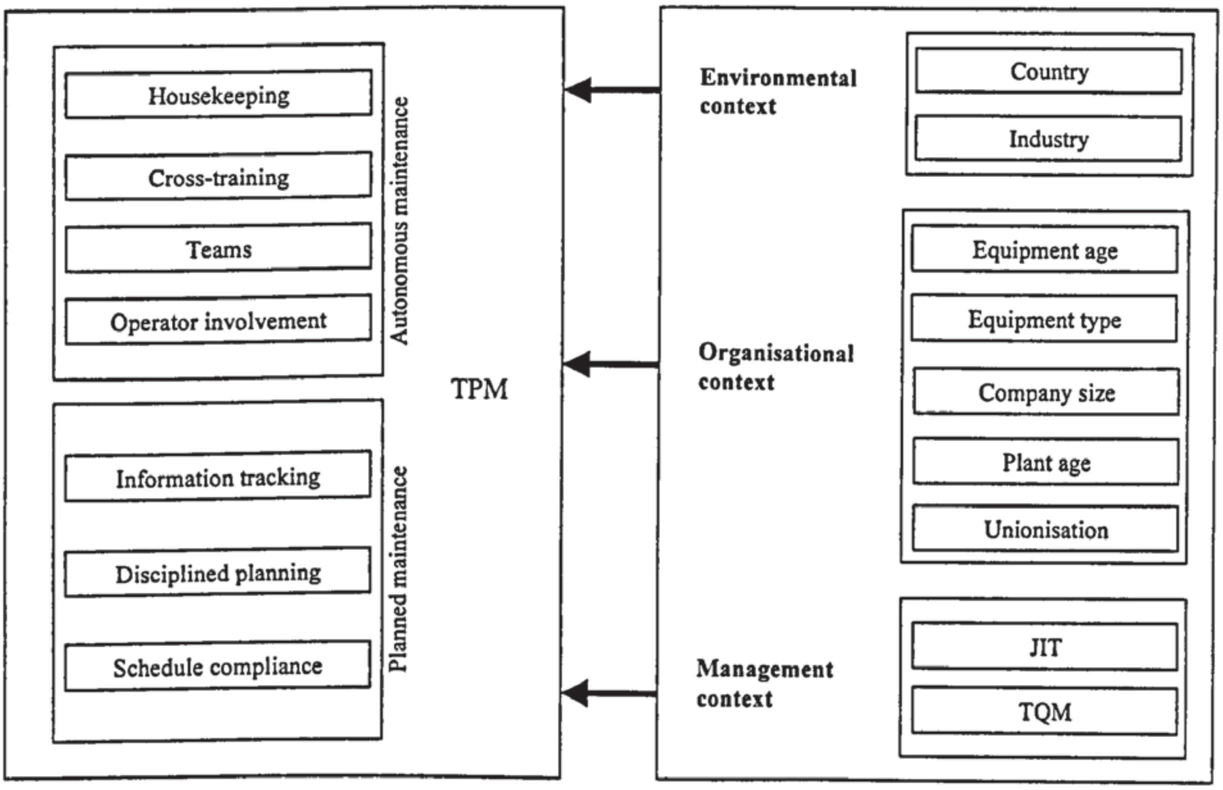


Figure 3.13 TPM framework

Discussion of RCM and TPM

The first difficulty in discussing these concepts is to determine whether definitive or generally accepted versions of RCM and TPM exist. The text of the originators of RCM (Nowlan and Heap, 1978) was written exclusively for the airline industry, but practitioner books on the subject for industrial application (Moubray, 2000; Smith, 1993) have kept close to the generic version[4] and this application is presented here. Consultants and individual practitioners have produced their own variants, and there is a lively internet debate on various forms of RCM. It is not the intention to discuss these. McKone et al (1999) quote Hartmann (1992) as saying there are differences between TPM in the US and Japan, and generally, country, plant and management specific

[4] A doomed attempt at a British Standard for RCM was made in 1994 (Document 94/408162); various versions have been developed, *inter alia*, by the US Defense Department, the Royal Navy, the Royal Air Force, and Electricité de France. These have been adapted specifically to meet the requirements of those sectors. The Society of Automotive Engineers adopted an RCM standard (SAE JA1011) in 2001.

aspects need to be taken into account. The acknowledged TPM expert is Nakajima, so the description above is essentially derived from Nakajima (1988, 1989), with additional material from Willmott (1994).

RCM and TPM are presented as ways of improving maintenance. The limitations of each should be recognised, otherwise the benefits they undoubtedly bring are dismissed because of issues having nothing to do with RCM and TPM[5]. RCM is criticised for being too time-consuming, frequently because staff do not have the knowledge of plant and equipment which RCM demands (Turner, 2000). This is not a fault of RCM, but indicates that employees are operating and maintaining machines without fully understanding how they work, how they fail and what happens when they fail. A significant benefit of RCM is what it teaches those who use it properly. Several multi-national companies have used RCM for deriving maintenance policies, as well as for training (Hipkin and Lockett, 1995). The discipline imposed by RCM makes people think beyond narrow definitions of maintenance as preventing failures. Achieving functionality ensures design parameters are related to performance, and money is not wasted on trying to prevent failures occurring, in reality, because designs are inadequate, machines are too small, or plant is operated incorrectly.

McKone et al (1999) contend that TPM is characterised by having well-defined areas of responsibility, appointing one individual with overall responsibility for maintenance of a line, and establishing direct contact between operators and maintainers. One of the main features of TPM is autonomous maintenance, part of which consists of operators' assisting with cleaning, lubrication, some adjustments, and minor repairs. Through their greater involvement, operators become more knowledgeable about how the equipment operates, how to stabilise conditions, and they may be able to halt deterioration (Nakajima, 1988). The framework in Figure 3.13 considers the relationship between environmental, organisational and managerial factors. The findings of McKone et al (1999) are inconclusive in establishing a link between TPM and specific industries, or between organisational variables and TPM. Their findings suggest successful

[5] This is analogous to the commonly encountered success factors and reasons for failure of TQM and BPR (De Cock and Hipkin, 1997).

implementation of TPM is more closely associated with the management of plant than environmental and organisational factors. Specifically, McKone et al (1999) suggest that learning has a significant role to play in TPM implementation.

Management commitment, appropriate support systems and effectively managing resistance to change are necessary for success in any management intervention (see for example, Doll and Vonderbremse, 1991; Meredith, 1987) and apply as much to TQM and BPR as to maintenance. Much of the TPM philosophy is directed at addressing these conditions. Other factors pertaining directly to maintenance, such as knowledge of machine capabilities, understanding of the production process, and a high level of production competence, are essential before maintenance requirements can be determined (Ferdows and De Meyer, 1990). In a study by Hipkin and De Cock (2000) TPM is criticised for being insufficiently prescriptive. Statements such as Nakajima's that maintenance should be done "at appropriate intervals" do not give sufficient guidance; the TPM 'zero defects' philosophy does not adequately take operating circumstances into account; as with TQM and BPR, the lack of a standard TPM methodology is both an advantage and a disadvantage, as this means there are many ways in which organisations can implement it, evaluate it, and measure its success.

3.10 RISK-BASED MAINTENANCE

Reference has been made to condition-based maintenance. Its role is becoming increasingly significant as theorists and practitioners accept the underlying premise in Figure 3.7 that many components do not lend themselves to scheduled restoration or replacement. Condition-based maintenance thus becomes a major intervention in proactive maintenance. This section discusses further aspects of the topic as part of risk-based inspection (RBI). The authoritative American Petroleum Institute (API) (2000: 1-2) describes RBI as a methodology for determining the optimum combination of methods and frequencies for maintenance inspections. RBI analyses inspection and maintenance activities to provide a higher level of coverage on high-risk items and appropriate efforts on lower risk equipment. Its purpose is to increase awareness of the need to assess on-site risk to employees, off-site risk to the community, business interruption risks, and the risk of environmental damage. This is rapidly assuming greater importance as safety and environmental expectations rise dramatically, and as the closer relationship between maintenance and plant safety is recognised, as illustrated by the following three quotations:

> "No one fully understands all the ways in which the primary protection system can behave. Its verification and validation may reveal errors in the program, but if those errors are rectified in complex systems, there is no way of knowing how that might affect the rest of the program. The system is too complex. It is going to be very hard, probably impossible to show that the system's reliability will meet safety requirements" (BBC interview during construction of Sizewell B nuclear power station in 1992).

> "The 110 kV assets were neither understood nor managed. There was no specific management policy, or defined asset management practice, no initial information base for ongoing planning of system design and operation. Decisions were based on incorrect information, so the environment in which the asset owner was operating was not understood" (from report on the Auckland power failure in 1998).

> "The worst consequences of incorrect or irresponsible custodianship of physical assets is that people die, sometimes in very large numbers" (Moubray, 1998).

While these comments may represent extreme views about safety and maintenance competence, they illustrate serious shortcomings that have had or could have serious consequences. Such events are most likely to occur when firms introduce novel and complex technology that is not fully understood, and are exacerbated when firms are not afforded the opportunity, or are unable to manage, the transfer of competencies developed elsewhere.

Risk

RBI quantifies risk associated with the failure of an asset in order to determine the most appropriate inspection techniques. The API (2000: 1-2) suggests that increased inspection can reduce the risk of failure if this initiates corrective or preventive measures, but inspection does not alter consequences, which are another component of risk. Consequences are changed through design changes or other corrective actions. Risk is not reduced to zero solely by monitoring, as uninspectable factors can contribute to failures. Typically these are human error, natural disasters, external events (collisions or falling objects), secondary effects from nearby units, deliberate acts (sabotage), fundamental limits of inspection methods, design errors, or previously unknown mechanisms of deterioration.

The relationship between the risk of failure and maintenance intervention may be intuitively interpreted as: more maintenance means a lower risk of failure, but this does not take into account the possibility that inspection and maintenance may themselves induce failures, which in effect means that more intervention increases the risk of failure. In terms of pattern F in Figure 3.7, inspection may introduce instability into an otherwise stable system, causing burn-in problems after inspection. In order to increase reliability, non-preventable failures should be reduced through design improvements and modifications in operating and maintenance practice.

An important component of risk is one of the most contentious in maintenance management: is the risk of failure of an item tolerable? In discussing varying beliefs relating to risk, Moubray (2000) suggests the dominant factor in assessing tolerance of risk is the degree of control that individuals have (or think they have) over a situation. The API suggests that people accept risk individually, but collectively society tries to control risk. Risk is important in the maintenance of protection, as one of the events that could hurt or kill someone could be a single failure mode, or a multiple failure, where both the protected item and its protection are simultaneously in a failed state.

Inspection

The API differentiates between functional and condition inspections in risk-based maintenance because inappropriate inspections do nothing to improve functionality. The rate of deterioration is a function of a complex interaction of material properties, the process environment, operating conditions, and state of stress. Deterioration is a failure mode for crushers and grinders, but unlikely in electronic control systems. A conservative estimate of the deterioration rate is calculated by assessing the amount of damage a component can withstand, and scheduling the next inspection before the anticipated failure. With each failure inspection, the actual deterioration rate is better defined, and inspection frequencies adjusted accordingly, as suggested in the multi-state model in Figure 3.2.

Qualitative and quantitative maintenance procedures can be applied to develop a ranking measure to be used for evaluating separately the probability of failure and the likely consequence of failure. Qualitative procedures are less discriminating, and provide less warning of impending failures. With reference to Figure 3.14 (adapted from API, 2000; Kollakot, 1980), qualitative inspections are more likely to detect potential failures closer to the point of failure. So, potential failure P_1 is more likely to be detected using condition monitoring equipment than, say, using human senses. The latter may detect potential failure P_2. In either event, the purpose is to estimate when the points of functional failure (F_1, F_2 or F_3) will occur, and thereby determine the time between the potential and functional failure (referred to by Moubray (2000) as the P-F interval), as this interval is essential in establishing inspection intervals: typically inspection intervals are half the P-F interval. The upper graph suggests a certain probability of failure associated with rapid deterioration, and an increasing probability of failure as further deterioration leads to ultimate failure.

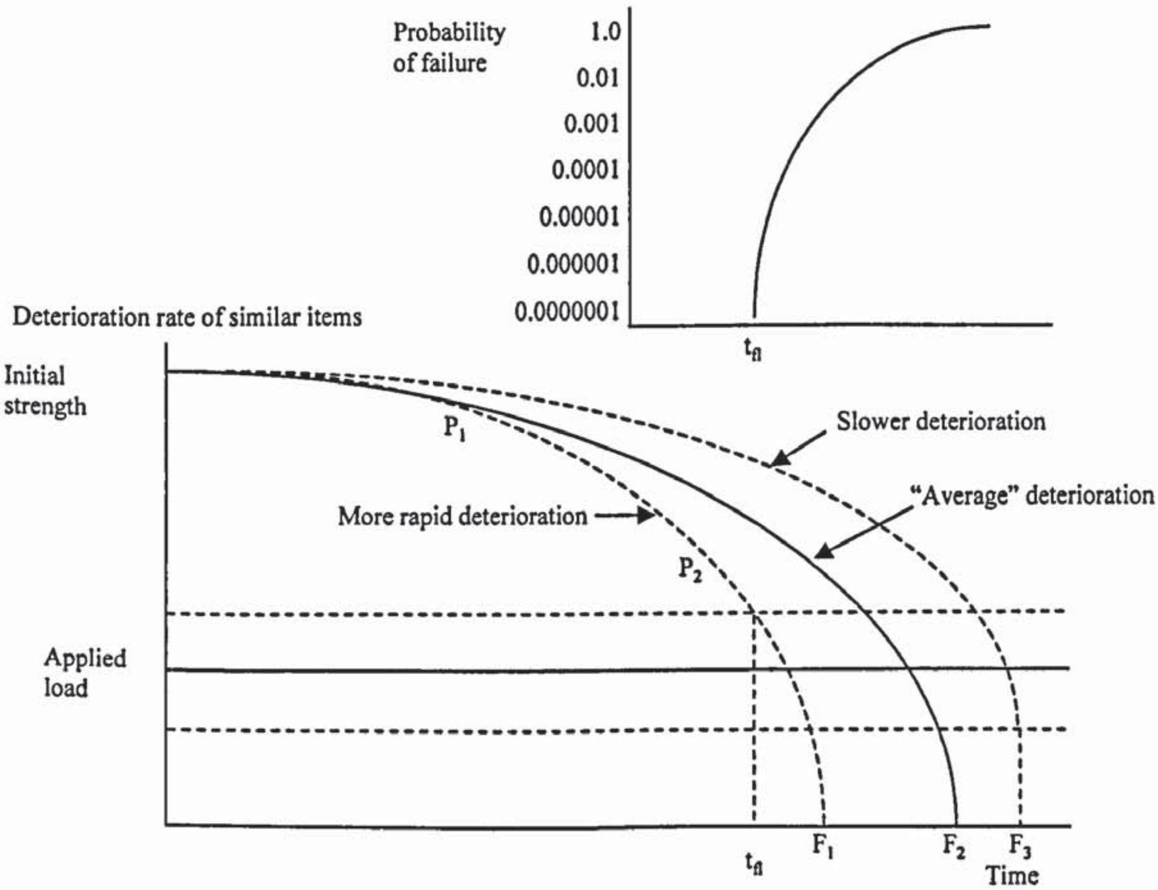


Figure 3.14 Deterioration and probability of failure with time

Inspection programmes are developed by systematically identifying a number of maintenance issues: what type of damage to look for, where to look for it, how to look for the damage (inspection technique), and when (or how often) to look (API, 2000: 1-9). Potential failures are identified by studying failure mechanisms, including design and construction data (equipment type and function, materials), process data (temperature, pressure, flows), and equipment history (previous inspection data, failure analysis, maintenance activity, replacement information, modifications).

Determining inspection frequency combines four risk-based factors (API, 2000):

- damage mechanism and resulting type of damage or failures
- rate of damage or failure progression
- tolerance of equipment to the type of damage or failure
- probability of detecting damage and predicting future damage or failed states with inspection technique(s).

Inspection frequencies are modified by increasing activity level or frequency if insufficient reduction in risk occurs, or decreasing activity level or frequency if no gain in risk reduction results from higher level of inspections. The API (2000: 1-9) provides general guidelines for inspection optimisation:

- equipment that has been inspected multiple times and has confirmed low deterioration rates may be over-inspected, so frequency of inspection can be reduced
- equipment that is subject to a large uncertainty in the failure rate will require frequent or thorough inspections to keep risk levels low (at least until sufficient history on performance has been established)
- equipment approaching the end of its life due to corrosion or other deterioration requires increased inspection activity to be sure that limits of deterioration (such as corrosion allowance) are not exceeded
- inspection programmes should be projected over a significant portion, at least half, of the equipment's intended remaining life.

These recommendations, extracted from API publications, constitute generally accepted maintenance practice, and provide useful guidance for effective maintenance intervention.

3.11 CONCLUSION

As part of a changing world of physical asset management in a high-technology environment, managers are confronted with many technical challenges such as condition monitoring, reliability and operability studies, computer design and information systems. While managers are obliged to keep the plant running, there are few opportunities to experiment with new approaches to maintenance. Where techniques such as RCM and TPM have been tried, their success has been limited because of inadequate planning, incorrect implementation and poor assessment. These are common management problems, and must be addressed appropriately. This chapter has attempted to summarise the main features presented in the literature, as the basis for further discussion when specific reference is made to the case studies.

Technology selection decisions have a major impact on operations and maintenance. The definitions of technology and TT in Chapter 2 include terms such as "capacity to produce ... quantum knowledge ... in production activities", but they also refer to "problem-solving and trouble shooting activities" (Adjibolosoo, 1994: 1557-1558). Production competency requires knowledge of functionality, and this chapter has pointed out that functionality is the essential link between operations and maintenance that leads to the productive use of assets. Physical asset management therefore becomes an indisputable part of TT. It will also be seen that maintenance was identified in the preliminary research as an important aspect of TT.

CHAPTER 4

THE SOUTH AFRICAN SITUATION AT THE BEGINNING OF THE 21ST CENTURY

4.1 INTRODUCTION

Studies of South Africa will be clouded by apartheid for decades to come. As much as Archbishop Tutu (1999) exhorts South Africans to cease blaming apartheid for every problem that arises, economic challenges and technology policies will for many years be affected by South Africa's history, particularly from 1948 when the white electorate granted the Nationalist Party a mandate for apartheid. Apartheid permeated the business and social life of all South Africans, and continues to do so. This chapter does not purport to be an economic or political treatise, but technology policy and technology transfer are affected by economics and politics. Because of its history South Africa is an intensely politicised country where decisions and actions are invariably seen in political and racial terms. A common dichotomy (encountered in the interviews discussed in Chapters 7 and 8) is that white managers justify the introduction of automation as the only way to meet the competitive challenge. The predominantly black[1] labour force interprets this as management's way of reducing the power of the unions and a firm's dependency on black labour, as well as undermining workers' democratic rights in the workplace. Whatever the merits of these arguments, they illustrate the conflict inherent in the working environment.

Violence and political chaos during the 1980s and 1990s preceding the first democratic elections in 1994 threatened to condemn the country to what became known as the 'low road' (Sunter, 1987) leading to economic disaster, racial strife and civil war. More than 22 000 people were killed in political violence between 1985 and 1994 (Dorrington, 2001). As a final resort, the policy of the liberation movements to make the country

[1] The issue of race in South Africa's history has produced a number of descriptions for the country's racial groups. In the apartheid era 'non-white' or 'non-European' implied Africans, coloureds (people of mixed origin), and Indians (Asians). Chinese and some other groups initially fell into this category, until their economic contribution to the country was recognised, so in order to encourage them to settle, they were declared 'honorary whites' in the 1960s and 1970s. In this thesis the term 'black' will refer to African, coloured and Indian.

ungovernable included strikes and industrial action that affected the entire economy. In spite of one of the most liberal constitutions in the world and great political progress since 1994, the social and economic divide manifested through poverty, crime and unemployment (such as the loss of 450 000 formal sector jobs between 1994 and 2000) afflicts the entire fabric of society.

The economic cost of political decisions (particularly by the apartheid regime, but also the ANC) has an influence on a country's technological development. Relatively high labour costs and militancy in sectors of the labour market reinforce some managers' contention that automation and high-technology will solve labour problems. Against this, a currency that has been extremely weak renders imported technology expensive, and further, poor education bedevils efforts to raise technological expertise and knowledge. For South Africa the challenge of globalisation is to achieve competitive advantage through the appropriate use of technology, and to develop new products for, and improved service to, local, regional and international markets.

In this chapter South Africa's demographic and economic position is discussed. Political matters and affirmative action are considered in so far as they affect industrial policy and technological matters. Education and Aids are examined as they have a profound effect on technology policy and implementation.

4.2 THE DEMOGRAPHIC AND MACRO-ECONOMIC PICTURE

Table 4.1 summarises the demographic and macro-economic situation in South Africa (at the time of writing, preliminary results had been released from the 2001 Census, but detailed figures were not yet in the public domain).

DEMOGRAPHY	
Population	44.8 million
Africans	77.5%
Coloured	8.4%
Indians	2.4%
Whites	11.5%
Other	0.2%
Area	1.2 million km^2
Official languages (% of population)	isiZulu (23.5%), isiXhosa (17.6%), Afrikaans (13.7%), Sepedi (8.8%), English (8.5%), Setswana (8.3), Sesotho (8.2%), Xitsonga (4.1%), Tshivenda (2.8%), Seswati (2.5%), isiNdebele (1.5%), Other (0.4%)

Provinces	Main cities	Province population	% of national GDP
Gauteng	Johannesburg, Pretoria	8 255 000	37.8
Western Cape	Cape Town	4 211 000	14.2
KwaZulu Natal	Durban	9 368 000	14.9
Eastern Cape	Port Elizabeth, East London	6 887 000	7.6
Free State	Bloemfontein	2 904 000	6.2
Mpumalanga	Nelspruit	3 126 000	8.2
Northern Cape	Kimberley	873 000	2.1
Limpopo	Polokwane	5 474 000	3.7
North Western	Mafeking	3 702 000	5.6

MACRO-ECONOMIC DATA

	1999	2000	2001
Total GDP (R bn[2])	796	874	953
Total GDP ($ bn)	130	126	114
Real GDP growth (%)	2.0	3.0	2.3
GDP per capita	3 045	3 115	2 579
Inflation[3] (% change)	5.2	5.4	5.9
Manufacturing output (% change)	-0.2	3.6	3.0
Agricultural output (% change)	3.4	3.8	1.2
Money supply M3 (% change)	10.2	7.5	14.1
Gross foreign reserves ($ bn)	11.2	11.0	9.8
Budget deficit (% GDP)	2.8	2.3	2.0
Total exports ($ bn)	35.2	38.8	36.4
Gold exports ($ bn)	4.0	3.9	3.7

Sources: Financial Times (2002), Census 2001 (2003), Statistics South Africa (2001), SA Reserve Bank (2001), SA Year Book 2001/02

Table 4.1 Demographic and macro-economic summary

[2] Income levels and comparative monetary measurements are generally given in South African rand. It would be unwieldy to convert the local currency into, say dollars, as the question of fluctuating exchange rates from month to month would arise. For example, the rand has depreciated from 50 South African cents to the dollar in 1970 to over R11 in 2002, but increased to R7 in 2003. International comparisons are made in dollars.

[3] Inflation rates in different publications appear inconsistent as the measures of inflation are often not specified. Two indicators of inflation are used: the consumer price index (CPI) and the CPIX (the overall consumer price index for metropolitan and other urban areas, excluding the influence of mortgage interest costs). The South African Reserve Bank's target for the CPIX between 3 and 6% was met in 2003 with a figure of 4.1% (CPI was 0.4%), after years where South Africa's inflation was higher than that of its main trading partners: 8.3% in 2000, 7.3% in 2001 and 9.4% in 2002 (South African Reserve Bank website, 2003).

After the discovery of diamonds in Kimberley in 1867 and gold in the Johannesburg area in 1886, the South African economy became increasingly dependent on mining, resulting in the formation of the large mining houses that dominated the industrial landscape for decades. From more than 50% in 1960, primary production and mining declined to 36% of GDP in 1998. Despite the Sharpeville massacre in 1960 and Soweto uprising in 1976, the 1960s and 1970s were periods of relative economic stability, when the South African economy grew at an average of 5.8% per annum. This began to falter in the 1980s, as shown in Figure 4.1 (South African Reserve Bank, 1996, 2001).

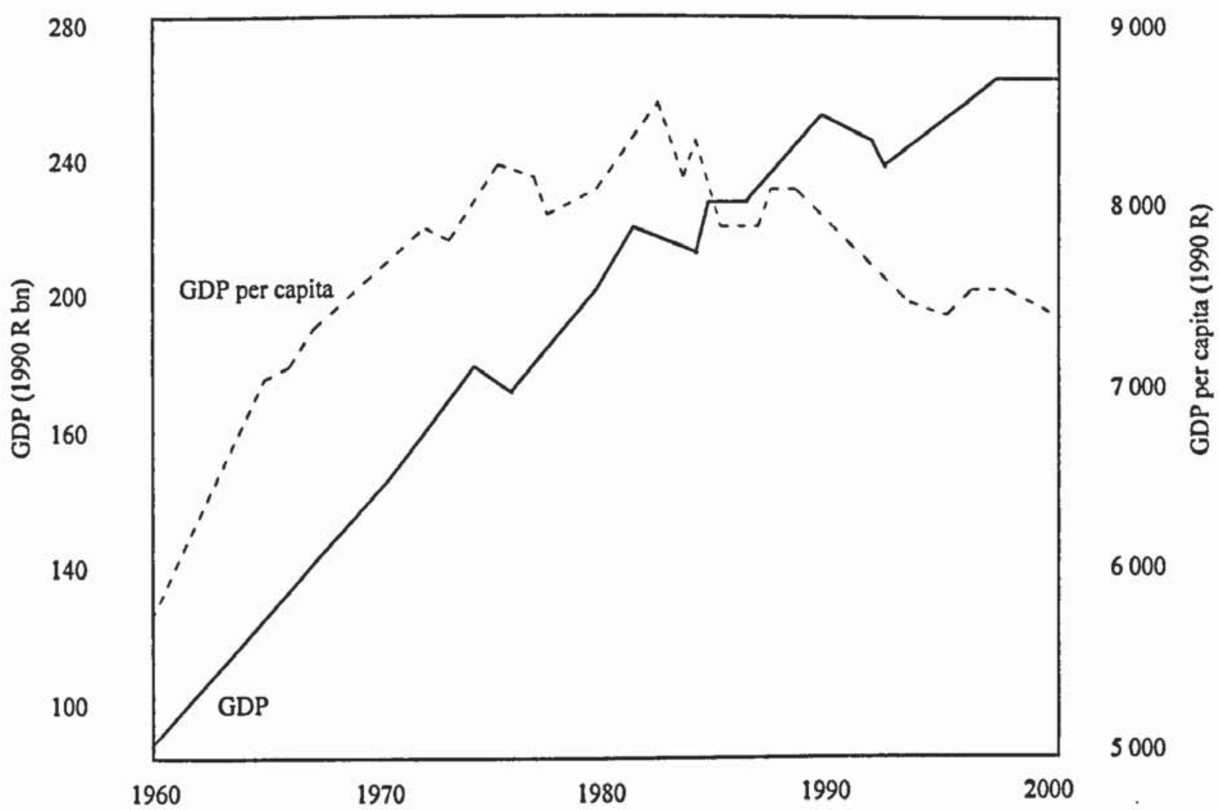


Figure 4.1 GDP per capita and GDP (1990 Rand)

Overall GDP figures for South Africa can be misleading as they indicate a middle income country, disguising the wealth of most whites and the abject poverty of many blacks, and Africans in particular: in 1998 10% of the population earned 47% of total income, and the poorest 20% earned 3% of total income (World Bank, 1999). A United Nations study (quoted in a Department of International Development report, 1998) placed the income of white South Africans in 19th position out of 173 countries; blacks were in 117th position, with an overall position of 86th. For many years income levels for individual jobs portrayed a bimodal distribution with whites earning significantly more than blacks, and males more than females (P-E Corporate Services, 2001). This began to change as a result of trade union pressure in 1979, when the first major trade union reforms were introduced, and in some cases because of a general shortage of skilled labour. There still remains a vast difference between white and black per capita earnings, despite an emerging black middle class.

United Nations studies describe poverty in broader terms than simply a measurement of low income and expenditure. Hirschowitz et al (2001: 54) define poverty as "the denial of opportunities and choices most basic to human development to lead a long, healthy, creative life and to enjoy a decent standard of living, freedom, dignity, self-esteem and respect from others". They quantify poverty in South Africa as follows: 17% of South African households earn less than R600 per month (equivalent to $90 in 2003 Rand), 25% between R600 and R1 000, 23% between R1 000 and R1 800, and 35% over R1 800. While 64% of all South Africans live in formal accommodation, only 52% of Africans have formal housing, 44% of households have a tap inside their dwelling, half have a chemical or flush toilet, and 29% have direct access to a telephone. These are overall figures and vary considerably by race, location and income level.

Despite a rapidly growing economy in the 1960s, economic activity was focused internally on a small economy of 3 million whites as the only significant purchasers of many consumer items, such as household goods and motorcars. This would ultimately limit industrial expansion, especially as sanctions prevented the export of many products, apart from those minerals initially excluded from sanctions. By preventing the creation of a black consumer class, apartheid policies stunted economic growth and resulted in shortages of vital skills that were essential if the economy were to grow further. An uneven pattern of growth emerged, particularly as the gold price increased from US$52 in 1972 to US$850 in 1980 (when gold constituted over 50% of all exports), declined to below $300 in 1999, and recovered above this level in April 2002.

In the 1980s the government expanded its heavily tariff-protected import substitution policy for two reasons: to reduce the country's dependence on mining, and to become self-sufficient in the face of increasingly damaging sanctions, initially by American and Scandinavian firms, and later when European countries refused to buy South African coal and food products. While this policy granted South Africa some independence from foreign companies, in the longer term it was largely a failure: per capita GDP at the time of the 1994 elections was less than that in 1970, after a quarter of a century of apartheid economic policies.

Growth and investment rates (as percentages of GDP) increased until 1975. After the Soweto riots in 1976, investments declined because of loss of investor and consumer confidence, and poor prospects for exports. Greater state expenditure to fund the army and police resulted in less finance being made available for some public enterprises. The electricity utility, Eskom, was an exception as it was able to obtain overseas loans, and embarked on a massive increase in new power station construction, resulting in over-capacity which will continue until 2006.

Since 1981 capital investments for state and private sector projects were, perhaps inadvertently, encouraged by favourable interest rates through the state sponsored Industrial Development Corporation, and cheap energy. Capital intensive facilities with little hope of being internationally competitive were preferred over labour intensive projects in order to reduce the effect of greater trade union militancy and because of an increasing shortage of skills that resulted from the exclusion of blacks from skilled jobs. This led to a decline in private sector employment. Labour costs increased after the first round of trade union reforms in 1979 (Hipkin, 1987). Public sector employment growth increased until 1991, partly as a result of the homelands policy[4] of the previous government where many government services were replicated in each

[4] An essential feature of the apartheid policy was the establishment of 'homelands' (or Bantustans) where more than a quarter of the black population had been forced into poverty stricken pseudo-self-governing territories. Four of these (Transkei, Venda, Bophuthatswana and Ciskei) were declared 'independent'. Tutu (1999: 63) describes the Bantustan policy as one where Africans would "enjoy autonomy in their own tribally-defined little states with a spurious independence recognised only by South Africa and its satellites and by no one else in the world; in this Alice-in-Wonderland scenario black South Africans would become aliens in the land of their birth, unable to claim political rights in South Africa itself. This policy was touted seriously by the Nationalists as South Africa participating in the new process of decolonisation and helping people evolve into new nations, when all it really was, was the old policy of divide and rule, of encouraging tribalism to counter the movement to unite black South Africans as Africans and not as members of different tribal entities."

homeland (there were 12 departments of health and 12 departments of education, catering for each of the 'national' groups). Labour productivity declined between 1960 and 1992, as shown by Bosworth et al (1995) in Table 4.2, which gives East Asian figures for comparison over the period 1960-1992.

	1960-1970	1970-1980	1980-1992	1960-1992 SA	1960-1992 East Asia
GDP/employee	2.3	2.1	-1.7	0.7	4.1
Contribution of:					
- capital	1.1	2.0	0.0	1.0	2.8
- education	0.2	-0.1	0.2	0.1	0.5
- total productivity factor	1.0	0.2	-1.9	-0.4	0.8

Table 4.2 Analysis of growth factors (percentage change in each period)

Bosworth et al (1995) suggest several reasons for declining productivity:

- investment allocation for political reasons was inefficient and resulted in surplus capacity in electricity, steel, railway transport, and oil
- protection against imports reduced exposure to international competition and effectively curtailed the need for innovation and efficiency
- job reservation for whites led to shortages of skilled labour.

During the 1980s the economic cost of apartheid soared. Government spending rose to support the security and military apparatus against rising internal black opposition, and external threats from freedom movements (ANC, PAC, SWAPO in Namibia). Expanding the homelands policy resulted in a 39% increase in the number of homeland and 'Bantu'[5] administration officials from 1980 to 1988. Further costs were incurred in moving millions of blacks to the homelands, where they were forced to live in the most rudimentary conditions. With the introduction of a tricameral parliament in 1984 for whites, Indians and coloureds, the number of civil servants in central government increased by 57% over the same period. Public expenditure as a percentage of GDP expanded from 27% in 1983 to 32% in 1991. This would have risen even further had some public investments not been curtailed (Cling, 2001).

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[5] Bantu is an adaption of the word *abantu*, the plural of the Nguni word *umuntu* meaning a person. The apartheid system used this in the singular or plural to refer to one or more black South Africans.

Unemployment is one of the most serious problems facing South Africa, and much of the current crime is attributed to this (Kotze, 2002). While total employment increased by one million between 1970 and 1995, the number of Africans employed decreased by 200 000, largely because of a significant reduction of jobs in agriculture and mining (Bhorat et al, 1998). Unemployment figures in South Africa depend on definitions of the term. Bhorat et al (1998) estimate the number of employed in the formal sector to be 7.5 million, and the number employed in the informal sector to be 1.8 million. Statistics South Africa (2001) defines the unemployed as economically active people who:

1. have not worked during the last 7 days prior to being interviewed
2. want to work and are available to start work within a week of the interview, and
3. have taken active steps to work or to provide themselves with self-employment in the 4 weeks preceding the interview.

The 'strict' definition includes these three, while the 'expanded' definition excludes the third point. Unemployment according to both definitions is shown in Table 4.3.

	Strict definition			Expanded definition		
Race	Male	Female	Total	Male	Female	Total
African	30.0	32.3	31.1	39.3	46.3	42.9
Coloured	21.1	22.8	21.9	27.6	33.0	30.3
Indian	13.9	23.0	17.6	18.0	28.8	22.5
White	5.6	7.8	6.6	7.7	1.1	10.1
Total	24.8	28.0	26.4	33.1	41.0	37.0

(Statistics South Africa, 2001)

Table 4.3 Percentage unemployment by race and gender, 2001

South Africa, like other third world countries has a significant proportion (46%) of its population living in rural areas (Hirschowitz et al, 2001). This was exacerbated by the apartheid policy of forced removals of blacks living in 'white' areas. The rural areas are the poorest, with the fewest facilities (such as health, education): 72% of the poorest people live in rural areas, where unemployment is estimated to be 51% (Department for International Development, 1998). Geographically these figures (as percentages of the total population) vary considerably as shown in Table 4.4. (Gauteng and the Western Cape are the richest provinces; the Northern Province and Eastern Cape are the poorest). For example, 17% of South Africa's poor live in Gauteng and 50% of the total population is considered poor.

Socio-economic indicators	Gauteng	Western Cape	Northern Province	Eastern Cape	Total SA
Poor	17	28	59	71	50
Unemployment	28	18	46	49	34
Rural population	3	11	89	63	46
Share of total population	18	10	12	16	100
Population living in shacks	1	1	32	41	18
Illiterates	10	7	37	21	19
Life expectancy	66	65	63	64	64
% of whites	23	21	2	5	11

Source: Cling (2001)

Table 4.4 Socio-economic regional differences in South Africa

After the first democratic elections in 1994, a Reconstruction and Development Programme (RDP) was established with the following aims: to construct one million houses and provide electricity to 2.5 additional households in the ensuing 6 years, to provide running water and access to sanitation, healthcare and telecommunications to everyone, to provide free healthcare to children under 6 years old, to provide compulsory and free education to children for 10 years, and to redistribute 30% of agricultural land to emerging black farmers.

Although the ministry entrusted in 1994 to implement the RDP was abolished in 1996 because bureaucratic confusion prevented RDP projects from being undertaken, some successes were achieved: between 1994 and 1998 three million people in rural areas had gained access to drinking water, an additional two million homes were connected to the electricity network (from 36 to 72% of all homes with the result that by 2000, 80% of urban and 46% of rural households had electricity), 1.3 million telephones had been installed, an additional 1.5 million children were attending school, 500 new clinics were built giving 5 million people reasonably close access to primary healthcare. However, little was achieved in the agricultural sector, and despite the encouraging expansion of electricity and telephones, the poorest remain without these (Hirschowitz et al, 2001).

Real gross fixed capital formation increased by 7.8% per annum between 1994 and 1997, as plant and machinery were replaced after the lifting of sanctions, and because of additional spending on social projects and infrastructure in poor areas. Thereafter fixed capital investment has declined. Economic growth remained sluggish: 0.5% (1998), 1.9% (1999), 3.1% (2000), 2.3% (2001), 1.5% (2002), 1.6% (2003) (SA Reserve Bank, 2003). These growth rates cannot accommodate the more than 450 000 new entrants to the job market each year, and redundancies in both the public and state sectors.

	Total R (m)	inc/dec (%)	as % of GDP
1991	77 000	-7.4	17.2
1992	73 000	-5.3	15.7
1993	73 000	-0.6	14.7
1994	79 000	8.2	15.2
1995	87 000	10.7	15.9
1996	94 000	7.5	16.1
1997	98 000	5.2	16.3
1998	104 000	5.8	16.8
1999	98 000	-6.0	15.2
2000	99 000	1.3	14.9

South African Survey (2001/2002)

Table 4.5 Investment: real gross fixed capital formation

While Africa has limited appeal for foreign investors, it offers a market for South African exporters. Whereas the apartheid government claimed that South Africa was a 'European' country, belonging to the developed world, the present government would not wish the country to be perceived as such. South Africa's economic performance since the 1970s into the 1990s has been similar to the rest of sub-Saharan Africa (Friedman, 1997): between 1973 and 1992, the per capita GDP of all developing countries increased by 2.3% per annum, whereas the per capita GDP of sub-Saharan Africa fell by 0.4% per annum and the per capita GDP of South Africa declined by 0.6% per annum. From the mid-1980s, investment levels in South Africa have been similar to the average in sub-Saharan Africa. The reasons for this are broadly the same: poor governance (despite claims of the former government to the contrary), inefficient resource allocation, inappropriate fiscal and monetary policies, lack of investment in human capital, inability to attract foreign investment, and corruption (Cling, 2001).

4.3 TRADE

The end of apartheid and the lifting of sanctions have fully exposed South African industry to world markets. The programme of import substitution that had been applied in a siege economy for decades has been replaced by an export-led growth policy and the rapid removal of many trade and import tariffs, forcing South African exporters to find entry into markets from which they were formally excluded. The country's traditional exports were raw materials. This has changed somewhat to include semi-processed goods, and manufactured products, as shown by the significant increase in exports of these items, shown in Table 4.6.

Sector	% of total (1990)		% of total (1998)	
Primary production		54.2		36.2
- Gold	29.8		16.2	
- Coal	5.9		5.2	
- Other mining	14.1		10.8	
- Agriculture	4.3		3.9	
Manufacturing		32.9		49.3
- Iron and steel	9.4		8.9	
- Non-ferrous metals	4.4		5.4	
- Industrial chemicals	2.6		4.8	
- Automotive	1.3		3.8	
- Other manufactured goods	15.2		26.4	
Other (non-classified)*		12.9		14.6
Total		100		100

* Other (non-classified) includes armaments not quantified in official publications

Source: Industrial Development Corporation (2000)

Table 4.6 Exports by sector

While South Africa's economic growth is export led, Cling (2001) gives data reflecting the low labour content of exports. Table 4.7 shows that South Africa's main export sectors have the lowest labour content.

Sector	No of employees to produce one billion Rand of added value
Iron and steel	7 000
Non-ferrous metals	6 000
Chemical products	7 000
Non-electrical machinery, telecommunications equipment	11 000
Automotive	9 000
Clothing	32 000

Source: Cling (2001)

Table 4.7 Labour content of exports

A labour intensive sector such as clothing has limited exports. The capital intensity of industries producing these exports is reinforced by the following examples of recent large projects in South Africa (Engineering News, Nov/Dec 2002):

1. The oil-from-coal company Sasol has announced a R7bn capital investment programme, which includes a gas pipeline from Mozambique to various plants in South Africa. There are also plans for bringing gas from Namibia to Cape Town. The empowerment company Mvelaphanda is developing gasfields 100 km off the west coast of South Africa.

2. Aluminium production by the UK/SA company Billiton near Maputo will double to 506 000 tons per annum at a cost of $860m. Additional harbour facilities and a transmission line will be required. Local empowerment will be important and SMEs will be used where possible. Much of the equipment will be sourced in South Africa.

3. Construction is taking place for a new deep-water harbour on the south-eastern coast (Coega Development Corporation).

4. The government has merged two wholly-owned state enterprises, Soeker (established to look for oil off the coast of South Africa) and Mossgas (a company set up to extract gas off shore). The new company, Petrosa, will engage in high-value chemical manufacture, and possibly enter the fuel-retail market. This will be managed by black empowerment partnerships.

5. South Africa produced 11m catalytic converters (10% of the world requirements) in 2001. Production is set to double with benefits for the platinum industry in South Africa, as well as stainless steel, monolithic brick, and metals coatings manufacturers.

6. The feasibility of a R7bn 80km railway line linking Pretoria and Johannesburg is being investigated.

The balance of trade with other African countries is much in South Africa's favour. South Africa's presence in these countries is evidenced by the expansion of mining, retailing, financial services, telecommunications, transport, healthcare, and electricity. South Africa is already the main supplier of electricity to Lesotho, Mozambique and Swaziland, and provides a partial base load and peaking service to Namibia, Botswana and Zimbabwe. South Africa has the largest economy in Africa, and it dominates economic activity in sub-Saharan Africa, as shown in Table 4.8.

	South Africa	Total sub-Saharan Africa	SA's share of sub-Sahara (%)	Sub-Sahara's share of world (%)
GDP ($bn)	126	305	41	1.1
Exports ($bn)	29	72	40	1.4
Population (m)	40	596	7	10.3
Stock market capital ($bn)	232	257	90	1.3
Electricity (m MWh)	187	246	76	1.9
Automobiles ('000)	4 028	8 344	48	1.6
Telephones ('000)	4 000	8 940	45	1.2

Source: World Trade Organisation (1998), quoted in Cling (2001)

Table 4.8 South Africa's relative position in Africa

Despite earlier comments that South Africa's aggregate economic performance has been much the same as most of sub-Saharan Africa, Table 4.8 shows what 45 million South Africans achieve in comparison to 550 million other Africans. Aggregate figures disguise a skewness strongly in favour of whites in South Africa, but South Africa does possess abilities not found elsewhere in Africa, such as research and development, high-technology knowledge in mining, armaments, IT and others. In this respect South Africa can be 'the engine for growth' for the southern African region and beyond, as envisaged by Prime Minister Jan Smuts in 1939 and recently by President Mbeki with his 'African Renaissance'. The African Renaissance is embodied in the New Partnership for Africa's Development (NEPAD), which espouses good governance and linkages among African leaders. South Africa has set an example to the rest of Africa through its political transformation.

4.4 POLITICS

Racial politics have always had a direct influence on South African industry and commerce. The 1920 African miners' strike was prompted by legislation which prevented Africans from progressing and earning higher wages. The 1922 miners' strike was motivated by white miners' resistance to attempts by mine management to promote blacks into skilled positions. Since the Nationalist party came to power in 1948, political influence was directed at all aspects of life in South Africa. One mechanism was through the Afrikaner Broederbond (fraternal society), a secret organisation open only to 'pure' Afrikaners. Wilkins and Strydom (1978: 1,2), writing at the height of apartheid, describe the organisation:

> "By stealth and sophisticated intrigue, this organisation has waged a remarkable campaign to harness political, social and economic forces in South Africa to its cause of ultimate Afrikaner domination. The South African Government is the Broederbond and the Broederbond is the Government. No Afrikaner government can rule South Africa without the support of the Broederbond. No Nationalist Afrikaner can become Prime Minister unless he comes from the organisation's select ranks. Its purpose was to further the cause of Afrikanerdom in all aspects of South African life from town and city councils, school boards, agricultural unions, the State-controlled radio and television networks, industry and commerce, banks and building societies. Its membership spirals insidiously upwards through the strata of South African society, into the provincial administrations, the departments of education, planning, roads and works, the hospital services, universities, the quasi-state corporations, the civil service, the National Party caucuses, working through the administrators of the provinces, through Parliament and the seat of government, until it finally reaches its apex in the offices of the Prime Minister".

The heads of parastatal organisations such as Eskom, Iscor (steel), the South African Broadcasting Corporation, Armscor (armaments), South African Railways, and so on, were 'broeders' (brothers) until the 1970s and early 1980s. The chief executive officers of the large Afrikaner corporations were also broeders, who had a profound effect on the lives of millions in their employ. The chairman of Eskom in the 1970s was Broeder RL Straszacker.

One implication of the Broederbond's influence on organisations such as Eskom was the strict application of government racial policies, justified on a legal basis. Thus, trade unions were not permitted until the changes in the law in 1979. Job reservation prevented training and advancing blacks beyond what was prescribed by law. It was inconceivable that a black could become a senior manager in a parastatal organisation. (In a similar vein today, organisations such as Eskom also rigorously implement current affirmative action policies of the ANC government.) Decades will pass before these effects of apartheid policies disappear.

Another legacy of apartheid policy was the homeland concept. For businesses the homelands were potentially important as the government wanted to establish 'border industries' adjacent to the homelands, or in the homelands themselves. From the government's perspective such industries would create employment opportunities outside 'white' South Africa, or on the periphery which meant that labour would live in the homelands and travel to their place of work. Generous tax concessions, transport and other allowances were designed to encourage investors to build factories in these areas. The policy was designed for labour intensive industries, so few high-technology factories were attracted to homelands where the local labour force was almost totally unskilled. Attractive salaries were paid to induce whites with the necessary managerial and technical skills to work in these areas. The remnants of the border industries are generally declining low-technology factories.

Significant changes took place during the first ANC government under Nelson Mandela. This transitional and reconciliatory period created a new system of government and the homelands were adandoned. The Truth and Reconciliation Commission (TRC) was set up to consider atrocities and politically motivated acts between 1960 and 1994. The TRC granted amnesty to applicants provided they made full disclosures of their acts, and that the rubric of proportionality applied (that is, the means were proportional to the objective) (Tutu, 1999). The end of apartheid did not solve the problems of the country, so 'delivery' of improved quality of life for impoverished citizens was to be the task of the second ANC government elected under Thabo Mbeki in 1999.

When the RDP (Reconstruction and development programme) was abandoned in 1996, it was replaced with a macro-economic policy entitled GEAR (Growth, employment and redistribution programme). This policy, designed to reassure foreign investors, governments and world bodies, such as the International Monetary Fund and World Bank, was in sharp contrast to the ANC's commitment during the liberation struggle to the Freedom Charter written in 1955 (Saunders, 1988: 388):

> "The People shall share in the country's wealth! The national wealth of our country, the heritage of all South Africans shall be restored to the people. The mineral wealth beneath the soil, the banks and monopoly industry shall be transferred to the ownership of the people as a whole. All other industries and trade shall be controlled to assist the well-being of the people".

The interventionist policy of the ANC was reduced somewhat with a declaration of its economic thinking in 1994 (ANC election document):

In restructuring the public sector to carry out national goals, the balance of evidence will guide the decision for or against various economic policy measures. The democratic government must therefore consider:

- increasing the public sector in strategic areas through, for example, nationalisation, purchasing a shareholding of companies, establishing new public corporations or joint ventures with the private sector, and
- reducing the public sector in ways that enhance efficiency, advance affirmative action and empower the historically disadvantaged, while ensuring the protection of both consumers and the rights and employment of workers.

The objectives of GEAR were the creation of 400 000 jobs per year, reducing inflation to less than 10%, removing exchange control regulations, reducing customs duties, and obtaining economic growth through exports, investments, and an increase in private savings. In reality, 450 000 formal jobs were lost between 1994 to 2000, of which 150 000 were in the public sector (SSA, 2001). With a reduction in defence expenditure since the end of apartheid, additional funds became available for other investments, although the government has been severely criticised for large massive arms deals (Financial Mail, October 2001), which threaten the position of the deputy president.

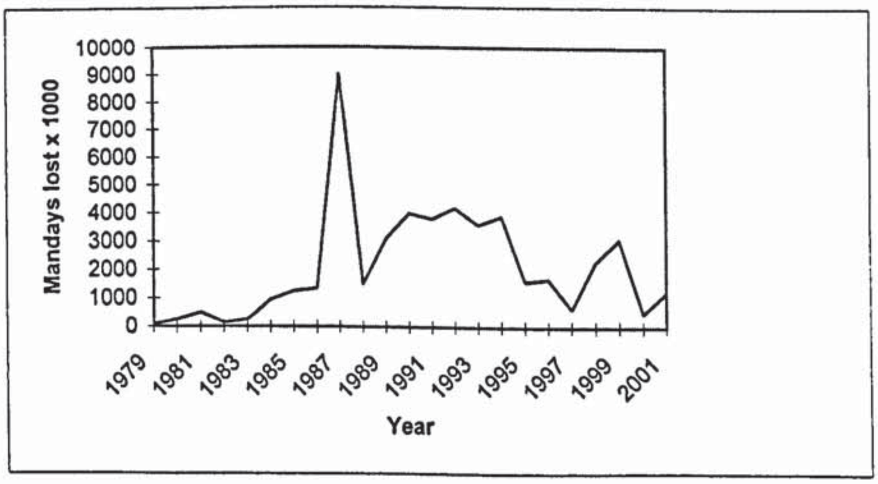
A bold programme of privatisation was announced in 1999 in which several large parastatal organisations were to be partly privatised: Telkom (with a partner from Malaysia), South African Airways (20% bought by Swissair, although following Swissair's financial troubles, the South African government repurchased its 20% share), the South African Airports Company, Safcol (forestry), the Post Office, the Aventura leisure resorts (to a large hotel group), Eskom and others. The sale of a third cellular network licence occurred in 2002.

The government's policy on investment, wages and employment, as stated by the Minister of Trade and Industry, Alec Erwin (quoted in Cling, 2001) is:

> "Promoting efficient investment, located in sustainable activity, spread across the enterprise system and geographically. It is this that will encourage labour-intensive growth, not trying to ensure that all productive activity is labour-intensive. Much modern production no longer lends itself to labour-intensive methods. Trying to force the economy in that direction would not create jobs. This reality gives the lie to the hare-brained proposals about low wages."

While South Africa is not a low wage country[6], it has only pockets of high technological ability and can therefore compete internationally in a limited range of products (South Africa Foundation, 2001). Labour intensive manufacturing will not provide the economic growth so desperately needed to reduce unemployment, but the country does not have the skills to become a high-technology manufacturer. Its economic future lies between these two extremes, and a balance in its trade between the developed world and developing countries, particularly with the rest of Africa.

The number of mandays lost through strikes is shown in Figure 4.2. The peak in 1987 was due to prolonged transport and mining strikes.



Business Day, 2002; South African Survey 2001/2002

Figure 4.2 Mandays lost as a result of strikes

Wages in real terms rose by only 2.6% per annum between 1994 and 2001, despite the fact that South Africa has one of the highest levels of unionisation in the world (South Africa Foundation, 2001). Various figures have appeared regarding the effects of wage increases on employment. GEAR claims an increase in real wages of 1% reduces (non-agricultural) employment by 0.4%. Fallon and Lucas (1998) claim that a 1% increase in real wages results in a 0.7% decrease in employment. The emphasis has changed from

[6] As an illustration that South Africa is not a low wage country, the cost of metre of fabric (in US cents) in South Africa is 86c, 75c in Italy, 69c in Japan, 42c in Brazil, 38c in South Korea, 37c in Thailand and 24c in India (Cling, 2001).

raising labour rates to encouraging labour market flexibility while at the same time protecting jobs as far as possible (Department of Finance, 1996).

The ANC government and its alliance partners, the Council of South African trade unions (Cosatu) and the South African Communist Party, introduced a number of measures relating to worker rights and employer responsibilities. The Labour Relations Act created a regulatory framework for worker rights and mechanisms for dealing with disputes and conflict situations. The Basic Conditions of Employment Act sets working conditions. The Employment Equity Act requires firms to report on the racial breakdown of their workforce. The Skills Development Act imposes a turnover levy to be used for training and skills enhancement. While the legislation has been blamed for creating a non-friendly investment environment, potentially leading to an uncompetitive and insufficiently flexible labour market (Ogilvie Thompson, Chairman, Anglo American, in South Africa Foundation, 2001), this has not prevented companies from laying off tens of thousands of workers. For example, the state railway transportation company (Transnet) and Eskom have both reduced their labour forces from around 65 000 to some 41 000 since 1994.

Cosatu aims to amalgamate a number of unions to establish 'super-unions' to achieve a 'one industry, one union' structure. The first super-union of 300 000 members was created from the National Union of Mineworkers and Cosatu's construction and energy unions. This super-union strengthens Cosatu's traditional membership base which has been drawn from the public sector, mining and manufacturing, although Cosatu has had little success in recruiting part-time workers and those from the informal sector (Financial Mail, November 2002).

4.5 DELIVERY, AFFIRMATIVE ACTION, BLACK ECONOMIC EMPOWERMENT AND EMPLOYMENT EQUITY

There are many aspects to 'delivery' in the South African context. It means providing houses and jobs, but it also introduces what is politically and economically feasible, and what approach is appropriate. The South African government has selected a free market macro-economic policy, but it has not left all subsequent developments to the market.

South African governments have always intervened in the labour market, which from the early 1900s operated under the system of job reservation. The most qualified and highest paid jobs were reserved for whites while blacks were obliged to take low skilled jobs. This was not only because the legislation precluded them from higher jobs, but also because their education had not prepared them for positions requiring higher qualifications: blacks were denied access to most apprentice training schools, the number of blacks accepted in 'white' universities was severely restricted. In this context the ANC government launched black economic empowerment, affirmative action and employee equity programmes. These have been widely criticised in the white business community, but also on theoretical grounds:

> "The Employment Equity Act is based on the unreflective assumption that the remedy for injustices inflicted on persons by virtue of their membership of a particular group calls for a group-based remedy. This parity of reasoning is seductive but is not without its own profound moral dilemmas ... if we wish our society to embrace affirmative action, not simply accept it grudgingly as a 'necessary evil', it is imperative to find a proper moral basis for it" (Van Wyk, 2000: 58, 59).

The aims of affirmative action were to rectify the consequences of discrimination that resulted in the unfair treatment of individuals or groups, in order to enable them to compete on equal terms with colleagues (Rossouw, 1994). South Africa has its affirmative action proponents and opponents who largely divide on racial lines (Olen and Barry, 1991; Rossouw, 1994). Van Wyk (2000: 62) contends that "affirmative action is inherently contentious because it encapsulates an enduring conflict in man's two streams of political philosophy, namely, equality (as represented by present-day egalitarian philosophies) and equity/merit (as represented by the libertarian points of view)". This thinking is consistent with advocates of reconciliatory measures and fair equality of opportunities (Rawls, 1971) in that affirmative action compensates for past discrimination by providing opportunities. Affirmative action addresses racism and sexism ('identifiers of disadvantage', Rawls (1971)). It provides role models for younger people who have suffered from discrimination, and contributes to defusing social unrest that may result from an unjust social dispensation.

Opponents maintain affirmative action habours feelings of resentment, frustration and even racism among those passed-over, and lack of respect by those whom the affirmative action appointees now manage. Taylor (1991) describes this as a violation of the 'liberty' principle. Those benefiting from affirmative action know that their promotion was based on preferential treatment and not merit. Standards may be lowered (educational, training, experience) as affirmative action appointees may not be able to do the job required of them (and indeed cannot be expected to) (Villere and Hartman, 1999). Whatever the merits of these arguments, it will be seen during the interviews in Chapters 7 and 8 that they were frequently raised.

In practice, affirmative action requires the racial composition of the public sector to reflect more closely the demographics of the country. By 1999 50% of public sector managers were to be black, 30% women, and 2% disabled. In the private sector, the Employment Equity Act of 1998 requires companies with more than 150 employees or a turnover exceeding R10 million to register their plans for achieving greater equity.

Black economic empowerment (BEE) is a further instrument to bring about conditions to increase the participation of blacks in the economy. The term has different meanings and connotations. Ramaphosa[7] (2003: 4) has suggested two definitions. BEE:

1. focuses on the entry and transition of acitivites of black people in business
2. is an integrated and coherent socio-economic process
3. is located in the context of the country's national transformation programme (the reconstruction and development programme)
4. is aimed at redressing the imbalance of the past by seeking substantially and equitably to transfer and confer the ownership, management and control of South Africa's financial and economic resources to the majority of its citizens
5. seeks to ensure broader and meaningful participation in the economy by black people to achieve sustainable development and prosperity.

Large organisations under black control are referred to as black empowerment companies, such as New African Investments Limited (NAIL), the mining group JCI

[7] Former leader of the National Union of Mineworkers; chief ANC negotiator in the deliberations between the ANC and the nationalist government that resulted in the interim constitution; now chairman of the Black Economic Empowerment Commission (BEEC), and one of the leading black businessmen in South Africa.

that was acquired by a consortium of blacks from Anglo American (JCI has subsequently failed), and Real Africa Holdings. At another level, (smaller) black empowerment businesses receive preference in the awarding of government contracts. A process of scoring favours firms with higher scores for the number of black directors and employees. Many 'white' businesses have appointed blacks to appropriate positions to ensure they are eligible for state tenders. When parastatal organisations are privatised, these will have a black empowerment ownership component. This will apply to further mobile phone licences, television channels, and Eskom (when 'moth-balled' power stations in long-term storage are returned to service, these will be managed under black empowerment auspices). Difficulties in attracting sufficient capital, management fallouts, and accusations that black empowerment only benefits a small black elite, have questioned its effectiveness. The government has sharply criticised the business sector for its tardy promotion of black empowerment, as only 17% of managers in the private sector are black (Business Day, April 2003).

Ramaphosa has suggested the government should actively intervene to promote black participation in the predominantly white economy. His comment on a World Bank report that 80% of managerial and 66% of clerical positions are held by whites was

> "markets will not eradicate these inequalities. Even well-functioning markets, in the absence of a counteracting policy, will work to the advantage of those who, through possession of skills or resources, already exercise considerable market power ... a little sacrifice of market forces today to undo the ills of apartheid will secure political stability and higher levels of investment tomorrow" (Business Day, June 2001).

The BEEC wishes to see 40% of executive and senior positions held by blacks within 10 years, and 25% black ownership of shares on the Johannesburg Stock Exchange Securities Exchange. After high-profile failures such as JCI, black empowerment is also sought through developing business and technology skills. Some large corporations are leading these developments, by assisting the small business sector. In response to some of the black empowerment failures, Sexwale (the former premier of Gauteng, South Africa's richest province) has joined the debate with his statement that empowerment cannot work if blacks simply parachute on to existing projects without bringing something to the party (Sunday Times, July, 2001).

4.6 EDUCATION

South Africa's poor educational standards and low levels of technological expertise are to a large measure attributable to policies that specifically excluded the majority of its population from a sound education:

> "Perhaps the most serious of all inequalities (during apartheid) was that relating to human capital where the destructive impact of the 'Bantu education' systems wrought damage that may take decades if not generations to repair. The mean-spirit which underlay the philosophy of 'Bantu eduction', the inadequacy of funds, and the crippling effect of job reservation and the colour bar on the acquisition of skills and experience by the majority of workers could almost have been designed to prevent them from being adequately prepared for the challenge of globalisation in the twenty-first century. In a world in which demand was shifting decisively towards the need for more highly skilled workers and away from unskilled labour, South Africa in 1993 found itself in a situation where 38% of those aged 16 and older had completed 10 years of schooling, and 20% had matriculated. While 61% of whites had completed school, only 11% of Africans had done so ... not only did the new South Africa find itself short of professional, technical and managerial expertise, but Africans were particularly disadvantaged. In 1989 1% of architects, less than 2% of engineers, and 13% of computer programmers were black" (The South African Survey, 2001/2002: 4).

A Unesco study on global basic education reported that South Africa's 10-11 year olds rank lowest in numeracy, literacy and life skills compared with their African counterparts, and that at least 13% of 6 to 14 year olds in South Africa do not attend school (Finance Week, 21 July, 2000). Table 4.9 gives a breakdown by race of educational levels (percentages in each category) of the employed in South Africa.

	African	Coloured	Indian	White	Total
None	19.7	10.1	2.0	0.7	14.1
Some primary	20.0	18.3	4.2	0.3	15.1
Complete primary	9.3	9.9	3.6	0.2	7.3
Some secondary	33.4	43.5	45.1	26.5	33.5
Matric (school leaving)	11.0	11.3	30.0	38.3	17.4
Higher	6.6	6.9	15.2	34.1	12.7
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: Hirschowitz et al (2001)

Table 4.9 Percentage of employed population over 20 years with various levels of education

Some 20% of employed African adults now aged over 20 years have never been to school. The functional literacy of the population is illustrated in Table 4.10.

	Number illiterate	Number literate	Proportion literate (%)
Africans	6 756 000	12 283 000	64.5
Coloured	610 000	1 651 000	73.0
Indians	86 000	628 000	88.0
Whites	47 000	3 611 000	98.7
Total	7 499 000	18 173 000	70.8

South African Survey 2001/2002

Table 4.10 Functional literacy of people over 20 in 2000

Table 4.11 contains the distribution of South Africans by employment category, race and gender. Much of this split is attributable to the poor education of blacks.

	African M	African F	Coloured M	Coloured F	Indian M	Indian F	White M	White F	Total M	Total F
Managerial and professional	14	20	15	20	38	34	46	45	21	25
Sales, clerical	16	17	13	24	22	42	14	38	15	23
Skilled craftsmen and operators	40	11	37	12	23	13	24	5	36	10
Unskilled	22	46	28	38	9	5	6	3	19	35
Sundry	8	6	7	6	8	6	10	9	9	7
Total	100	100	100	100	100	100	100	100	100	100

Source: 1997 Household Survey (Statistics South Africa) (2000)

Table 4.11 Labour distribution by employment category, race and gender

Figure 4.3 illustrates how far South Africa trails its trading partners as far as technical education is concerned with only 20% of students studying science and technology-related subjects. It is not surprising that there is a shortage of science and engineering expertise when the architect of apartheid, Hendrik Verwoerd, decreed in the 1960s that schools must equip black children to meet the demands which economic life imposes on them: "what is the use of teaching a Bantu child mathematics when it (sic) cannot use it in practice? ... education must train and teach people in accordance with their opportunities in life ...". Apartheid policy deprived blacks of the opportunity to acquire and use mathematics and science. It is ironic that "Bantu education had come back to haunt its creators" (Mandela, 1994: 576) as the cause of the Soweto riots in 1976 which prefaced the ultimate demise of apartheid.

Source: Engineering News (2001)

Figure 4.3 International comparison of students in technical education

4.7 AIDS

The 2001 Medical Research Council report on Aids (Dorrington, 2001: 5,6) begins:

> "South Africa is experiencing an HIV/Aids epidemic of shattering dimensions ... the mortality of young, adult women has increased rapidly in the last few years with the mortality rate in the 25-29 year age range in 1999/2000 being some 3.5 times higher than in 1985. The mortality of young men has also increased ... mortality in the 30-39 year age range in 1999/2000 was nearly 2 times higher than in 1985 ... we estimate that about 40% of the adult deaths aged 15-49 in the year 2000 were due to HIV/Aids and that about 20% of all adult deaths in that year were due to Aids. When this is combined with the excess deaths in childhood, it is estimated that Aids accounted for 25% of all deaths in the year 2000 and has become the single biggest cause of death. The projections show that without treatment to prevent Aids, the number of Aids deaths can be expected to grow, within the next 10 years, to more than double the number of deaths due to all other causes, resulting in 5 to 7 million cumulative Aids deaths in South Africa by 2010 ... the rapid change in the empirical death rates confirms predictions of the profound impact of Aids on mortality. These shocking results need to galvanise efforts to minimise the devastation of the epidemic".

Similar horror stories abound: 59% of Aids deaths will be female by 2010 (Mindscape, 2000). South Africa has 500 000 Aids orphans (Financial Mail, November 2000). Aids will wipe 0.3-0.4% off GDP each year for the next decade (Financial Mail, December 2000). Aids will claim 10 million Southern Africans by 2015 (Mining Weekly, 2001).

The role of President Mbeki in this has been controversial, and he has been severely criticised (Focus, 2003; South Africa Foundation, 2001):

> "It hardly bears repeating that this is an area where we as South Africans have failed to manage damaging perceptions ... leadership has a special role in this" (AJ Trahar, CEO Anglo American).
>
> "The president has allowed himself to become embroiled in theoretical controversy, thereby deflecting energy from confronting a major challenge to our society's future" (J Ogilvie Thompson, Chairman Anglo American).
>
> "A great opportunity to change the health of people has been lost through inaction" (Myslik, director of a medical company).
>
> "In South Africa no other crisis is grimmer, or more morally compelling, than that of the lack of clear policy on HIV/Aids treatment. What appears to be an insensitive approach in the way that the national government and the health ministry have responded to questions and challenges about the the state of people living with Aids, makes me wonder whether moral considerations ever enter policymakers' minds. The apparent absence of empathy for people living with Aids, and of moral standards that apply to the rest of us is an especially troubling feature that one has observed in government-public debates on the crisis of Aids in South Africa" (Pumla Gobodo-Madilizela, senior consultant for the African Ethics Initiative, University of Natal).

Some organisations have formulated policies for managing Aids. HIV incidence among South Africa's 500 000 miners is estimated at 25%, and 27% of mineworkers will have died from Aids by 2005 (Mining Weekly, 2001). These figures are even more alarming in the context of the migrant labour system, considering how Aids spreads in rural areas. Anglo American has introduced prevention campaigns and encouraged voluntary anonymous HIV prevalence surveys, counselling and testing (Business Day, February 2001). The mining group Goldfields estimates that medical costs, personnel turnover and lost production will increase gold production costs by $10/oz by 2008. Sunter dispels the notion that Aids only affects black unskilled workers: the HIV prevalence rate of 2-3% for white South Africans is 12 times that among adults in Europe and 5 times the US figure (Financial Mail, December 2000). The government has agreed to provide retroviral drugs to pregnant mothers, although no details are available.

4.8 CONCLUSION

"The South African Government deserves high marks for economic policy, but seriously flawed areas - the labour market, lack of skills, inability to control crime - inhibit South Africa's growth potential in the longer-term" (Gerson, CEO of Merryl Lynch, quoted in the Financial Times, 2002). South Africa seems unable to increase its growth rate above 3% (Financial Times, 2002). The failure to reach some of the expectations of the domestic and international community, as well as several political factors (such as Aids) and developments in bordering countries, have resulted in a sharp fluctuation in the value of the rand. This is exacerbated by a loss of some domestic confidence after the moves of several major companies of their listings to London. With 4.7m people being HIV positive out of a population of 45 million, it has been suggested that Aids could reduce GNP by 17% in the next 10 years (Financial Times, 2002).

Countries set to benefit most from globalisation are those with competitive advantage through specialisation in products and services most sought after in world trade. Geographical proximity also provides advantages (such as high-technology industries in Korea and Malaysia that are relatively close to their regional markets). South Africa's regional (African) markets may offer long term potential, but many African countries are poor and beset by political instability and low growth prospects. It would appear that South Africa's best options still lie in exports to the developed world. After the rapid decline in the currency between 1994 and 2002, exports were particularly price competitive. Much of this cost advantage has disappeared with the strengthening of the Rand by 40% against the dollar in 2003 (Economist, 19 December 2003), so exporters will have to rely on quality and technological developments to meet order winner criteria. Achieving competitive advantage in this way will be limited by the lack of a skilled labour force.

While international investors view South Africa's constitution, free press, financial systems, and general infrastructure favourably, they are deterred by high taxation, strong trade unions, violence and corruption, and high levels of crime, where private security companies employ more than twice as many guards as there are uniformed police officers in the South African Police Service. South Africa's geographical position is also a negative factor, particularly as the gateway it provides to Africa is the entrance to a blighted continent (The Economist, 2001). Africa's GDP is almost negligible in world terms (Yeats et al, 1997), and the continent seems unable to prevent itself from descending into a poverty trap, and falling further behind other developing countries.

This chapter has presented the context in which TT takes place in South Africa. The country will increasingly rely on global activities where technology plays a key role in achieving competitive parity with other nations. Education, skills, training and business structures must be adapted to assist TT. Competitive advantage is gained through proactive strategies that accommodate local conditions, but transcend the constraints encountered in developing countries.

CHAPTER 5

RESEARCH METHODOLOGY

5.1 INTRODUCTION

Management research is concerned with the way in which culture, history and philosophical beliefs lead to theory and knowledge. Chia (2001: 6) explains the research process as one where "we actively cut, draw out and construct social reality from an initially undifferentiated flux of interactions and sense-impressions. These isolated parts of social reality are then identified, labelled and causally linked to other parts of our experiences in order to form a coherent system of explanation". The processes identified by Chia suggest the need for a framework in management research, which leads Weick (1989: 516) to comment:

> "Theorists often write trivial theories because their process of theory construction is hemmed in by methodological strictures that favour validation rather than usefulness ... Theory cannot be improved until we improve the theorising process, and we cannot improve the theorising process until we describe it more explicitly, operate it more self-consciously, and decouple it from validation more deliberately".

Recognising the need for a research framework, Sayer (1992) also acknowledges the importance of examining relations and structures, and the social processes accounted for by the fabric of society. Silverman (1998: 1) believes in the importance of "a dialogue between social science and the community based on a recognition of their different starting points". This supports Sayer's (1992) concern with relying on actors' accounts, particularly as rule-governed actions are constrained by conditions not always of the actors' choosing. The researcher's challenge is therefore to determine causality and provide explanations therefor.

This chapter investigates various theoretical research approaches, within the context in which technology is being transferred, and explores a number of theoretical constructs in order to establish a methodological basis for the empirical research, including: positivism and phenomenology, intensive and extensive research design, theory building and case study research, followed by a discussion of data collection and analysis. With this background, the research approach is selected and the research questions formulated. The final two sections consider the methodological contributions and limitations, and triangulation.

5.2 POSITIVISM AND PHENOMENOLOGY

The positivist and phenomenological divide is important in management research, which has traditionally followed the positivist route, achieving neutrality through quantification, replicability and generalisation. Positivist research adopts a deductive logic and proceeds in four stages (Robson, 1993):

- proposing hypotheses that suggest relationships between events or variables
- expressing the hypothesis as a relationship between the variables and testing it
- examining the outcomes of the inquiry
- modifying the theory in the light of the findings, if necessary.

The deductive nature of this approach (Saunders et al, 1997) seeks to explain causal relationships, normally requiring quantitative data[1], with a structured methodology to facilitate replication. One strength of positivism is its apparent detachment (Easterby-Smith et al, 1991), achieved through an independent observer who determines what is to be studied using objective criteria. Causal explanations and fundamental laws explain human behaviour through hypothesis testing. Quantification reduces issues to the simplest measurable elements thereby permitting generalisation, provided samples are large. Through explicitly stated theories and hypotheses, positivism claims a clear distinction between facts and value judgements. These are achieved by statistical and mathematical techniques that provide objectivity, neutrality and detachment by the researcher (Gummesson, 1991).

Chia (2001) describes an apparently endemic predisposition in management research to the rigid representation of individual and identifiable objects, actions and phenomena as

[1] A broad definition of 'data' is taken, which includes responses to questionnaires, transcripts of hearings, and case studies. Bartunek et al (1993: 1366) suggest that data is "a hypothetical construct referring to subjective contextual coding, objective counting, building objective measures into subjective composite measures, perceptions of reality, objective measures of reality, numerical information, semantic information, and information obtained orally, visually or cognitively."

a series of outcomes and end-states. This results in a fixation on the positivist method, with precision and accuracy becoming the basis for representing and explaining social and material phenomena (Pfeffer, 1993). Management research appears then to require a choice between positivist and phenomenological paradigms.

Phenomenology facilitates an understanding of how and why from the participant's point of view (Prior, 1998), and provides rich descriptions and sensitivities. Its flexibility gives the researcher the ability to react to, and investigate emerging findings. Phenomenology defers to a pervading influence of understanding through observation and familiarity, with a commitment to perceive activities, norms and values from the perspective of those being studied (Prior, 1998). Merleau-Ponty (1962: 161) (quoted in Chia, 2001) acknowledges a conceptual order or enduring principles that may claim supremacy over personal observation, and speaks of the "natural-cultural-historical milieu" which forms the starting point for phenomenological observation.

In some management research, experiences are seen and recounted as conscious actions, signs, expressions and intentions, in a cultural and socio-historical context. Hermeneutic inquiry is a process for the researcher to look for a reliable and dependable rendering of these. The researcher seeks not so much the original intention of an action, but "a 'fusion of horizons' in which the reader/researcher achieves a level of coherence and comprehension in his/her own system of understanding" (Chia, 2001: 15). Reliance on experiential accounts may raise the researcher's suspicion of underlying meanings of opinions and expressions. These may be deliberate or unconscious, and may be motivated by circumstances that influence a true interpretation of the environment. Durkheim (1967: xiii) claims some phenomena cannot be deduced, but require a form of empirical observation that "treats facts as things" to enable researchers to discover elements making up representations of the world and the tools people use when interacting with others (Baszanger and Dodier, 1998).

Analysis of what is reported requires decoding and interpretation. 'Hermeneutics of suspicion' relates to scepticism of the authenticity of 'experiential' accounts, which Habermas (1984) attributes to prevailing cultural, ideological and political 'superstructures'. From a post-modern perspective, Chia (2001: 17) sees interpretations of what actors say and what they mean as a result of embedded contextual and cultural factors and experiences. The preliminary surveys conducted in the early phases of this research revealed a discrepancy in what some literature predicts and what the results reveal in relation to cultural issues in TT.

With limited literature, a deductive approach with hypothesis formulation and testing may not be possible. Giddens and Turner (1987: 2) repudiate the idea of theory-neutral observations and challenge the post-empiricist approach: "... while systems of deductively-linked laws are no longer canonised as the highest ideal of scientific explanation. Most importantly, science is presumed to be an interpretive endeavour, in the sense that problems of meaning, communication and translation are immediately relevant to scientific theories". Using deduction the researcher looks for causal explanations that gradually emerge from actions, through reasons and rules, and finally develop into structures and causal powers.

Also of importance is the ability to "increase the likelihood of developing empirically supported new ideas and theories, together with increased relevance and interest for practitioners" (Alvesson and Deetz, 2000: 60). Yet these authors (2000: 61) claim that too much emphasis is placed on the merits of quantitative vs. qualitative research: "The crucial issue for researchers is not the choice between quantitative or qualitative methods, but involves much more fundamental ontological, epistemological and axiological concerns". An important question is whether researchers focus excessively on "techniques through which social life is represented in the course of research, as opposed to the process of representing social reality" (Morrow, 1994: 207).

It will be seen that the lack of 'explicitly stated theories' relating to the research questions does not permit the observations to which Chia (2001) refers, and indicates that a positivist approach is not entirely suitable for the research topic proposed in this thesis. Hypothesis testing is questionable for research where so much has yet to be observed, internalised and analysed. Following Durkheim (1967) the investigation in this thesis requires a degree of empirical analysis to enable the researcher to discover fundamental aspects of TT. This will be applied in the preliminary survey conducted to establish important factors in TT in South Africa. The main component of the research follows a phenomenological approach in order to understand, explain and exploit the richness of the information to be collected, and to embark on theory building for TT in the chosen application.

5.3 INTENSIVE AND EXTENSIVE RESEARCH DESIGN

Problems of explanation arise because some research instruments are inappropriate for the topic under investigation and ill suited to meet the expectations of the researcher. Qualitative information relating to processes and events requires a different research approach from statistical measurement of quantifiable characteristics. In order to differentiate between such situations, Sayer (1992) distinguishes between intensive and extensive research designs (shown in Table 5.1). These describe two broad categories of research that ask contrasting types of questions, utilise different techniques and provide for distinctive boundary demarcations.

Table 5.1 Intensive and extensive research (Sayer, 1992: 243)

Sayer (1992: 242) describes these briefly as follows: "in intensive research the primary questions concern how some causal process works out in a particular case or limited number of cases. Extensive research is concerned with discovering some of the common properties and general patterns of a population as a whole." He makes some important comments about the "widely conflated and confused" nature of the two approaches, suggesting that extensive research may typically use descriptive and inferential statistics, with large-scale formal questionnaires of a population or representative sample, where individuals "are only of interest in so far as they represent the population as a whole, (whereas) intensive research focuses mainly on groups whose members may be either similar or different but which actually relate to each other structurally or causally."

Interviewees in intensive research are chosen individually as the research proceeds and pictures emerge of its direction. In extensive research samples are determined in advance to ensure they are representative. Respondents are asked the same questions. Sayer (1992: 245) suggests extensive research "sacrifices explanatory penetration in the name of 'representativeness' ... extreme standardization disregards the differences in types of respondents and in the contexts which are causally relevant". While the aim is to focus on individuals taxonomically (that is, groups whose members share similar attributes, but which may not interact with each other), extensive research suffers from relative weakness in researching causality.

Less standardised interaction with respondents provides the researcher with an opportunity for learning from them. Intensive research encourages meaningful communication to maximise the flow of information by adapting preconceived or standardised questions according to what the respondent is saying. Sayer (1992: 248) acknowledges that causal groups are not easily demarcated and often change as situations develop, but emphasises that causal groups "are rarely just background; exploration of how the context is structured and how key agents under study fit into it - interact with it and constitute it - is vital for explanation". The results from intensive research are not 'representative' of the entire population. Results may therefore be unique at the level of concrete events, but Sayer (1992: 249) contends "the abstract knowledge of these may be more generally applicable, although it will take further research to establish just how general they are".

The preliminary research referred to earlier (and presented in Chapter 6) uses an extensive research design for its initial quantitative component that seeks regularities and patterns through a survey of a population and statistical analyses. Thereafter, given the type of data needed to address the research questions, the prevailing environment, and attitude of respondents to the research, the extensive approach was considered inappropriate. Intensive research methods have therefore been selected for the analysis of the case studies.

5.4 THEORY BUILDING

Theory building "permits a wider range of observation and inquiry than the more traditional theory testing" (Flynn et al, 1990: 252), and begins with "no theory under consideration and no hypotheses to test" (Eisenhardt, 1989: 536). Increasingly research goes beyond the relationship between measurable variables in the physical world to building theory within constraints of underlying assumptions. Astley (1985: 497) claims

> "No theory can simply 'describe' empirical reality in neutral linguistic terms; all theoretical perspectives are infused by the biases inhering in particular world views. The search for a standard list of variables is, consequently, based on a misapprehension since differences in perspective between theoretical approaches cannot be resolved through an appeal to 'objective' truth".

Shipman's (1982: 26) claim that "new data exhaust old theories" means that attempts to build theory challenge theoretical models that overtly or covertly form the basis of management research. He further claims that conceptualisation and operational definitions are rarely subject to control, so it is possible that existing theories may be inadequate in new investigations. Because there is limited literature in the area studied in this dissertation, theory pertaining to other TT contexts is reviewed, and accepted or rejected depending on the research findings. While the results from the preliminary surveys and the research questions provide initial direction, they do not constitute a 'standard list of variables', which will constrain the investigation. The research will examine these issues, and underlying biases and assumptions. So, the intention is to use the case studies to contribute to a theory of TT in the South African situation.

5.5 CASE STUDY RESEARCH

According to McCutcheon and Meredith (1993: 240) the purpose of case study research is to "assess the conditions surrounding the phenomenon to build a plausible explanation or discover a causal relationship that links the antecedents to the results". Case studies are widely used in TT studies (for example, 22% of the studies described in the sample of TT literature in Chapter 2 were case based). Patton (1990: 54) asserts

> "case studies assume special importance when one needs to understand some special people, particular problem, or unique situation in greater depth and where one can identify cases, rich in information, rich in the sense that a great deal can be learned from a few exemplars of the phenomenon in question".

Patton further sees scope for a case study approach in third world situations with limited research based on academic literature, and where data collection through large scale quantitative surveys may be impractical, time consuming and expensive. Case study research allows the researcher to gain a full appreciation of the research context and processes, by understanding the how, why and what questions (Robson, 1993). These are achieved through inquiry and investigation of "a contemporary phenomenon in a real-life context, especially when the boundaries between the context and the phenomenon are not clearly defined and in which multiple sources of evidence are used" (Yin, 1994: 23).

Qualitative studies oriented towards case studies seek patterns of unexpected and anticipated behaviour and relationships. Weick (1989: 524) refers to this as sense making and believes "the contribution does not lie in validated knowledge, but rather in the suggestion of relationships and connections that had previously not been suspected, relations that change actions and perspectives". Stake (1995) suggests case study research seeks 'centrality of interpretation' that can take the form of assertions rather than findings because, despite efforts to reflect opinions of participants and describe events objectively and ensure non-intervention, the researcher ultimately offers a personal interpretation. This immediately leads to the accusation that qualitative research is subjective, with high ethical risks, and "its contribution to disciplined science is slow and tendentious ... many findings are esoteric (and) the worlds of commerce and social service benefit all too little from investments in qualitative research" (Stake, 1995: 45).

De Cock (1995) presents two views of case studies. Firstly, case studies have high internal validity but low external validity, implying that such cases explain local causality and are therefore unsuitable for generalisation. Secondly, with proponents such as Eisenhardt (1989), cases are useful for theory building and are "most appropriate in the early stages of research on a topic or to provide freshness in perspective to an already research topic". De Cock (1995) criticises the view of Tsoukas (1989) that preliminary case study work should ideally be followed by quantitative research because this suggests that the occurrence of predicted results in a number of cases permits transcending local boundaries. De Cock (1995: 36) comments further: "the verification process based on replication logic takes over: cases which confirm emergent relationships enhance confidence in the validity of the relationships; cases which disconfirm the relationships provide an opportunity to refine and extend theory".

In accommodating theory building Eisenhardt's (1989) case study approach (shown in Table 5.2) follows the thinking of Glaser and Strauss (1967: 536) that

> "theory building research is begun as close as possible to the ideal of no theory under consideration and no hypotheses to test ... thus investigators should formulate a research problem and possibly specify some potentially important variables, with some reference to extant literature".

Steenhuis and de Bruijn (2003: 790) believe that Eisenhardt "takes a position between the inductive grounded theory approach and the more deductive case study approach, because it combines the advantages of both: it is structured yet open". Where theory exists, it may be used to note potentially valuable variables, but it does not constitute a basis against which the case study will test its findings. Case studies constitute a recognised source for recording detailed observations of a single situation from which theory building emerges.

Step	Activity
Getting started	Definition of research question
Selecting cases	Specification of population
Crafting instruments and protocols	Data collection methods (qualitative/quantitative approaches)
Entering the field	Data collection and analysis, including field notes; flexible and opportunistic data collection
Analysing data	Within-case analysis; cross-case analysis using divergent techniques
Shaping hypothesis/ research question	Iterative tabulation of evidence for each construct; replication logic across cases; search for evidence for 'why' behind relationships

Table 5.2 Eisenhardt's (1989: 533) approach to case study research

In addition to the above comments, a number of criticisms are levelled at the case study approach. Where theory is derived from a single practical example, the question of generalisability arises. It is not possible to increase the quantity of data by analysing more organisations, because by definition, a single case study is just that. The organisation may consist of a number of plants (in this research, the main case will comprise a number of power stations), but beyond this finite number, no additional directly comparable data can be gathered. De Cock (1995: 37) places the generalisability debate in the context of

> "Capturing uniqueness and richness of each case (and specifying how specific structures and processes generate particular outcomes in certain circumstances) rather than on the explanatory dubious and empirically precarious matching of largely quantitative variables (this does not preclude, however, an explanation of inter-case differences and similarities)".

5.6 DATA COLLECTION

Management research involves data collection, but the relationship between data and what is observed can be problematic. Whitley (1989) envisages difficulties in theory construction because the relationship between phenomena and what can be observed is loose and open ended. On the other hand Sayer (1992: 199) claims "the implicit conception (of research) tends to assume the universality of closed systems, a regularity theory of causation, an atomistic ontology and an equivalence of explanation and prediction". The research challenge is thus to explain how empirical data (in this research, the data obtained in the preliminary surveys) provides specific indicators in a theory building context (Layder, 1993). Sources of information include:

- **Preliminary surveys of South African managers**

Preliminary surveys (described in Chapter 6) were used to obtain direction for the research, and for the researcher to align with the mental map of players (Miles and Huberman, 1984).

- **Public information from official sources**

The South African economic and industrial situation at the beginning of the 21st century is discussed in Chapter 4 using economic data from official sources.

- **Internal company documentation**

Technology policy from case organisations provides valuable insight into strategic and managerial thinking regarding technology (Chapters 7 and 8). Maintenance documentation and information systems are a further source of information.

- **Authoritative papers and articles**

These include publications in the public domain written about the case firms. The main case organisation, Eskom, has a high profile, but little has been published about Eskom in refereed journals. South African newspapers and practitioner magazines give Eskom extensive coverage (referred to in Chapters 2 and 7).

- **Interviewing**

Interviewing is widely used in qualitative research. In the case studies chosen for this research, interviews were conducted at various levels. Policy makers at corporate level in the utility and in the mini case studies were interviewed to establish what, why and how technology was selected, and to assess the strategic role of technology. Managers at power stations and at plant level in the mini cases were interviewed to ascertain their opinions on technology choices, and to discuss other transfer and implementational issues. Supervisors, operators and maintenance personnel were also involved in data gathering through interviews, to provide "richness that comes from anecdote" (Eisenhardt, 1989: 538).

The author conducted interviews in several languages besides English (Afrikaans, Sesotho, Zulu), as lower level staff had little or no knowledge of English. In order to obtain a broader perspective, owners[2] of technology were interviewed. To expand the study, four mini cases were selected. While data collection methods were the same with these, perspectives from different angles add a further dimension for triangularisation. At a practical level, choosing the ideal company is a luxury seldom afforded researchers. Approval by head office does not guarantee access at plant level. Interviewees need to benefit from participation in a research exercise, particularly if extensive demands are made on their time.

- **Direct observation**

This involves observing what people do in the workplace, and can take the form of participant observation or structured observation. In order to arrive at a 'true' theory, Alvesson and Deetz (2000: 38) believe we require "compelling conceptions of core life issues, often challenging both existing assumptions and supporting dominant values". This is not necessarily achieved by collecting large volumes of data, but is often obtained through observation. While the challenge in observation is to ensure sufficient distance and to maintain a critical perspective, the mechanism has "the objective of sharing people's lives while attempting to learn their symbolic world" (Delbridge and Kirkpatrick, 1994: 37). In order to gain greater insight into human interactions in the work situation, the author was able to observe certain activities, such as maintenance meetings and operational testing, but had no direct influence on events.

- **Questionnaire surveys**

As part of the preliminary work, questionnaires raised a broad range of issues that formed the basis of in-depth discussions. No additional surveys were administered.

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[2] During the apartheid era, economic sanctions meant Eskom could only buy from certain countries that have continued to supply technology. The US is underrepresented at technological levels, and it is more difficult for US companies to develop this market because of the hold of European firms. The original choice of supplier was in many respects political, but has now become commercial, and operationally easier because European systems are better suited (for example, use of the metric system, common voltage and frequency in South Africa and Europe). Only European suppliers were interviewed.

5.7 ANALYSIS

The TT process in the case studies is reported, summarised, and analysed in Chapters 7, 8 and 9. Descriptions of the way in which technology decisions were made and what TT meant to interviewees were part of the analysis. Interpretation of opinions and actions involves exploration and explanation. Theory generation can only follow once this sequence has been completed (Gummesson, 1991). Analysis of the data gathered from interviews essentially consists of identifying patterns in TT. Incidences in the acquisition of new equipment and systems further describe part of the TT process. The management, implementation, adoption, adaptation and maintenance of the technology tell another part of the story.

One component of TT is the extent to which decisions made at one level are implemented, taken further or operationalised at another. The analysis in Chapter 9 identifies key factors at each level in the Salami and Reavill (1997) model discussed in Chapter 2. For example, strategic and policy issues were discussed at Level 1. It was important to identify the items from the preliminary surveys that featured only at one level, and as policy issues, were raised at Level 1, but also impacted on decisions at lower levels. Thus, policies discussed at one level required interpretation at lower levels. Broad technology parameters such as overall goals derived from the technology are set at Level 1, so analyses at Levels 1 and 2 assess the extent to which these objectives were being met, and so on through the steps in the process. The selection and analysis issues at Levels 2 and 3 have an impact on the management and implementation of technology at Level 4. Interviews with technology suppliers were also structured around these levels to assess if they viewed technology policy, evaluation, adaptation, and so on, in the same way as acquirers.

The research uses qualitative methods, causal analysis, observation and interviews. Data is largely of a qualitative nature, consisting of words rather than numbers. The intention is to show the characteristics of TT, rather than to draw conclusions about the generalisability of findings. In this context Miles and Huberman (1984: 72) consider data analysis as consisting of a number of concurrent flows of activities: data reduction, data display and conclusion drawing, where data reduction refers to "the process of selecting, focusing, simplifying, abstracting, and transferring 'raw' data ... the researcher's choices of which data chunks to code, which to pull out, what the evolving story is, are all analytical choices".

When analysing interviews and findings, key issues were sought to identify emerging patterns concerning decision-making procedures, implementation policies, adaptation methods, knowledge transfer, training processes, and so on. From a maintenance perspective, analyses consider understanding of functionality of equipment, how they fail, causes and immediate effects of failure, consequential analysis, and decision making processes for remedial action. The role of the technology owner and acquirer was assessed in setting maintenance policy.

Answers to the research questions discussed later were recorded, using a form of narrative. In its purest sense narrative provides an episodic dimension of an account of the development of a series of events and activities. Analysis of the data addresses causal explanations of why events described in the narrative occur. Sayer (1992: 259, 260) discusses several topics relating to representation and presentation, and the way in which knowledge is communicated. He differentiates between narrative and analysis:

> "Narrative is an account of some process or development in terms of a story, in which a series of events are depicted chronologically ... its power derives from the way in which putting things in chronological order, in a story, gives the appearance of a causal chain or logic in which each event leads to the conclusion. Analysis is the explanation of concrete cases by the direct application of abstractions or theoretical models of what are believed to be widely replicated structures and mechanisms. As such it tends to abstract from particular historical sequences ... (requiring) a leap across the intermediate steps between abstract and concrete in the hope that the model will still serve to identify and keep processes without too much distortion".

Narrative and analysis are not mutually exclusive, but undue attention on analysis plays down the importance of method, while narrative is criticised for a disproportionate emphasis on theoretical generalisation. This suggests that narrative is constrained by linear description and may not adequately address causality where, in the words of Abrams (1982: 307):

"The principles of explanation underpinning the research lie buried beneath the rhetoric of a story. My own impression is that the function of narrative is to carry - in a highly persuasive way not accessible to intellectual scrutiny - those bits of the argument the author does not choose to make available for direct critical examination on the part of his readers".

Sayer (1992: 262) suggests that analysis explains 'much by little' (thin description) and

"is an economising view of theory (that) is more appropriate to abstraction of objects (relations, mechanisms, concepts) which are stable and pervasive, while 'thick description' (narrative) is more appropriate for accounts of concrete situations in which there is considerable historical and geographical specificity and change".

The danger in treating 'thick description' synonymously with narrative is to neglect theory or to combine many theoretical insights and fail to examine concepts relying excessively on the 'art' of description.

5.8 SELECTION OF RESEARCH APPROACH AND RESEARCH QUESTIONS

In seeking Chia's (2001) coherent system of explanation, this research required a starting point and a way to proceed. The literature suggests that the research direction should either be set by positivist thinking, or by following a phenomenological agenda. Eisenhardt's (1989) belief that case studies are most appropriate in the early stages of research is followed in this thesis, which is essentially covering an under-researched topic. Her approach to case study research in Table 5.2 includes the use of quantitative and qualitative approaches. While the research in this thesis is primarily conducted through the use of case studies, it was also necessary to acquire sufficient initial understanding of the environment being studied. This was done by conducting a preliminary survey of South African managers described in Chapter 6. While factor analysis was used in the analysis of the data, the survey was not, as purported by Pfeffer (1993) in such cases, conducted with a fixation on the positivist method, with precision and accuracy becoming the basis for representing and explaining social phenomena. It was intended to identify important factors in TT in the South African context so that these could be used later in the case study research.

This research seeks an understanding of the underlying mechanisms of TT, and explanations of the events that occur. Primary data gathering is through interviews, designed as intensive research around research questions, and stated as such rather than as hypotheses, to indicate that the purpose is not to obtain specific answers to specific questions, but "to reveal patterns of responses, and answers will not be interpreted in isolation" (De Cock, 1996: 40). Intensive research permits theory building through observation and inquiry, emphasising causality, the role of individuals and comprehension of how processes work. This is best achieved through case study research where in-depth information can explain special events and problems that are fundamental to an understanding of TT. Although the TT literature can provide valuable support to the researcher, unique features of the South African context require that the research starts at a point prior to where existing theories can be verified.

Stake (1995: 17) suggests that a case has a boundary and working parts, with issues that are "intricately wired to political, social, historical, and especially personal contexts ... issues help us expand upon the moment, help us see the instance in a more historical light, help us recognize the pervasive problems in human interaction". He guards against confusing information questions with issues, despite the importance of information questions in understanding the case. Issue questions are "substantive questions posed in negotiating the study, in early contacts with the case, or from experience or relevant literature" (Stake, 1995: 20). These are then transformed into research questions. According to Parlett and Hamilton (1976) (quoted in Stake, 1995), formulating and examining research questions is a three-stage process: observation, renewed inquiry, and explanation.

The literature review demonstrated that scholars approach TT from a number of perspectives. Global, economic and political issues impact on strategic decisions. Technology capability and environmental conditions influence technology selection, configuration and coordination. A comprehensive approach to studying TT requires a framework to assimilate the disparate views of TT. One model which incorporates these is that proposed by Salami and Reavill (1997), introduced in Chapter 2. Its appeal is its structure and its inclusion of technology selection and management. It suggests that many levels in the organisation are involved with TT. The influence of individuals changes as economic, strategic, human resources, implementation and evaluation issues are addressed. The process consists of a number of 'steps'[3], starting at a macro-level (Level 1), through surveys of technology (Level 2) and technology selection (Level 3), to detailed implementation and maintenance (Level 4), and evaluation and modification (Level 5). The study of TT thus comprises consideration of technology selection and management of technology.

This study presents five main research questions, each followed by a number of subsidiary questions that expand on and explore the main questions. While the structure of the research questions is based on Salami and Reavill's (1997) framework, each question is also derived from the literature, as indicated by the sources in brackets.

1. Research question 1

Do technology suppliers and acquirers reach common accord in the selection of technology, in accordance with the acquiring country's needs, capabilities, limitations and human resource factors? (Samli et al, 1992)

Subsidiary questions

Does the decision-making process for selecting technology by a firm in an acquiring country identify

1.1 the needs and demands of the acquiring country? (Kumar and Jain, 2001; Lall, 1993; Williams, 1996)

1.2 the acquiring country's capabilities and limitations? (Burgess et al, 1998; Quinton, 2002)

1.3 important macro- and micro-economic human factors relating to new technology? (Gergen and Whitney, 1996)

1.4 the acquirer's goals and objectives to be achieved through the technology? (Nagabhushana and Shah, 1999; Phillips et al, 1994)

[3] Salami and Reavill's model (1997) contains five 'steps'. This suggests a sequence of events, which applies to the thinking process for TT. This is not always a linear, sequential process, so the 'steps' are referred to as 'levels'. The questions to be posed for each 'step' will effectively relate to different levels of decision making and implementation.

2. Research question 2

Are technology options investigated taking into account the goals of the acquirer, costs and benefits of the technology, the resources of the acquirer, and economic and technical factors in technology transfer? (Loveridge and Pitt, 1990)

Subsidiary questions

Do analyses and surveys of available technology

2.1 identify appropriate technologies for meeting the acquirer's goals? (Alcorta, 1999)

2.2 take into account costs and benefits of the new technology? (Lado and Vozikis, 1996; Spann et al, 1995)

2.3 assist in evaluating technology on the basis of the acquirer's resources? (Voss and Blackmon, 1996)

2.4 consider basic economic and technical factors affecting the TT process? (Deluzio, 1993; Hirschmann, 1958)

3. Research question 3

Do final decisions for adopting the most appropriate technology consider the basic human factors for adopting new technology, include an evaluation of final costs and benefits, require knowledge of possible suppliers, and compare alternative sources of technology? (Husain and Sushil, 1997)

Subsidiary questions

Do decisions for final technology selection

3.1 take into account human factors pertaining to the new technology? (Bolden, et al, 1997; Lynskey, 1999; Voordijk, 1999)

3.2 evaluate final costs and benefits of the new technology? (Baines et al, 1999; Bartlett and Ghosal, 1989)

3.3 follow a comprehensive analysis of all possible technology suppliers? (Olayan, 1999)

3.4 assess alternative sources of technology? (Plenert, 1994)

4. Research question 4

Do technology suppliers and acquirers agree on implementation, adaptation and maintenance by providing guidelines on management and implementation, personnel and training, selecting new technology, and identifying criteria for improved adaptation of new technology? (Barkema et al, 1997; Martinsons and Schlinder, 1995)

Subsidiary questions

Do implementation and maintenance of technology involve suppliers and acquirers in

4.1 providing guidelines for management and implementation of new technology? (Hart and Schlesinger, 1991; Leonard-Barton, 1995; Williams, 1996)

4.2 personnel training and other human resource issues? (Baranson, 1969; De Meyer, 1992)

4.3 selecting alternative approaches to TT? (Lennon, 1997)

4.4 identifying criteria for better adaptation of new technology? (Lall, 1993; Sharif, 1997)

5. Research question 5

Is the TT process assessed and re-evaluated with reference to the acquirer's goals and performance criteria, necessity for modifications of technology, analysis of success and failure, and R&D innovations for further development of technology? (Katz et al, 1996)

Subsidiary questions

Are evaluation and modification of new technology

5.1 based on specific criteria derived from the acquirer's goals? (Armistead et al, 1995; Grant and Gregory, 1997)

5.2 based on guidelines for redirecting the labour force? (Gergen and Whitney, 1996)

5.3 assessed by the success, failure and efficiency of new technology? (Riis and Sun, 1994)

5.4 instrumental in leading to innovative programmes through R&D to develop technology? (Platt and Wilson, 1999; Kumar and Siddharthan, 1994)

In chapters 7 and 8 each question in Salami and Reavill's framework (1997) is analysed with reference to the case studies. Appendices VI and VIII contain details of the interviews.

5.9 METHODOLOGICAL CONTRIBUTIONS AND LIMITATIONS

Certain criticisms of methodological approaches are common to most management research (Gummesson, 1991):

- access to reality and insight into a specific problem and social environment
- selection of quality criteria (reliability, validity, objectivity, relevance, etc.).

From the discussions above, the phenomenological approach adopted for this research provides one way of 'accessing reality', as opposed to a positivist reliance on interpretations of quantitative data. While quantitative data may be the basis of 'what questions to ask' (the preliminary research provided one dimension in determining what questions to ask), theory building through case studies grants insight into the research problem and the social environment. From a theoretical perspective, a contribution of the research is to show that while a phenomenological approach dispels the idea of neutrality and unbiased research, "acceptable validity and reliability can be obtained through revealing an inner interpretation of events" (Glaser and Strauss, 1967: 118).

If substantive conclusions reflecting 'reality' are to be drawn from interviews, the researcher must be satisfied that the details and the inferences are indeed genuine observations and a true reflection of a situation. In turn their interpretation must not be influenced by preconceived values, practices and expectations. This requires a balance between closeness to, and intellectual distance from, the case organisations, and becomes more difficult the closer case study research comes to an ethnographical approach. Miller and Glassner (1998: 97) contrast the positivist goal of creating the 'pure' interview, "enacted in a sterilized context ... as a mirror reflection of reality", with social constructionists who claim that "no knowledge about a reality that is 'out there' in the social world can be obtained from an interview". They discount the conclusion that interviews are meaningless beyond the context in which they were conducted, in the belief that through analysis of the interview data, it is possible to learn about the social world beyond the interview context.

Problems with interviews are well documented. Van Maanen (1979) summarises these as follows: (1) Respondents want to mislead the researcher, (2) Respondents themselves are misled and wrong about certain issues, and (3) Respondents are sometimes totally unaware of certain aspects underlying many of their own activities. Clearly, if they want to mislead, the researcher's options are limited to careful preparation and the use of other research methods (triangulation) as aids in detecting possibly devious responses. Van Maanen (1979: 545) comments on genuine misbeliefs by respondents: "It seems almost universally true that the secrets of one group are revealed most readily by members of another group". Relatively large numbers of interviews may reveal inconsistencies, unconscious and unacknowledged conditions, and unintended consequences of actions (Giddens, 1984).

The research for this thesis was conducted in South Africa between 1999 and 2002, a comparably stable period after the turbulent apartheid years and the events following the first democratic elections in South Africa in 1994. The South African business environment nevertheless remains intensely political and a great deal of residual mistrust remains. Access to respondents was not always easy and some individuals were hesitant to participate, and they were on occasions reluctant to be fully open and forthcoming. These issues do not correspond precisely to Van Maanen's concerns, but are important for the researcher as they may not be isolated events and opinions may, in fact, have deeper significance.

Strauss and Corbin (1990: 27) claim that good research should meet the following criteria: "significance, theory-observation, compatibility, generalizability, reproducibility, precision, rigor, verification". It may not be possible for all research to have such foundations, but these factors set standards against which research approaches can be measured.

The importance of validity and reliability arises in all forms of research. Turner (1983) and Miles and Huberman (1984) claim that case studies do not necessarily provide sufficient basis for making general theoretical claims. Saunders et al (1997: 345) contend that rigorous testing of propositions, looking for alternative explanations and seeking to explain why negative cases occur, enable researchers to move towards the development of valid and well-grounded conclusions. Patton (1990: 14) compares validity in quantitative and qualitative research:

> "Validity in quantitative research depends on careful instrument construction to be sure that the instrument measures what it is supposed to measure. In qualitative inquiry, the researcher is the instrument. Validity in qualitative methods, therefore, hinges to a great extent on the skill, competence and rigor of the people doing the fieldwork".

Reliability, validity and generalisability of the interview process are important from an objectivity perspective. A lack of standardisation and data collection procedures question the reliability of the interview process, due to interviewer and interviewee bias. Marshall and Rossman (1989) suggest that because some events are complex and dynamic, findings may not be repeatable as they reflect only what is occurring at one particular point in time. Questions for discussion during interviews will be standardised as far as possible for each level described pertaining to the research questions. Validity requires continuous assessment and reappraisal of assumptions, theories, models, and revised limitations of a study.

More specifically, Steenhuis and de Bruijn (2003: 792) discuss construct and external validity, where the former

> "concerns the establishment of correct operational measures for the concepts being studied. Since much case study research depends on interpretation, there is a probability that the researcher misinterprets the information and hence reaches the wrong conclusions. The key issue for misinterpretations is that the number of units (cases) is smaller than the number of variables".

While it is desirable to make generalisations from research, a limited number of observations may not be a sound basis for generalisation (Gummesson, 1991). This pertains to external validity which establishes "the domain to which a study's findings can be generalised" (Steenhuis and de Bruijn, 2003: 792). Generalising from a specific situation should become "a working hypothesis, not a conclusion" (Cronbach, quoted in Patton, 1980: 280). It is intended that gathering data and information from a wide range of sources will mitigate criticisms of qualitative research. Research results from the main case study describe one parastatal organisation in South Africa. The mini cases investigate smaller organisations, giving a broader perspective of TT.

External validity can be enhanced when case studies results are extended by replication through investigation of other cases (this is the reason for studying the mini cases). McCutcheon and Meredith (1993: 246) caution that

> "this replication logic of using more cases is designed to extend the findings to other groups or settings, not to augment the number of data points to increase the confidence of within-group findings. A multiple-case study should not be misconstrued as a small-sample survey ... (we wish to extend) findings across the entire group but their external validity, the degree to which they apply beyond the group itself, cannot be established without testing other groups ... Generalising a case study's findings to other situations faces the same issues as generalising those from a large-scale survey but we may have more confidence in extrapolating the case study's results if the cases used are maximally different. If patterns are found under extreme conditions, there is greater confidence (based on logic rather than statistical evidence) that resultant theories are broadly applicable".

The researcher thus relies on logical analysis to extrapolate theory to other situations, while ensuring that similar factors should be present in the other situations.

Qualitative research has become more widespread and academically acceptable, although there remains a perception that a qualitative approach is an easier method, that less hard data is required, and that fewer rigorous statistical analyses are necessary. Nevertheless, Van Maanen (1988: 9) supports the qualitative approach as "an array of interpretive techniques which seek to describe, decode, translate and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world".

5.10 TRIANGULATION

The researcher needs to demonstrate through triangulation how the research problem is approached from a number of ways in order to improve the reliability of the results. Multi-methods create 'distance' between research approaches to ensure "methodological redundancy instead of complementarity" (Gummesson, 1991: 122).

The multi-methods will include interviewing individuals at a number of levels in the line hierarchy, as well as policy makers and specialists in staff positions.

Many authors discuss the importance of triangulation. Denzin (1970: 297) defines triangulation as "the combination of methodologies in the study of the same phenomenon". Gill and Johnson (1997) downplay the importance of triangulation in qualitative research, but their view is not accepted throughout the literature. Stake (1995) sees the purpose of triangulation as increasing credence in an interpretation, and demonstrating commonality of an assertion. 'Multi-method' perspectives will thus remain important, whatever the research approach adopted. Triangulation can take several forms (Bryman, 1988; Patton, 1990):

1. Data triangulation involves data collection from several sources, such as from a number of individuals at different levels in the organisation, or outside the organisation. Data collection may occur at a number of locations, and at different times, essentially, to describe a limited series of events.
2. Investigation triangulation indicates the use of a number of different observers to collect data. A range of individuals from different backgrounds, classes, genders, ages, and so on, can be useful in obtaining the broadest possible perspective.
3. Methodological triangulation refers to the use of a number of techniques to research a phenomenon.
4. Theoretical triangulation looks at one phenomenon from a number of different theoretical perspectives.

In this study, triangulation enhances validity by using a number of accounts to explain a series of events, and to assess the extent of mutual confirmation (Bryman, 1988). As shown in the upper part of Figure 5.1, the literature, the preliminary research, and the case studies (main and mini) are the central features of the research. The lower part of Figure 5.1 expands each component. The literature draws from the TT literature (Chapter 2), the maintenance literature (Chapter 3), and publications on South Africa (Chapter 4). The preliminary research uses the importance and control scores presented in Chapter 6, the statistical analysis, and interviews with managers. Data from Eskom (the main case study discussed in Chapter 7) comes from interviews at head office and at four power stations, as well as technology suppliers. The mini cases (Chapter 8) provide data from four organisations, where managerial and supervisory, and operator and maintenance staff were interviewed. This approach concurs with Eisenhardt's (1989: 541) "iterative process ... to compare systematically the emergent frame with the evidence from each case".

5.11 CONCLUSION

This chapter has presented and evaluated a number of methodological research approaches. While the formulation of the research questions defines the broad parameters for the research, the extent to which the literature assists the researcher, the nature of the data obtainable from the case organisations, and the topic itself give further direction to the choice of methodological approach. Chapter 6 details the preliminary research referred to in this chapter. A phenomenological study using case studies points to intensive theory building research. Chapters 7 and 8 describe the selection of the case studies and data collection. Chapter 9 contains the analysis of the data.

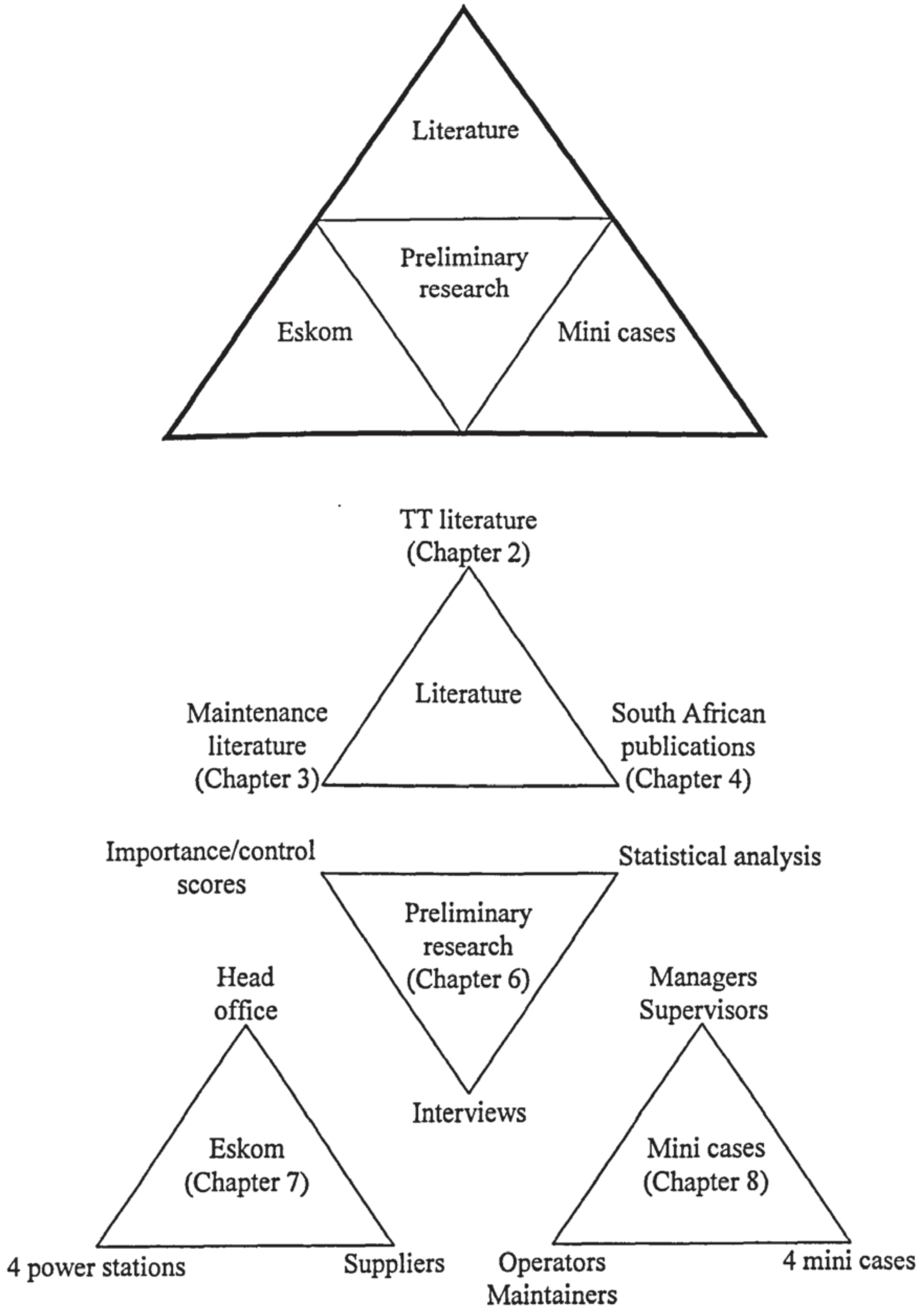

Figure 5.1 Elements of triangulation

CHAPTER 6

EMPIRICAL STUDY OF SOUTH AFRICAN MANAGERS' PERCEPTIONS OF TECHNOLOGY TRANSFER

6.1 INTRODUCTION

A preliminary survey was conducted to provide a basis for the study of TT in the case organisations described in Chapters 7 and 8. Managers were asked to score the importance of items in transferring technology and the extent to which they could control them, both now and in 3 years' time. As this research progressed, preliminary findings were presented at a number of conferences (see Hipkin and Bennett, 2001a, 2001b, 2002a, 2002b, 2003a, 2003b) and the completed research has also been published (Hipkin and Bennett, 2003c).

The approach adopted uses a methodology developed by Naudé et al (1990) where scores relating to TT were plotted on an importance-control grid. Factor analysis was used to group 78 items into 12 factors affecting TT. This chapter gives details of the methodology, the survey sample, the importance-control grid, and the factor analysis of the results. A summary of the interviews held with a sample of managers in order to understand and interpret the quantitative data is also provided.

6.2 THE EMPIRICAL RESEARCH

This preliminary research examines the perceptions of 253 South African managers who were attending business school management development and executive management programmes at the University of Cape Town from 2000-2002. Table 6.1 shows the breakdown of the sample. Although analysis of results by race and gender did not produce statistically significant differences, some comments are attributed to black and white managers in the discussion as these explain differences in viewpoints otherwise disguised by averaged scores.

A total of seven cohorts of managers participated. As the survey progressed, more was learnt about TT, but the same items used were for all groups. The 30 managers attending the first programme were asked to list the issues they felt were important in TT in their organisations. Their responses produced 113 items. Once the author clarified what the managers had wished to convey in naming these, overlapping items were eliminated, resulting in a list of 89 items. Appendix IV contains present and future importance and control average scores for each item. The factor analysis further reduced the 89 items to 78.

Sector		Number of respondents	Percentage
Construction		20	8
Consumer goods manufacture		38	15
Financial institutions		25	10
Heavy manufacturing		53	21
IT		13	5
Mining		25	10
Automotive		20	8
Utilities		18	7
Primary production		28	11
Retailing		13	5
	Black	White	Total
Males	99 (39%)	43 (17%)	142 (56%)
Females	78 (31%)	33 (13%)	111 (44%)

Table 6.1 Breakdown of sample of South African managers, N = 253

The first and subsequent groups of managers were also asked to score how important these items were in managing technology, and to what extent they could control them. The meaning of each item was explained before the scoring process began, to ensure a consistent interpretation of all items. We explained to managers that 'importance' referred to significant issues in the workplace, where poor decision-making, errors and lack of adherence to desired performance requirements might potentially carry serious consequences. 'Control' related to a manager's power to direct, regulate and influence. The scoring was on a Likert scale of 1 (not important/no control) to 5 (most important/much control) for the following criteria:

1. How important this item is now, in so far as it affects TT in your working environment
2. How much control can be exercised over this item now
3. How important this item will be in three years' time
4. How much control can be exercised over this item in three years' time

The managers surveyed were strategically important as they would be in senior positions within a few years. Follow-up interviews of 30 minutes' duration were held with 63 managers in order to clarify emerging results, and to understand and interpret the quantitative data. Eisenhardt (1989: 538) comments on combining qualitative and quantitative evidence: "qualitative data are useful for understanding the relationships revealed in the quantitative data or may suggest directly theory which can then be strengthened by quantitative support". In drawing conclusions from a limited sample, Linz (1988) comments that "sample size is less important than are experience, competency and objectivity of participants". The use of a number of techniques (in this preliminary research, the importance/control scores, the statistical analyses, and the interviews, as shown in Figure 5.1) to research a phenomenon constitutes a form of methodological triangulation (Bryman, 1988; Patton, 1990).

6.3 THE IMPORTANCE-CONTROL GRID

The methodology uses a model of Naudé et al (1990) to relate the importance of different factors in a manager's operational environment to the extent to which a manager is able to control them. While important issues demand managers' attention, Naudé et al (1990) show that, particularly in transitional environments, managers are often unable to control a number of key areas. Using this framework researchers are able to isolate individual issues and study these in relation to the complexity of a manager's environment. By plotting the scores on a grid, the following distinct areas may be identified:

- *core issues*, which managers see as the most important and over which they can exercise the most control; these issues require the greatest management time, effort and planning
- *complex issues*, which are perceived as being important but over which managers can exercise limited control
- *simple issues*, which are of lesser importance and which are easily controlled by management
- *peripheral issues*, which are generally of limited importance and over which little control can be exercised.

The grid provides a visual aid for identifying areas of frustration and ineffectiveness, and can be extended to suggest action for improving integration. The terms 'core', 'complex', 'simple' and 'peripheral' are labels for easy reference to the quadrants. Such labels cannot fully describe all possible combinations of complexity, importance, frustration, control and challenges in managerial decision-making. The importance-control grid is shown in Appendix V, on which the current and future factor scores (see next section) have also been plotted. Using factor analysis on current importance scores[1], items were grouped into 12 factors: technology, economic and political, maintenance, knowledge, people and systems integration, supply chain, strategy, operational management, contractual, high-technology, financial, resistance to change.

6.4 FACTOR ANALYSIS RESULTS

Factor analysis was used to group items into the most significant factors in technology and operations integration. In this paper factors refer to "clusters ... that could be measuring aspects of the same underlying dimension" (Field, 2000: 423). Details of the factor analysis are not shown, but some of the significant findings are summarised below. Using current importance scores, 21 eigenvectors with eigenvalues greater than 1 gave 21 factors that explain 79.9% of the total variance. A scree plot revealed a point of inflexion after 12 factors (with eigenvalues greater than 2, explaining 65% of the variance). Communality values after extraction vary from 0.490 (Robustness of technology: installation without adaptation) to 0.910 (Assimilation of new technology), suggesting that the variance associated with each item has a high common variance.

The rotated component matrix calculations identify 21 factors where variables "load highly onto these components" (Field, 2000: 463). Using Field's criteria for selection and omission of factors, 12 were chosen as the remaining 9 had only one or two associated variables with factor loading scores less than 0.4. Factors, items and loadings

[1] It is recognised that different factor groupings may have resulted from factor analyses performed on the other data sets (present control, future importance, and future control scores). However, analysing four sets of factors would be unwieldy and would add little to the underlying purpose of the factors analysis: to provide a manageable clustering of items.

are shown in Appendix IV. Although respondents scored 89 items, rotated component matrix results excluded 11 of them so 78 of the items are retained for the analysis.

6.5 RESULTS AND DISCUSSION

The statistical results provide a quantitative analysis of the important factors for technology and operations integration. A qualitative dimension was obtained from interviews conducted with 63 managers from the sample in order to explain the positioning of the items and factors on the importance-control grid. The first group of managers listed issues important to them, so it is expected that most factors here would lie on the right hand side of the grid (quadrants 3 and 4). This section discusses those factors that reflect greater degrees of imbalance, and significant differences between present and future scores. Reference is made to factor and item positions, but for the sake of visual clarity, only factor scores have been plotted in Appendix V.

Technology

The factor analysis identifies technology as the factor that explains 9.8% of the total variance. The most important items in this category were better quality through technology, and its complexity. Managers felt that a measure of the success of TT was higher quality since this was one of the main reasons for adopting new technology. Complexity was important because undue complexity caused great difficulties in operating the technology. Managers were not able to exercise much control over the complexity of technology designed abroad. In the future, it would become even more important; yet managers envisaged that they would be able to exercise even less control (future scores place this item in the 'complex' quadrant). Two items (sensitivity of technology in terms of design, fabrication, operations and maintenance; robustness of technology: installation without adaptation) are in the 'complex' quadrant, indicating that managers felt that sensitivity and robustness were important, but that firms were unable to control these items at present, and limited change was envisaged in the future.

Economic and political issues

The literature emphasises the importance of economic and political issues on TT in developing countries. These explained 7.9% of the total variance and received high importance and low control scores, positioning them firmly in the 'complex' quadrant. Such issues are likely to cause the greatest frustration for managers who saw an increase in the importance of these items, but envisaged little additional control in the next 3 years. The scepticism of businesses towards much of the South African government's labour legislation has been widely reported (von Holdt, 2000). There was unanimity from blacks and whites regarding the serious effects of crime in South Africa (this item received the highest importance score, but one of the lowest control scores).

The frustration with economic and political matters (such as pressure from unions, affirmative action and employment equity policies) reflected the different socio-economic perspective between business, workers, and the government whose constituency lies to a large extent with workers and poorer sections of the community. Some white managers complained that affirmative action and employment equity requirements compounded their difficulties in transferring technology. Black managers saw government intervention as an essential component for correcting decades of discrimination. The poorly educated South African workforce was of concern to all managers who predicted more acute shortages of skilled staff in the future. Black managers suggested that some control of this factor was possible through better schooling, bursaries, and education programmes funded by business, particularly as the legacy of 'apartheid education' worked its way out of the education system.

Maintenance

Maintenance was one of the most important components in TT, explaining 7.9% of the total variance. Availability and reliability were achieved through correct operating practices and good maintenance, and there was a close relationship between safety and maintenance. Managers experienced control difficulties with three items that lay in the 'complex' quadrant: spares availability, the cost effectiveness of maintenance, and the problems of 'burn-in' of new technology whereby considerable time elapsed for new equipment to settle in, or for operators to master the technology. This is illustrated in Figure 6.1, which forms part of Figure 3.7. Future control scores for these items would increase marginally as managers recognised that correct installation, operating and maintenance should ideally reduce the 'burn-in' period, as indicated by the dotted line.

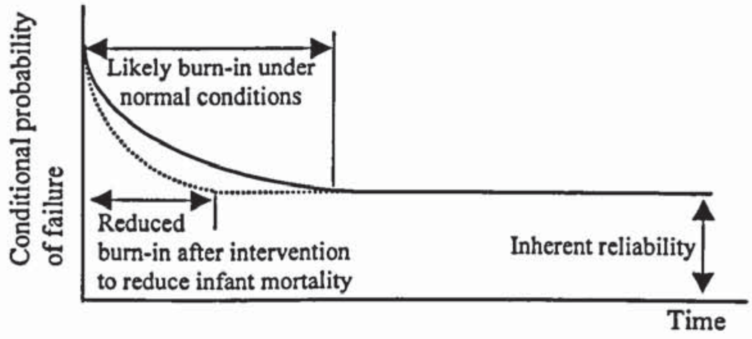

Figure 6.1 Failure pattern showing 'burn-in'

Another important item is the determination of maintenance tasks and maintenance intervals. Managers felt that with poor operational understanding of the technology and inadequate back up from suppliers, this would remain a significant obstacle to TT. Several managers clearly saw that extending learning and knowledge concepts to maintenance would improve the performance of equipment and reduce the effects of failure. The interviews revealed that many managers were unaware of the importance of knowledge in a maintenance context. Because failure data records were of limited use, the scope for effective maintenance action was restricted. Future maintenance control scores were somewhat higher than current scores, suggesting an improvement in maintenance performance provided management information systems addressed uncertainties confronting the maintenance function.

Knowledge

Managers explained that a major difficulty in transferring technology was a lack of understanding of new technology. Most managers advocated training courses for achieving this. All knowledge items lie in the 'core' quadrant apart from diffusion of intangible knowledge, a task that could not be achieved by training. Most respondents gave South Africa's poorly educated labour force and weak education systems as further reasons for not being able to create a learning organisation. Several respondents saw that competent middle managers were an essential interface between operations, maintenance and engineering functions, yet recent downsizing exercises and resignations had reduced their number, and diminished the extent to which learning in the organisation could be expanded. Suppliers were criticised for providing insufficient failure data. Managers ascribed failures and low availability of equipment to inadequate maintenance knowledge, and in turn charged that suppliers' suggested maintenance and recommended spares holding did not take into account local operating conditions.

People and systems integration

This factor included a number of technical and human resource items. Importance scores were among the highest, as they emphasised the necessity for integrating new and existing systems, and providing support for new technology and operator training. Shortages of skilled personnel received the lowest control score, as highly qualified technicians were extremely difficult to recruit. This was exacerbated by the shortages of skilled personnel suffered by local representatives or agencies of foreign technology suppliers, and because the limited exposure to high-technology equipment by many employees necessitated a long training processes. These would remain significant barriers to TT, which was further impeded when senior managers did not clarify the rationale for adopting new technology or demonstrate their commitment to operationalising the technology.

Supply chain

Present scores show that supply chain issues were amongst the least important and managers did not perceive that they could exercise much control over these. Managers envisaged a significant change in the future as supply chains and networking became integral parts of their businesses. They recognised that they would remain dependent on imported technology, necessitating long-term relationships with technology suppliers. The only item lying outside the 'core' quadrant was the expertise of international suppliers, about which managers could do little, other than choose different suppliers should a supplier not have the relevant expertise. Local sourcing would become less important, supporting managers' contentions that globalisation had spelt the end of protectionism of local industry. The reason for the low importance of supply chain management was that for decades sanctions had prevented South African firms from doing business in many parts of the world. An inward-looking self-sufficient mentality also had to change as managers recognised the importance of good relationships with suppliers for solving operational difficulties. Use of the internet and dependence on suppliers for technical assistance would be increasingly significant in the future.

Strategy

Alignment of business goals, systems and technology received the highest future importance score under this factor. All items (apart from global markets) lie in the 'core' quadrant, indicating the managers' beliefs that technology played an important role in strategy formulation. Lower control scores were ascribed to operational difficulties with new technology. Managers envisaged a significant increase in the importance of strategic items in the future, and control would be enhanced.

Operational Management

The items under this heading included human resource and technical issues. Lack of labour commitment and productivity was the only item currently in the 'complex' quadrant, indicating its importance, but managerial perceptions of this item differed. White managers complained of poor commitment and negative attitudes of many workers; black managers condemned deficient management practices and discriminatory policies in the past. Poor education and historical prejudices were formidable barriers to overcome. Transfer of systems, managerial philosophy and values were important items which managers would increasingly be able to control as staff accepted responsibility and technical knowledge was assimilated. Managers felt that the current emphasis on short-term operational returns from technology would decrease as executives realised that cost-benefit analyses for new technology justification were of limited value.

Contractual

Because relationships with suppliers were to a large extent set in a confrontational, legalistic mindset, managers did not conduct their operations along co-operative supply chain lines. Contractual issues were deemed important, and would become even more so in the future. The emphasis appeared to be on ensuring contractually bound assistance and support, rather than forming relationships with suppliers. Some managers explained this by pointing to the high staff turnover they experienced, as a result of skilled staff emigrating, and qualified black employees being lured away by other higher-paying companies.

High-technology issues

The factor analysis distinguished three items under this heading from other technology-related items. The present scores placed them on or close to the importance-control grid diagonal. Importance scores were amongst the lowest, suggesting that expert systems, the novelty of new technology and process optimisation were not central to TT. Future importance scores increased, but managers did not feel their control would change much, as the degree to which these issues arose depended on the technology selected.

Financial

The present and future importance scores for financial items were consistently high. Low control scores showed that finance was a 'complex' issue. Frustration from the inability to do anything about the cost of imported technology was aggravated by a declining currency. The future control score was higher as respondents felt that greater choices of technology would permit multi-sourcing of new technology. Through a greater understanding of the technology, managers felt they would better be able to control the hidden costs of technology implementation.

Resistance

Two items appear under this heading, each with low importance and high control scores, placing them in the 'simple' quadrant. Managers paid little heed to these in practice, as none of the interviewees had encountered serious resistance to new technology.

HIV/Aids

Managers scored HIV/Aids as extremely important (a score of 5), but gave a low control score of 1. This does not appear in Appendix IV as low correlations in the factor analysis eliminated this item. Managers felt they could do little about aids-related illness and death, but Aids was having a significant impact on succession planning and training. One manager claimed that for every craftsman or skilled operator that was required, three were trained. The South African Medical Research Council (Dorrington et al, 2001) reported that in 2000 40% of all deaths in the age group 15-49 were Aids related, and this is precisely the age group from which employees were drawn.

Summary of empirical study

The statistical results support the sentiments expressed in the interviews and the findings from the importance-control grid plots. While the importance-control framework provides no formal ranking of the factors, the factor analysis provides a useful summary of the most significant issues in TT. The factor in Appendix IV labelled 'Technology' is the most significant, explaining 9.8% of the total variance, followed by 'Economic/political' (explaining 7.9% of the variance), and so on. The last three factors (high-technology issues, financial and resistance to change) in total accounted for 6.9% of the variance.

Appendix IV also contains z-scores for testing whether the differences between present and future importance scores, and present and future control scores are statistically significant. The z-scores in italics (less than 1.645) indicate that for $\alpha = 0.05$ there is no significant difference. There is no clear pattern to indicate which items are significant, but 50 out of 78 importance scores, and 60 out of 78 control scores demonstrate a significant difference between present and future scores.

6.6 CONCLUSION

An understanding of TT in South Africa was sought from this empirical research, and the findings are only directly relevant to South Africa. Technology is not greatly driven at a strategic level or aligned with corporate goals. It essentially enhances competitive advantage by supporting internal capabilities (Leonard-Barton and Deschamps, 1988; Martinsons and Schindler, 1995). The results further support authors such as Burcher et al (1999) and Grant and Gregory (1997) that TT requires integration of systems and human resources with the technology.

As explained in Chapter 5, the items identified by this preliminary research were used in conjunction with the elements in the Salami and Reavill framework to structure the interviews. Each item in Appendix IV was allocated to a level in the framework, as shown in the second column under the heading 'S&R level'.

CHAPTER 7

DETAILS OF TECHNOLOGY TRANSFER AT ESKOM

7.1 INTRODUCTION

Eskom is a technology leader in South Africa with investment in technical research and development projects amounting to R325 million in 2002 (1.2% of total revenue). It is estimated that in 2002 research provided a return of 5:1 in terms of avoided costs and direct cost reduction, and extensive non-quantifiable benefits were attained in social, environmental and customer satisfaction (Eskom Annual Report, 2002). Eskom's research covers a broad range of activities, such as wind, solar, biomass and nuclear generation. However, base load for South Africa's generation will come from coal fired power stations for many years. For this reason, this thesis has investigated technology and its transfer at these power stations.

Eskom was selected as the main case study for the research, so this chapter provides background information on Eskom, and current restructuring deliberations on energy policy in South Africa, and then presents the structure of the interviews with Eskom's head office and power stations on technology transfer. The interviews were structured around two sets of questions:

- the framework by Salami and Reavill (1997), shown in Appendix II
- the preliminary studies of South African managers' perceptions of TT (discussed in Chapter 6, with quantitative results in Appendix IV).

7.2 ESKOM AND THE ELECTRICITY INDUSTRY IN SOUTH AFRICA

In many respects Eskom is the electricity industry in South Africa. It generates 95.6% of the country's electricity, private generators account for 3.1% and municipalities produce 1.3%. Eskom also generates more than 50% of Africa's electricity (National Electricity Regulator (NER), 2001). The organisation was established as the state-owned electricity utility in 1923. Its first power station was commissioned in 1925, and from 1927 it took over the power stations of the Victoria Falls Power Company. While its management has not always been as directly politically infiltrated as other state organisations, during important periods of its existence the government appointed its chairmen. This resulted in Eskom's adherence to the policies of the government of the time, with the associated political ramifications. Since the 1994 democratic elections in South Africa Eskom has been a leading proponent of the present government's affirmative action and employment equity policies.

The Eskom Conversion Act of 2001 provided for the conversion of Eskom into a public company, Eskom Holdings Limited, with the South African government as the sole shareholder, and a board of directors. Eskom's strategic intent and policy documents have important implications for the way in which the organisation will operate in the future. The Eskom Annual Report (2002) publishes these as follows:

- Eskom is proud of being an African business
- Eskom will run as a global business
- Eskom will promote economic growth in South Africa and Africa through active contributions to the New Programme for African Development (NEPAD)
- Eskom will move into energy related products and services
- Eskom will form joint venture partnerships to augment skills and open up new markets
- These intentions rest on several key strategies
  - Advancing Eskom's role as the leading electricity supplier in Africa
  - Expanding Eskom's business reach through e-business
  - Partnering South Africa into Africa

Diversification will take place through Eskom Enterprises comprising:

- The development, operation and maintenance of infrastructure in the energy and telecommunication sectors
- The provision of contracted R&D, utility management and consulting services
- Investment in the creation or acquisition of assets and business ventures in the energy generation and transmission fields, in telecommunication and information technology
- Extracting or refining primary energy sources prior to conversion into secondary energy forms such as electricity

The National Electricity Regulator provides the following aims for the sector:

- The establishment and operation of an effective and efficient rationalised, viable electricity supply industry
- Eliminating monopolies in the generation and sales/supply sector
- Rationalising end-use prices and tariffs
- Giving customers the right to choose their electricity supplier

- Creating an electricity market
- Introducing competition into the industry, especially the generation sector
- Addressing the impact of generation, transmission and distribution on the environment
- Permitting open, non-discriminatory access to the transmission system
- Levelling the playing fields between distributors of electricity
- Encouraging private sector participation in the industry

Eskom's power stations have a generating capacity of 32 974 MW, shown in Table 7.1.

Name of station	Number of generating sets and nominal MW rating	Current available MW	Number and MW rating of generators in reserve storage
COAL FIRED			
Arnot	6 x 350 = 2 100	4 x 330 = 1 320	2 x 330 = 660
Camden	8 x 200 = 1 600		8 x 190 = 1 520
Duvha	6 x 600 = 3 600	6 x 575 = 3 450	
Grootvlei	6 x 200 = 1 200		6 x 188 = 1 130
Hendrina	10 x 200 = 2 000	10 x 190 = 1 900	
Kendal	6 x 686 = 4 116	6 x 640 = 3 840	
Komati	5 x 100 = 500		5 x 95 = 475
	4 x 125 = 500		4 x 104 = 418
Kriel	6 x 500 = 3 000	6 x 475 = 2 850	
Lethabo	6 x 618 = 3 708	6 x 593 = 3 558	
Majuba	2 x 657 = 1 314	2 x 612 = 1 224	
Matimba	6 x 665 = 3 990	6 x 615 = 3 690	
Matla	6 x 600 = 3 600	6 x 575 = 3 450	
Tutuka	6 x 609 = 3 654	6 x 585 = 3 510	
Total coal fired		**28 792**	
GAS FIRED			
Acacia	3 x 57 = 171	3 x 57 = 171	
Port Rex	3 x 57 = 171	3 x 57 = 171	
Total gas fired	**342**	**342**	
HYDRO ELECTRIC			
Gariep	4 x 90 = 360	4 x 90 = 360	
Vanderkloof	2 x 120 = 240	2 x 120 = 240	
Total hydro electric	**600**	**600**	
PUMPED STORAGE			
Drakensberg	4 x 250 = 1 000	4 x 250 = 1 000	
Palmiet	2 x 200 = 400	2 x 200 = 400	
Total pumped storage	1 400	1 400	
NUCLEAR			
Koeberg	2 x 965 = 1 930	2 x 920 = 1 840	
TOTAL		**32 974**	

Source: Eskom Annual Report (2002)

Table 7.1 Eskom power stations and generating capacity

As a result of an ambitious expansion programme in the 1980s and 1990s Eskom has surplus generating capacity, and certain older power stations have been 'moth-balled' by placing them into reserve storage. Projects are currently underway to return these to service as part of a number of black empowerment partnerships.

Eskom is also investigating alternative sources of energy. It has a share in the pebble-bed modular reactor (PBMR), with the South African Industrial Development Corporation (25%) and British Nuclear Fuels (22.5%). This presents an interesting instance of technology transfer, as some of the technology is licensed from the German company HTB GmbH, and some developed by Eskom itself. The idea is to construct modular units of 110-125 MW. The South African National Nuclear Regulator has approved the safety case for the PBMR. Approval is awaited from the National Electricity Regulator and the Department of Environmental Affairs and Tourism. If approval is granted, construction on the pilot plant is scheduled for 2004. Eskom is due to purchase the first 10 units, with the US and China expressing strong interest.

The environment-impact assessment (EIA) and feasibility study for Eskom's solar generation project comprises testing of a 100MW demonstration solar thermal electric (STE) plant, at a cost of R2.2bn ($200m). Part of this cost is attributable to unique technology and components, none of which are mass-produced at this stage.

Table 7.1 shows that the majority of electricity is generated from coal (87%). Certain municipalities (Johannesburg, Cape Town, Pretoria and Bloemfontein) have their own power stations and major distribution networks. The Johannesburg metropolitan authority distributes electricity to 5 000 industrial customers, 12 500 commercial customers, and 230 000 residential customers. Municipal infrastructures (such as electricity, water and recreational facilities) favoured the former white areas, but these are in urgent need of upgrading and maintenance (Engineering News, 2002). Municipalities have recently merged so further difficulties are experienced with integrating electrical metering and reticulation systems.

Electricity distribution restructuring has been approved, with the establishment of six state-owned regional electricity distributors (Reds) in 2002/2003. These will effectively consolidate 500 distributors. Municipalities in rural areas have little or no infrastructure, inadequate budgets, and untrained human resources to provide electricity. Certain municipalities are unable to pay Eskom for electricity, either because income received from residents for electricity has been used for other items, or because the culture of non-payment for electricity in some communities has meant that the municipalities receive no income from electricity sales. The creation of Reds would deprive some municipalities of a substantial proportion of their overall income (up to 40% from electricity sales in certain cases). The government claims that the electrification process remains a social issue, the execution of which will not burden the Reds, but their policies will be guided by the electrification objectives of the government (Engineering News, 2002).

Responsibility for electricity supply performance lies with the transmission service provider (currently this is Eskom, apart from some transmission functions undertaken by municipalities) through contracts with various parties, as illustrated in Figure 7.1. PQ refers to power quality which is a measure of 'quality' in electrical supply.

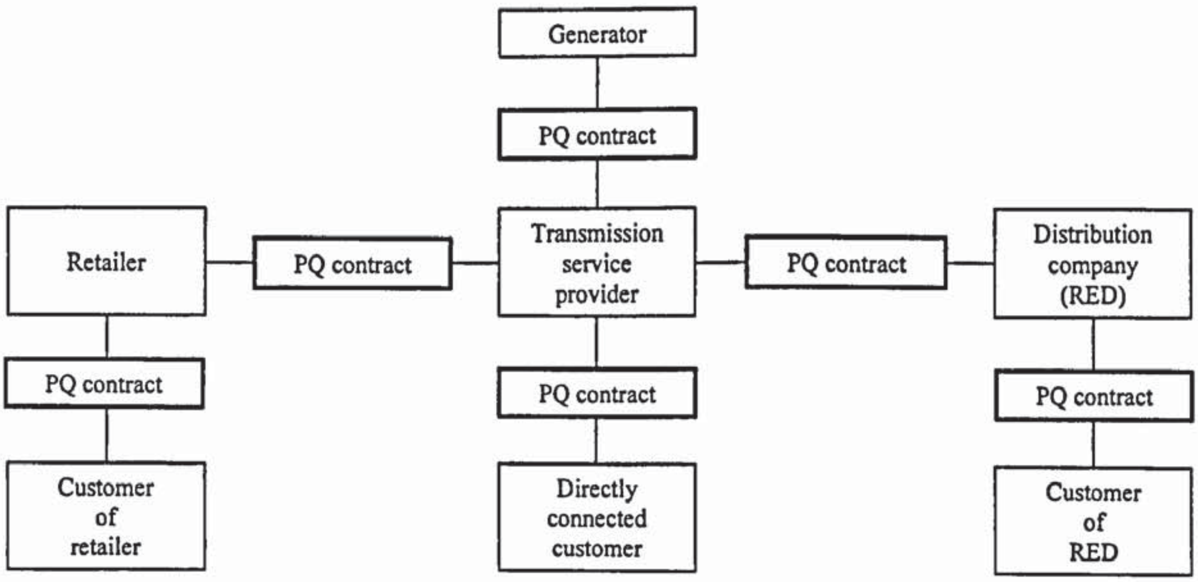

Figure 7.1 Power quality contracts to be implemented by the transmission service provider

7.3 PERFORMANCE AND POWER QUALITY

The breakdown of generation expenditure is shown in Figure 7.2 for 1999/2000 (NER, 2001). Apart from energy costs, which are beyond the generators' control, severe cost control measures have resulted in modest cost increases in other areas. Performance figures have improved over the years, as illustrated in Figures 7.3 (Transmission system interruption[1]) and 7.4 (Generation low frequency incidents) (NER, 2001).

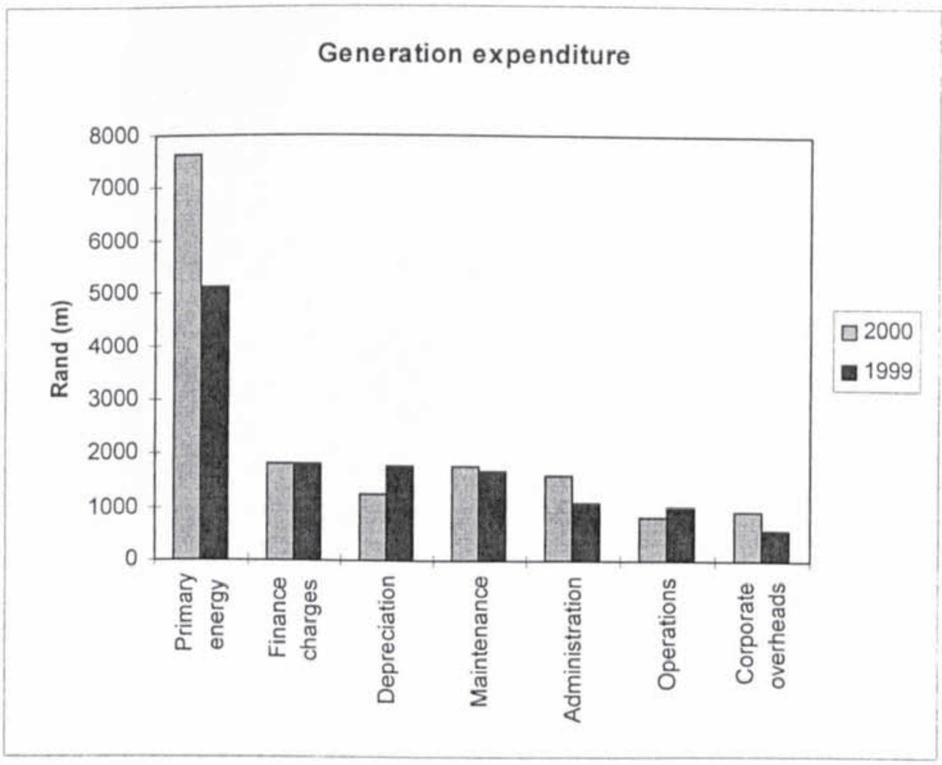

Figure 7.2 Generation expenditure (1999 and 2000)

The categories of power quality are shown in Table 7.2.

Voltage waveform quality	Voltage events
Voltage distortion (harmonics)	Voltage depression < 3 sec (dip or "sag")
Voltage imbalance (unbalance)	Voltage interruption
Voltage magnitude (regulation)	Rapid voltage changes
Voltage fluctuation/modulation (flicker)	

Table 7.2 Categories of power quality parameters

[1] The transmission system interruption index measures the duration and amount of consumer load interrupted (MWh), and this is expressed in terms of the duration of the peak system demand. During 2000 the energy not supplied amounted to 4.1 minutes of peak demand. A 30 minute interruption to a large city or industrial area with 1 000MW demand will add 1 system minute to the index.

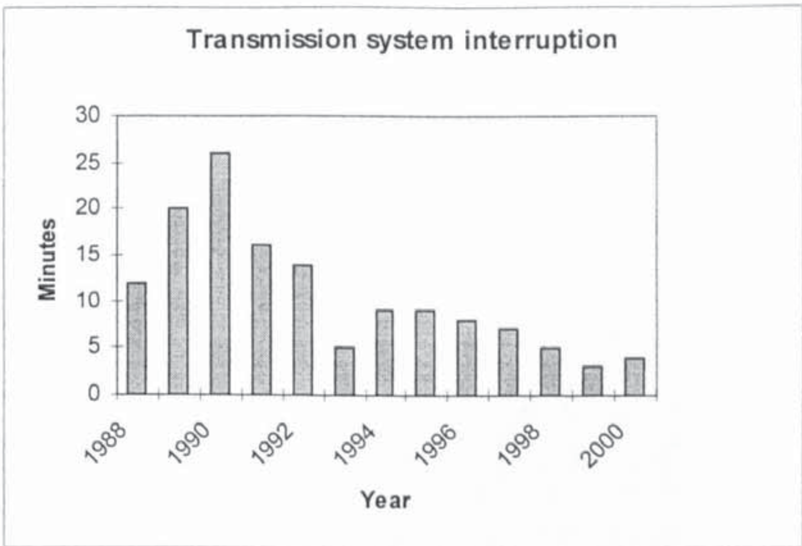

Figure 7.3 Transmission system interruption

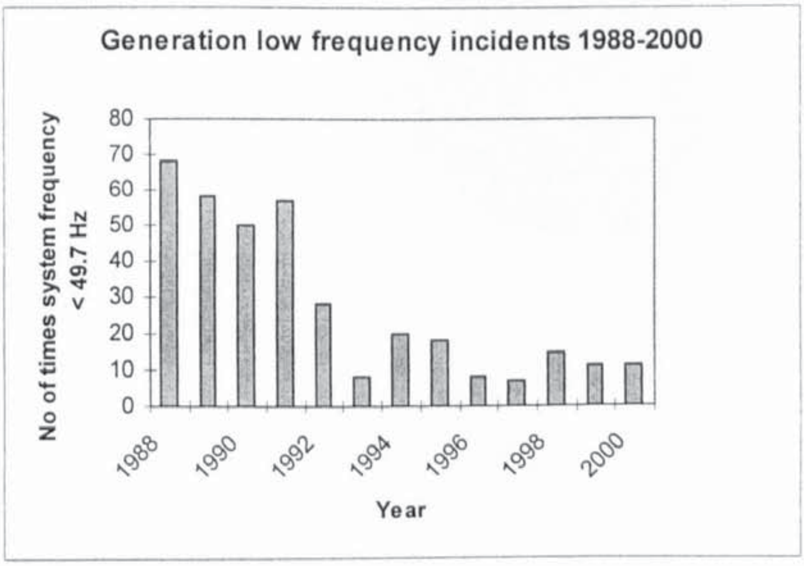

Figure 7.4 Generation low frequency incidents

7.4 PROJECT MANAGEMENT AND TECHNOLOGY IN POWER STATIONS

Eskom's technology strategies are determined at head office, where new projects are investigated, and feasibility and preliminary designs undertaken in accordance with Eskom's policies. The installation of equipment and systems in power stations takes place in a number of circumstances, so technology is transferred under different conditions. A new power station follows one process, and modifications to existing plant, equipment and systems proceed in other ways, depending on how and where the changes are initiated.

A large coal fired power station can take 10-13 years from initial conception to final commissioning. All units[2] are broadly similar, although contracts for a 6 unit power station are usually awarded in two stages: units 1-3 and units 4-6. This does permit some changes in designs and specification, but Eskom's levels of influence decrease significantly once the first set of contracts has been awarded. Figure 7.5 illustrates conceptually the decreasing influence of designers as a new power station project progresses.

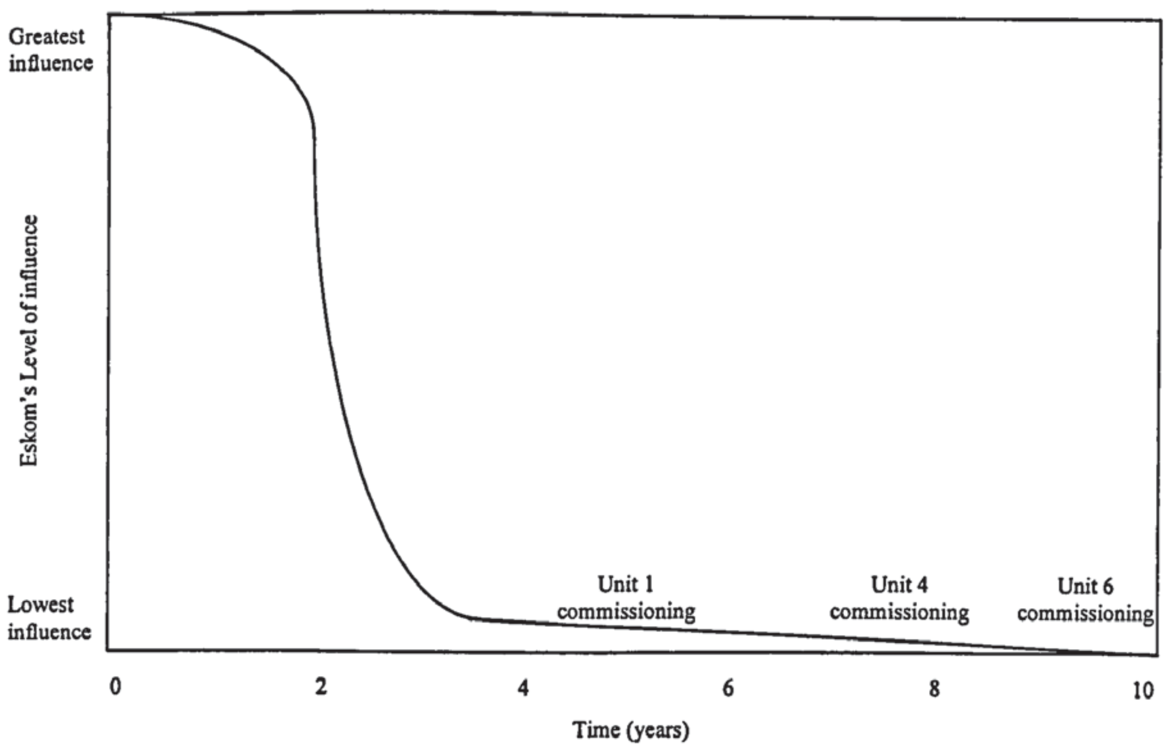

Figure 7.5 Conceptual decrease in level of influence of designers with time

- New power station projects

Teams at head office in Johannesburg (Megawatt Park) determine specifications, manage the tendering process, and sign contracts for new power station projects. An

[2] The term 'unit' refers to a boiler-turbine unit and all associated plant.

engineering design and construction department provides the project management services both at head office and for construction, installation and commissioning at site. Units are then handed over to operations at this stage. Various feedback mechanisms exist, as shown in Figure 7.6.

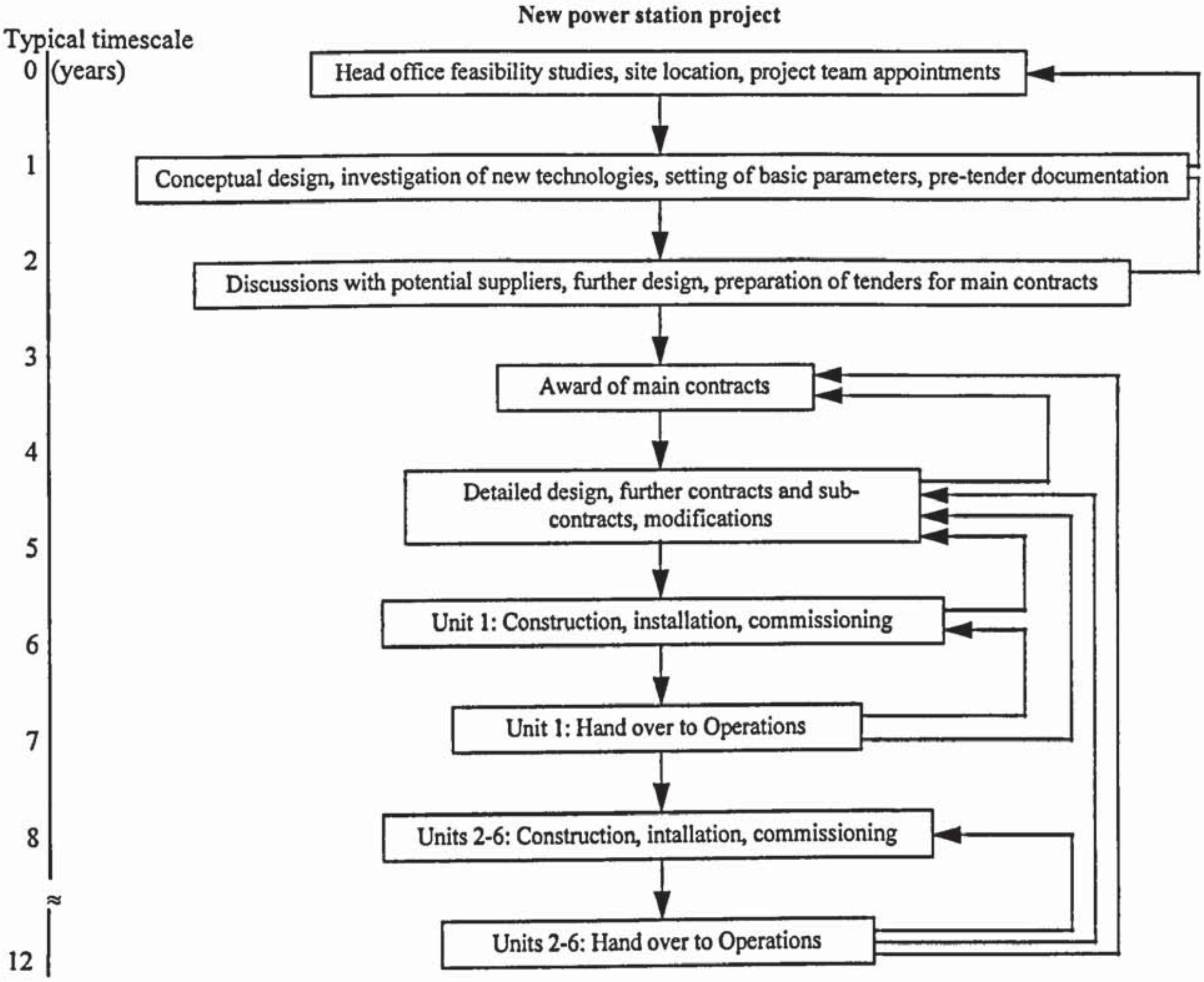

Figure 7.6 Outline of power station construction project

Technological considerations enter the cycle in a number of places. At the conceptual stage, certain basic considerations are discussed. As an example, water shortages in South Africa favour the use of dry cooling. A decision on dry cooling will have a major impact on all main contracts, from the civil specifications to the boiler, turbine and associated plant contracts. Investigations by head office staff of technological alternatives are investigated and detailed discussions are held with potential suppliers before contract documentation is prepared. Once the main contracts (such as the coal mine contract, and civil, boiler, turbine contracts) are awarded, further detailed investigations of technologies are carried out. The contractors determine much of the technology for the boilers and turbines, within contract parameters.

When construction and installation commence, the process of technology implementation is set in motion. Eskom engineering site construction staff are responsible for monitoring installation, commissioning and taking over plant from the contractor. While an understanding of the technology is naturally desirable, their task is essentially to ensure compliance with the contract. Operating during this stage is done by the technology supplier, with Eskom operations staff in attendance. The next step involves the handover of all plant to Eskom operations staff who then run and maintain the completed power station. Transfer of technology should take place at this point.

While senior power station operations staff are appointed several years before initial commissioning, their role in technology selection is limited. They are largely bound to accept technology specified by Eskom head office design teams and provided by technology suppliers. The power station management team is responsible for setting up the functions that will operate and maintain the power station, and provide administration and support.

- Modifications to existing plant, equipment and systems

The first units of Eskom's older running power stations were commissioned in the 1970s and 1980s (Hendrina, Arnot, Kriel, Matla and Duvha Power Stations). The next stage of construction, ending in the 1990s comprised Eskom's largest power stations (Tutuka, Lethabo, Matimba and Kendal). Another is still under construction (Majuba), and some moth-balled power stations are being upgraded for a return to service. The initial process of TT to the older stations should have taken place decades ago. From the interviews it will be seen that there is still much to be learnt at the older power stations, but a new dimension to TT is added with each modification. A modification arises from several sources. Operating difficulties and failures experienced since commissioning are frequently addressed through redesigns. One power station manager suggested that about one third of failures result from deficient designs.

Head office also proposes changes to existing systems on the basis of broader operating experience at a number of power stations, or because of statutory or safety related issues. Technology suppliers also recommend modifications as a result of their worldwide experience. Whatever the reason for changes, a certain degree of TT will be required. Eskom staff tend to refer to technology suppliers or owners as 'contractors', so the terms 'supplier', 'owner' and 'contractor' will be used interchangeably.

7.5 STRUCTURE OF INTERVIEWS

The process of studying TT in Eskom's power stations was predominantly through interviews with head office and power station staff. The 5 levels in the Salami and Reavill framework apply to different levels of decision making. In the Eskom environment, the levels relate approximately to the categories of staff in Table 7.3.

Level	Description (Salami and Reavill)	Location and category of staff in Eskom	
1	Decision for selecting technology	Head office:	strategic
2	Analysis and survey of technology	Head office:	strategic engineering departments
3	Selecting technology	Head office: Power stations:	engineering departments management
4	Implementation and maintenance	Power stations:	management and supervisory
5	Evaluation and modification	Power stations:	management and supervisory operational (operations/maintenance)

Table 7.3 Levels in Salami and Reavill framework and categories of staff at Eskom

A matrix template was derived to summarise the interviews, with the relevant preliminary research items (in the first column) discussed under each research question (the headings of columns 2, 3 and 4). The matrix containing Level 1 items only is illustrated in Table 7.4. Where appropriate a brief comment in a cell indicates the nature of the relationship between the elements in Salami and Reavill's model component and an item from the preliminary research. Fuller details of interviews are presented in Appendix VI.

Items from the preliminary survey | *From subsidiary research question based on Salami and Reavill* | *From main research question based on Salami and Reavill* | *From subsidiary research questions based on Salami and Reavill*

Level 1	Decision for selecting technology			
	1. Identification of needs and demands of acquiring country	2. Identification of limitations, advantages and disadvantages of needs and demands	3. Identification of important macro and micro human factors for use of new technology	4. Identification of acquirer's goals and objectives
ECONOMIC/POLITICAL				
Crime levels in South Africa				
Low educational levels of labour				
Effects of globalisation				
Overall level of economic development and infrastructure				
General conditions in a developing country				
Government regulations and bureaucracy (planning permission, work permits, etc.)				
STRATEGY				
Statement of clear objectives to be achieved by new technology				
Technology implemented because of market demand (demand-pull)				
Technology as strategic resource for competitive advantage				
Technology to assist in shift from product to process base				
New business climate (global markets)				
Alignment of business goals, systems and technology				

Table 7.4 Matrix template for interviews showing elements from Salami and Reavill model and items from preliminary research (Level 1)

Levels 1 and 2 are only considered at head office since power station staff have little, if any, influence over the issues at these levels. Decisions at level 3 are taken at head office, although power station managers contribute on the basis of their more immediate experience and the direct impact of these decisions on operations. Power station managers and supervisors take decisions at levels 4 and 5. Elements at level 5 apply to mainly operations and maintenance staff.

7.6 HEAD OFFICE INTERVIEWS

The number of head office staff interviewed was as follows:

Power station project managers	2
Procurement specialists	2
Senior engineers	4
Human resources manager	1

7.7 POWER STATION INTERVIEWS

This section provides background details of the power stations that were studied. Many respondents at power stations did not want to be named, and in some cases did not want their power station to be mentioned. In order to respect this, power stations and individual respondents have not been specifically given. Further, generating capacities, specific or unique technologies, and suppliers at the power stations have not been mentioned as these could easily identify the power stations. A further issue raised by some managers was that placing technical and operational details in the public domain was inadvisable at a time of significant organisational change and the possible privatisation of Eskom's generation plants. Comments have therefore been attributed to three levels: managers, supervisors/foremen, and operators and maintenance craftsmen.

The management structure of all power stations is essentially the same: a power station manager and a senior team comprising operations (production), maintenance, resources, and other functions including outage management and performance monitoring. Each boiler-turbine unit operates a multi-shift operation with senior shift supervisors, unit shift supervisors and several levels of plant operators. The maintenance function has three sections: mechanical, electrical, and control and instrumentation, which have a number of supervisory and engineering assistant staff, technicians, craftsmen, and labour assistants. Power stations typically employ around 800 staff. Electrical protection and test staff form an additional, more independent team. Eskom has a central maintenance function, Roteck that performs specialised work at all power stations. Power stations are based in geographical regions that co-ordinate certain functions and provide technical advice and administrative support.

Power station managers have little say in choosing technology. Where Eskom does specify technology, decisions pertaining to appropriate levels of complexity and robustness are taken at head office. Power station managers are involved with how technology is transferred from owner to acquirer. Several managers believed this was an area that needed considerable attention as equipment was installed, commissioned and handed over to operating staff without adequate transfer of technology: training was invaluable in enabling operators to run the plant, but TT needed to address the transfer of explicit and tacit knowledge.

A number of interviews were held with suppliers of technology. These were fortuitous in that some suppliers were on site at the time of the power station interviews. Off-site interviews were also held with four suppliers. Mention is made of these in the discussion that follows. Interviews were conducted with whites in English or Afrikaans, depending on the language preference of the interviewee. Interviews with blacks were in English or Afrikaans, or if they preferred, in Sesotho and, in some instances, in Zulu. Technical terms in these languages are not usually used, or are unduly complex and frequently not understood by native speakers themselves so English words were used. The power stations are referred to as PSW, PSX, PSY, and PSZ.

It became clear that few respondents related to the concepts of technology and technology transfer. They were quite willing to recount stories and describe events, but they were unable to interpret incidents in terms of technology: they spoke about machines and the ability to maintain them, rather than technology and its transfer through knowledge and understanding.

Access was difficult at lower levels at certain power stations as operators and maintenance staff were either reluctant to discuss work related matters, or they wished to obtain their union's approval before agreeing to be interviewed. Table 7.4 gives the number of respondents interviewed at each power station.

Level in the Salami and Reavill model		PSW	PSX	PSY	PSZ
Level 3:	Power station senior and middle management	4	4	3	2
Level 4:	Supervisors	5	6	4	4^w
Level 5:	Maintenance craftsmen	4^w	4	5	2
	Operations staff	2^b	3	1^w	2^w
Technology owners (suppliers)		3	1	2	-

^{w} denotes white respondents, ^{b} denotes black respondents

Table 7.5 Number of respondents interviewed at power stations

Power station PSW was completed in the 1980s. At the time of its construction a significant amount of technology was introduced that was new to Eskom. Although its units have been in service for twenty years, managers and supervisory staff indicated that there were still areas of plant where they had still not mastered the technology, and technology owners were called upon for assistance.

Power station PSX is one of Eskom's newer power stations, whose sixth unit was completed in the 1990s. In order to speed up its power station construction programme, Eskom replicated and adapted its earlier (1980) power station specifications. Operating and maintenance staff who had been transferred from certain older power stations were thus familiar with much of the technology installed.

Power station PSY was constructed during Eskom's expansion period in the 1980s and 1990s. Its technology is essentially the same as the other power stations, and some equipment was provided by the same suppliers.

Power station PSZ is one of Eskom's older power stations, completed in the 1980s. The TT discussions related one particular event. A significant upgrade of a boiler control system had been undertaken, and this case addresses the introduction of a new system requiring the transfer of a technology that was new to most operations and maintenance staff. The structure of the interviews was similar to that of the other power stations, although not all items were applicable, and only one technology supplier was involved.

The power station's original boiler control system was never considered entirely satisfactory. Head office engineers and the initial control system supplier claimed that operators were not fully able to operate the boilers, but this charge was rejected by power station staff as the boilers should have been able to operate automatically under normal conditions. Automated start-up and shutdown had never functioned as intended.

Power station management perceived a lack of head office interest in modifying the existing boiler control system, because head office engineers were fully occupied with six new power station projects, and power station PSZ had been handed over to Eskom's generation undertaking some years before. There was also an element of internal politics whereby head office staff did not want to antagonise the original boiler control system supplier, as this supplier was working closely with head office staff on new power stations. PSZ management were obliged to do much of the design work and project management for the new control system themselves. The supplier of this system was not interviewed.

7.8 SUMMARY OF ESKOM INTERVIEWS

Details of the head office and power station interviews appear in Appendix VI. Table 7.5 summarises the interviews. For each level in Salami and Reavill's model four elements are shown in the top rows. The second component, derived from the preliminary research, provides the items identified in the left hand columns of the tables. Where appropriate a brief comment in a cell indicates that the interviews revealed a relationship between the elements in Salami and Reavill's model and an item from the preliminary research.

Level 1	**Decision for selecting technology**			
	1. Identification of needs and demands of acquiring country	2. Identification of limitations, advantages and disadvantages of needs and demands	3. Identification of important macro and micro human factors for use of new technology	4. Identification of acquirer's goals and objectives
ECONOMIC/POLITICAL				
Crime levels in South Africa	Of great importance to the country, but does not affect technology decisions significantly	Crime does not directly affect needs and demands	Emigration of skilled personnel as a result of crime affects Eskom and SA generally	Crime does not affect Eskom's goals and objectives
Low educational levels of labour	A great problem for operations and maintenance at power stations. Shortage of skilled staff at head office	Poor education levels not considered in technology selection, but the operation of the technology may not be as good	Eskom spends large amounts in educating and training the workforce, because of poor school education, and affirmative action	Goals and objectives are not influenced by educational crisis in SA, but achieving goals rendered more difficult
Effects of globalisation	Globalisation has no great effect on power station projects	Globalisation does not limit demands	Globalisation broadens scope of potential technology suppliers	In a coal fired power station context, globalisation does not affect goals and objectives
Overall level of economic development and infrastructure	Eskom is obliged to acquire much of its high-tech equipment and systems abroad because of SA's relatively low level manufacturing capabilities	SA's relatively low growth rate has reduced electricity demand, although expansion into Africa will increase demand somewhat	Poor education, low productivity and limited experience with high-tech systems in SA means that new technology is not always fully utilised	Eskom's strategic thinking in terms of expanding the electricity network in SA and beyond requires additional infrastructure
General conditions in a developing country	Expanding electricity distribution will increase demand, but poor households can only afford to use electricity sparingly	SA's position as a developing country does not affect technology decisions	Poor levels of education, inadequate operating and maintenance skills may reduce effectiveness of new technology	Eskom specifies the best technology it can afford, without considering SA's attributes as a developing country
Government regulations and bureaucracy (planning permission, work permits, etc.)	Eskom follows government policies regarding affirmative action and black empowerment	Difficulties in obtaining work permits for foreign staff can adversely affect technology implementation	Government is not seen to be doing enough to improve education. Labour relations fractious at times	In following government BEE guidelines Eskom has revised purchasing policies, the full extent of which is not yet clear
STRATEGY				
Statement of clear objectives to be achieved by new technology	Technology must reduce operating costs to produce cheaper electricity	Cost cutting partly achieved through new technology improves overall efficiencies	Greater productivity is essential to reduce costs, so that tariff increases remain low	Technology to assist in availability and reliability, and low cost production
Technology implemented because of market demand (demand-pull)	No direct needs	None	None	Not in terms of influence of technology on market demand

Table 7.6 Summary of Eskom interviews

Technology as strategic resource for competitive advantage	No	None	No	No
Technology to assist in shift from product to process base	No, as process has always been significant	No	No	No
New business climate (global markets)	Power stations not directly affected	New purchasing policies may render supply chain less efficient	No direct factors	None
Alignment of business goals, systems and technology	To create efficient electricity generation	Purchasing and affirmative action may affect new technology implementation	Improved education and training required to achieve alignment	Technology not directly addressed in Eskom's stated goals and objectives

Level 2	**Analysis and survey of technology**			
	1. Identification of appropriate technologies to meet acquirer's goals	2. Identification and analysis of cost and benefits of new technology	3. Evaluation of imported technology on the basis of acquirer's resources	4. Analysis of economic and technical factors affecting TT
TECHNOLOGY				
New technology to meet exact needs of customer	Negotiation between Eskom and supplier	Formal cost benefit analysis difficult	Eskom human resources not a deciding factor in technology choice	Technology selected on basis of engineering judgement
Better quality through technology	Technology to produce required availability and reliability	Relationship between 'quality of product' and technology difficult to quantify	Eskom human resources not a factor in relating 'quality' to technology	Assessment of technology made to ensure compliance with performance standards
Improved output through new technology	Technology to produce required availability and reliability	Relationship between output and technology difficult to quantify	Eskom human resources not a factor in relating output to technology	Assessment of technology made to ensure compliance with performance standards
ECONOMIC/POLITICAL				
Pressure from labour unions, affirmative action and employment equity policies	Technology selection not affected	Technology selection not affected, but operators and maintainers will require extensive training	Technology selection not affected	Technology selection not affected
The brain drain - skilled people leaving the country	Technology selection not affected, but impact significant	Technology selection not affected, but impact significant	Evaluation not affected	Analysis not affected
STRATEGY				
Distinctive competency to be derived from technology	Distinctive competency not a goal	Distinctive competency not identified	Distinctive competency not evaluated	Distinctive competency not analysed

MANAGEMENT POLICIES FOR TECHNOLOGY				
Belief in need for and commitment to technology, and establishing clear objectives for technology	Definite commitment to best affordable technology	Cost and benefit analysis of limited use because of difficulties in quantifying benefits	Evaluation based on engineering judgement, not acquirer's resources	Analysis based on ability of technology to meet performance standards
HIGH-TECH ISSUES				
Novelty of technology	Not significant	Not significant	Not significant	Not significant, provided no danger of obsolescence

Level 3	**Selecting technology**			
	1. Determination of basic human factors for adopting imported technology	2. Evaluation of final costs and benefits of new technology	3. Determining relevant technology suppliers	4. Estimation of alternative sources of technology
TECHNOLOGY				
Appropriate technology base established from partnership	No indication that less complex technology is more appropriate for South African workforce	No evaluation at power station level of appropriate technology	Head office appoint contractors having considered appropriateness of technology	Head office evaluates alternatives, with some consultation with user (power station staff)
Sensitivity of technology in terms of design, fabrication, operation and maintenance	Technology should be sensitive to physical operating conditions, not workforce	No consideration of technology costs from a sensitivity perspective	Head office appoint suppliers having considered sensitivity	Head office evaluates sensitivity, with some consultation with user (power station staff)
Transfer of core technology from owner to acquirer	Limited transfer of core technology to operators and maintainers	TT through training seen as only way of raising skills levels. Costs not considered at power stations, especially as Eskom's affirmative action policy is adhered to strictly	Suppliers with relevant technology selected, and required to assist in TT	Power station not directly involved with alternative technologies from a TT perspective
Complexity of technology	Eskom uses world-class specifications. These determine complexity of technology	Cost implications of complexity not considered at power stations	Within contractual constraints, head office approves technologies offered by suppliers	Power station has limited input with discussions of complexity of alternative technology
Robustness of technology: installation without adaptation	No need to adapt technology for local conditions, apart from environmental issues	Cost of more robust technology not considered at power stations	Within contractual constraints, head office assesses technology robustness	Power station has limited input with discussions of robustness of alternative technology
KNOWLEDGE				
Diffusion of intangible knowledge throughout the organisation	Little true diffusion because of low levels of education and poor technological understanding of power station operation	Attempts to 'diffuse' knowledge through training and skills development. Costs not considered at power station level	Not directly addressed in contracts, but knowledge transmission managed as part of training by supplier	Power station has limited input with discussions of knowledge diffusion of alternative technology

SUPPLY CHAIN				
Changing approach to supply chain management	No supply chain approaches	Contacts with suppliers relatively informal, with limited direct cost implications	Direct purchase with close negotiations between head office and supplier during design and construction phases	Negotiations with suppliers not a power station function with new power stations
Moves to appropriate local sourcing	Moves to 'black empowerment companies' in terms of Eskom's purchasing procedures	Possible higher costs through sourcing locally in accordance with Eskom's favouring of black empowerment companies	Black empowerment companies an additional link in purchasing process	Choice (of black empowerment or otherwise) made by head office. During normal operations power stations appoint suppliers
Expertise of international suppliers	Generally highly regarded by Eskom, and essential to assist where Eskom staff unable to solve problems	No formal cost benefit analyses in using international suppliers for maintenance, but their expertise is deemed essential	Suppliers chosen because of technological expertise, and Eskom's previous experiences	Power station generally tied to suppliers appointed in terms of original contracts
Use of the internet in supply chain management	None	None	Limited	Limited
STRATEGY				
New relationships with stakeholders	New relationships with black empowerment suppliers, although these suppliers have little technical expertise	Possible higher purchasing costs from black empowerment companies	Limited direct contact between power stations and new stakeholders	Dealings with stakeholders (and suppliers) during normal operating conducted by power station staff
Nature of technology partnership (FDI, licensing, JV, etc.)	Not an issue at power station level	None	Limited formal technology partnerships at power station level	Dealings with technology partners during normal operations conducted by power station staff
OPERATIONAL				
Promoters/champions essential for new technology	No	No	Project manager at head office; engineering staff at new power station site; operations appoint commissioning team	Normal project procedures apply, with appointment of project manager
Change management processes for new technology implementation	Affirmative action appointments require adaptation of attitudes, which is not easy to achieve with certain elements of the labour force	Costs of training and promotion of certain appointees not quantified	No specific processes established for different suppliers	Discussions by power stations with suppliers to discuss change management processes
Short term operational returns expected from technology	No	No cost benefit analyses at power station levels	Contractual performance standards to be delivered by supplier during acceptance testing	On a project basis, power station may seek operational performance figures from suppliers

CONTRACTUAL				
Contractual arrangements	Determined by head office. Operational staff have limited responsibility or expertise	Head office awards contracts and considers financial implications	Contracts administered by head office and site engineering department with each supplier	Normal project procedures apply for appointment of suppliers during power station operation
Operational compatibility between owner and acquirer	Satisfactory from Eskom's perspective. Suppliers complain of low levels of Eskom technological expertise	Head office deals with technical interfaces, and cost implications	Interfaces managed by head office and site engineering staff	During normal operations, negotiations between power station staff and suppliers regarding compatibility
INTEGRATION OF TECHNOLOGY				
Integrating new technology with existing systems	Few difficulties experienced with integration with Eskom systems	Cost of limited importance	Suppliers (particularly main contractors) required to integrate systems	During normal operations, negotiations between power station staff and suppliers for integration
Development of communications and IT systems	No problems	Small cost implications	Eskom policies followed	Normal procedures apply
MAINTENANCE PLANNING				
Lead time to acquire technology/spares availability	Spares requirements not determined by Eskom on basis of failure data. Lead times of spares from abroad can be long	Little rigorous cost benefit analysis of options	Suppliers provide contract spares in terms of contract. Subsequent delivery of spares negotiated with power station	Detailed negotiations with different suppliers
Features requiring unique spares, specialised maintenance	Supplier provides specialised spares. Eskom's centralised maintenance function has some testing facilities	Essential spares acquired as required, within constraints of reducing value of spares holding	Suppliers proved expertise, in conjunction with Eskom's centralised maintenance department	Detailed negotiations with different suppliers and other Eskom departments
MANAGEMENT POLICIES FOR TECHNOLOGY				
Internal support, communication and co-operation	General acceptance of new technology	Cost of limited importance	Suppliers provide support for operations and maintenance. Informal co-operation	Detailed negotiations with different suppliers and other Eskom departments for modifications
General exposure of staff to high-tech equipment and systems	Limited high tech exposure by many operating and maintenance staff	No direct cost implications, but lack of technical awareness has indirect cost implications	Suppliers organise visits to familiarise selected Eskom power station staff	Discussions with suppliers or technology exposure for modifications
Internal infrastructure/facilities to accommodate new technology	Eskom has good infrastructure	Not directly attributable to individual power station	Supplier to provide testing facilities, and measurement points for acceptance testing	Detailed negotiations with suppliers regarding infrastructure requirements for modifications

HIGH-TECH ISSUES				
Use of expert systems/intelligent machines	Little use of expert systems. Condition monitoring increasing, but Eskom skills limited	Increasing use of condition monitoring will have cost implications. No evidence of cost benefit analysis	Limited to what supplier provides in terms of the contract	Reliance on suppliers for technical expertise where appropriate
Process optimisation for full benefit from new technology	Difficult for power station staff to address	Not at power station level	Supplier responsible to provide optimisation in terms of contract	Negotiations with suppliers for modifications
FINANCIAL				
Cost a major factor in technology selection	Not at power station level	Cost benefit analysis not considered at power station level as factor in technology selection	Supplier to submit tenders for relevant technology. Power station not involved	Power station responsibility for modifications after acceptance of unit includes cost considerations
Justification of technology on a cost/benefit basis	Not deemed necessary at power station level	Not at power station level	Supplier provides cost schedules for compliance with specification	Power station responsibility for modifications after acceptance of unit includes cost benefit considerations

Level 4	**Implementation and maintenance**			
	1. Importance for suppliers involved in management and implementation of TT	2. Importance for personnel training and other HR issues	3. Importance for selecting alternatives for TT	4. Identification of criteria for better adaptation of new technology
TECHNOLOGY				
Assimilation of new technology	Assimilation by user important for suppliers to ensure performance standards are achieved	Assimilation best achieved through training and familiarisation	Difficulties in assimilation not seen to be determinants of technology alternatives	Assimilation is not a deciding factor at power stations when considering better adaptation
KNOWLEDGE				
Understanding of new technology	Understanding of technology essential for supplier to ensure performance standards are achieved	Understanding of new technology achieved through training and familiarisation	Difficulty in understanding technology not seen to be determinant of technology alternatives	Understanding new technology is not a deciding factor at power station level when considering better adaptation
Understanding hardware and software	Understanding by user of hardware and software required for achieving performance standards	Understanding of hardware and software achieved through training and familiarisation	Understanding hardware and software not seen to be determinant of technology alternatives	Understanding hardware and software is not a deciding factor at power station level when considering better adaptation
Codification and documentation of knowledge relating to technology	Supplier contractually responsible for documentation	Detailed and correct documentation assists in training process	Codification not seen to be determinant of technology alternatives	Codification/documentation are not deciding factors at power station level when considering better adaptation

Failure data from supplier on which to base proactive maintenance	Provided by some suppliers, but of limited use to power station	Details of failures (failure modes) assists in maintenance training	Non-quantified failure data is influential in excluding or permitting technology alternatives	Failure data influences decisions at power station level when considering better adaptation
SUPPLY CHAIN				
Establishing supplier networks and accessing local infrastructure	Supplier to remain in close contact with technology specifiers (head office) and user (power station)	Close contacts with user assists training	Supplier networks not considered when assessing technology alternatives	Supply chains are not a deciding factor at power station level when considering better adaptation
Trust between technology user and supplier	Supplier to retain trust between technology specifiers (head office) and user (power station)	Close contacts with user enhances trust	Trust is influential in considering suppliers of certain technologies	Previous experiences regarding trust may be a deciding factor at power station level when considering better adaptation
Dependence on supplier for technical assistance on a long term basis	In supplier's interest for Eskom to remain dependent for technical assistance	Eskom dependent on supplier for technical assistance and training	Dependence is influential in considering suppliers of certain technologies	Previous experiences regarding supplier assistance may be a deciding factor at power station level when considering better adaptation
Procedures for problem solving and negotiation with suppliers	Laid down procedures beneficial to supplier	Eskom dependent on supplier for problem solving and training	Problem solving and negotiations are influential when considering suppliers of certain technologies	Previous experiences regarding problem solving may be a deciding factor at power station level when considering better adaptation
OPERATIONAL				
Lack of labour commitment and productivity/ability to take responsibility	Supplier experiences difficulties in training and transferring knowledge to unresponsive Eskom staff	Supplier experiences difficulties in training unresponsive Eskom staff	Internal issues (lack of commitment, etc.) not influential in considering technologies	Internal issues (lack of commitment, etc.) are not influential in identifying better adaptation
Empowerment	Supplier to adhere to Eskom's empowerment policies	Supplier should provide training in response to empowerment policies	Internal issues (empowerment) not influential in considering technologies	Internal issues (empowerment) are not influential in considering better adaptation
Cost of training and developing local workforce	Supplier to arrange contractual agreements for whatever training required	Supplier not necessarily contractually bound to provide training, but should make provision	Cost of training and development not influential in considering technologies	Cost of training is not influential in considering better adaptation
Transfer of physical equipment, systems, managerial philosophy, values	Supplier transfers equipment (and where relevant systems) according to contract.	Training required during handover of physical equipment and systems	Transfer of physical equipment may affect technology alternatives	Transfer of physical equipment is unlikely to be influential in considering better adaptation

CONTRACTUAL				
Technical documentation and drawings	Supplier responsible for technical documentation	Technical documentation contractually required and assists in training	Documentation is a contractual requirement so not directly considered when evaluating technology alternatives	Documentation is a contractual requirement, but will not influence decisions regarding better adaptation
Post-installation back-up and support by technology supplier	Contract specifies support by supplier	Support by supplier ensures a good image of supplier by Eskom	Post-installation experience may favour the technology offered by a supplier	Previous experiences regarding back-up may be a deciding factor at power station level when considering better adaptation
MAINTENANCE				
Availability and reliability of equipment	Supplier responsible during maintenance period for availability and reliability	Supplier can assist with maintenance training to ensure availability and reliability	Availability and reliability experience may favour the technology offered by a supplier	Availability and reliability may be a deciding factor at power station level when considering better adaptation
INTEGRATION OF TECHNOLOGY				
Training by suppliers in the use of new technology	In supplier's interests to provide training to ensure equipment correctly operated and maintained	Training important for new technology to ensure correct operation and maintenance of equipment	Training requirements are not significant when choosing a new technology	Training would be required but is not a deciding factor at power station level when considering better adaptation
Difficulties in implementation because of shortage of skilled personnel	Suppliers experience difficulties because of skills shortages at Eskom, but also in SA generally	Training becomes even more important with skills shortages and lack of technological expertise of Eskom staff	Difficulties in finding skilled personnel are not considered when choosing a new technology	Despite difficulties in finding skilled personnel, this is unlikely to influence decisions of better adaptation
Installation and commissioning of new systems	Supplier contractually bound	Training appropriate during installation and commissioning. Supplier should insist on presence of Eskom commissioning representative	Installation and commissioning are not usually significant when choosing a new technology (unless a technology requires an exceptional installation)	Installation will not be deciding factor at power station level when considering better adaptation
MAINTENANCE PLANNING				
Cost effectiveness of proactive maintenance	Supplier not involved with cost effectiveness of maintenance, although recommends maintenance	Training in maintenance could usefully include consideration of cost effectiveness of maintenance	Maintenance cost effectiveness at power station level is not an issue when considering new technologies	Cost effectiveness of maintenance will not directly influence decisions regarding better adaptation of technology
Problems of 'burn-in' with new equipment and systems	Supplier reduces this as far as possible	Training in proper maintenance can remove one significant cause of infant mortality	'Burn-in' at power station level is not generally an issue when considering new technologies	'Burn-in' will not directly influence decisions regarding better adaptation of technology

FINANCIAL				
Quantification of hidden costs of technology (TT, HR, environmental, etc.)	Supplier not directly involved with hidden costs	Not directly related to supplier training	Qualitative reports regarding hidden costs of technology by power station staff may affect decisions	Hidden costs will not directly influence decisions regarding better adaptation of technology
RESISTANCE TO CHANGE				
Resistance to technology because it is not local	No problems reported	Not directly related to supplier training	Not an issue	Resistance to change is unlikely to be an issue

Level 5	**Evaluation and modification**			
	1. Criteria for evaluating performance of entire process based on acquirer's goals	2. Guidelines for redirecting labour force into modification of new technology	3. Evaluating success or failure and efficiency of new technology for the future	4. Introducing innovative programmes through R&D to develop imported technology
KNOWLEDGE				
Understanding of failure modes and effects	Understanding failures will not contribute to evaluating performance	Understanding failures may well contribute to modifications of new technology	Understanding failures may influence an evaluation of new technology	Understanding failures may, in the longer term, influence innovative programmes
Understanding impact of maintenance/failure on overall process	The impact of failures will affect overall performance	Understanding the impact of failures may well contribute to modifications of new technology	Understanding the impact of maintenance may influence an evaluation of new technology	Understanding the impact of maintenance may, in longer term, influence innovative programmes
MAINTENANCE				
Safety assurance through maintenance	Safety considerations will influence an overall evaluation	Safety issues may well contribute to modifications of new technology	Safety issues may influence an evaluation of new technology	Safety issues may, in the longer term, influence innovative programmes
Appropriate maintenance policies (intervals and tasks)	Appropriate maintenance will directly affect performance evaluation	Maintenance requirements (tasks and intervals) may contribute to modifications of new technology	Maintenance tasks may influence an evaluation of new technology	Maintenance tasks may, in the longer term, influence innovative programmes
Failure data generated internally	Failure data may assist in evaluating performance	Failure data may contribute to modifications of new technology	Failure data may influence an evaluation of new technology	Failure data may, in longer term, influence innovative programmes
RESISTANCE TO CHANGE				
Difficult to accept other ways of working	Unlikely	Unlikely	Unlikely	Unlikely

Table 7.6 Summary of Eskom interviews

CHAPTER 8

DETAILS OF TECHNOLOGY TRANSFER IN MINI CASES

8.1 INTRODUCTION

The purpose in selecting the four mini cases was to seek common elements and identify differences in technology transfer in a variety of organisations. This chapter begins with criteria for the selection of the mini cases. The organisations described in Appendix VII were possible candidates for the mini case studies to which the author had reasonable access, and which had recently implemented a new technology project. A brief description of their activities is given, and reasons for acceptance or rejection of the cases are provided. Thereafter the chosen mini cases are described in greater detail. A summary of the interview findings is given at the end of the chapter. Appendix VIII contains details of the interviews conducted in each mini case.

8.2 CRITERIA FOR MINI CASE SELECTION

Power generation is a process activity, so it was decided to limit the choice of mini cases to process industries[1]. Reasonable access to the companies was the first requirement. The mini cases were intended to complement the main case study to obtain insight in areas not necessarily directly addressed in the Eskom case study. The findings from the mini cases may corroborate or gainsay the Eskom findings. Issues that did not emerge clearly from the Eskom study are those highlighted in the literature as relating to more 'traditionally manufacturing' aspects, such as quality, delivery, customer service, and the strategic role of technology. Organisations subject to quality requirements imposed by local markets, exports or government regulations would present interesting applications for TT.

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[1] The mining industry was excluded from the study for several reasons. The South African mining industry has amongst the most developed mining technologies in the world, so the extent to which technology is transferred from abroad is limited. The history of the mining industry and the nature of mining itself have created operational conditions that differ substantially from the manufacturing sector. For example, job reservation, migrant labour and safety practices have affected the mines in fundamentally different ways from manufacturing industries.

Following the descriptions of the cases, an assessment was made regarding which companies would contribute most to the research.

8.3 SELECTION OF MINI CASE STUDIES

The organisations described in Appendix VII are representative of a wide range of processes that may be appropriate for further TT investigation. The literature highlights a number of important considerations for TT in developing countries. Some of these are listed in the left hand column of Table 8.1. Preliminary discussions were held with candidate case organisations to gauge the extent to which these items were significant or relevant in their technology projects. While all organisations were prepared to discuss TT, the final selection also depended on how easy access would be, and how recently their technology had been implemented.

Table 8.1 summarises the applicability of some items regarding TT in developing countries. The items appearing in the left hand column were selected from the literature that made specific reference to manufacturing and the preliminary surveys. The preliminary research had not been completed when candidate mini cases were being investigated, so the factor analysis descriptors and item scores had not been finalised. The author made an assessment of which items listed in the first column of Figure 8.1 would be best illustrated through deeper investigation of the candidate firms. So, for example in Table 8.1, country infrastructure was important for the firm operating the loadout station (in that good rail transportation and harbour facilities were essential for this firm). Deregulation and privatisation were not significant at the time for this firm. International competition was a key feature and technology was certainly a driving force in improving performance of the loadout facility.

The numeric count of the number of items pertaining to each firm was an important selection consideration: the more items that were important to an organisation, the more likely that a study of that firm would provide useful insight into TT. The final choice was also influenced by ease of access to firms and the stage of TT in each. The four companies selected are described in the next section.

Items	Loadout	Paper	Water	Flour	Oil	Steel	Sweets	Beer	Food oil	Lime	Cling film	Food
Country infrastructure	√	x	√	√	x	x	x	x	x	√	x	x
Deregulation	x	x	√	√	x	x	x	x	x	x	x	x
Privatisation	x	x	√	√	x	x	x	x	x	x	x	x
Culture			√		x	x	x	x	x	x	x	x
Local competition from foreign firms	x	x	x	√		x	√	x			√	√
International competition (exports)	√	√	x		x	√	x	x	√		√	√
Creation of technology 'anchor'			√			x	x		x		x	x
Supplier relationships/dependency		√	√	√		√			√	x	√	√
Mix of foreign and indigenous technology	√	√	√	√	√	x	x	√	x	√	x	x
Technology and strategy	x	x		√	x	√				x	√	√
Justification of technology decisions			√	√	√	√		√		√	√	√
Skills shortages	√	√	√	√	√	√	√		√	√	√	√
Training	√	√	√	√	√	√	√	√	√	√	√	√
Improved quality		√	√	√	√	√	√		√		√	√
Cost reduction	√	√	√	√	√	√	√	√	√	√	√	√
Productivity and output improvement	√	√	√	√	√	√	√	√	√	√	√	√
Innovation through technology			√									
Adaptation of technology										√		
Incremental enhancements	√		√	√		√	√		√			
Replication through technology											√	
Maintenance	√	√	√	√	√	√	√	√	√	√	√	√
Flexibility												
Response time											√	√
Organisation structure												
Managerial control			√	√		√						√
Information systems			√	√							√	
Total √	9	9	18*	17*	8	12	8	6	9	9	14*	13*

√ = yes x = no blank = no firm indication

* The four companies selected are: Flour mill, Water company, cling film manufacturer, food processing company

Table 8.1 Items highlighted in the literature for TT in developing countries - relevance/applicability in each case

8.4 DESCRIPTION OF MINI CASES

This section provides further details of the activities of the mini cases selected for detailed analysis. For reasons of confidentiality, companies have not been named, so a short name has been assigned to each.

8.4.1 Flour mill (Flourco)

The mill is owned by a large South African corporation and run as an independent subsidiary. Recent rationalisation has seen a variety of food production activities at the mill reduced to the milling of wheat to provide bread flour, and its associated by-products (bran and semolina). Wheat is delivered by road from external storage on a just-in-time basis. While the physical and chemical properties of the wheat (kernel weight and size, impurities, falling weight, protein content) are carefully monitored, variations in wheat quality influence throughput and blending may be required. The addition of water, cleaning and milling are continuous processes planned to produce flour adhering to strict regulatory and baking standards. Efficiencies and yields are carefully monitored to ensure that unusable by-products are kept to a minimum.

Some of the milling equipment and storage bins have been in service for more than 50 years. With the recently installed computerised control system, the process is almost totally automated. The control system represented a considerable technological advance. While individual machines were not replaced, equipment such as valves and some pipework were upgraded or renewed. The latest technology has raised efficiencies and yields. The mill operates on a continuous basis for 6 days, and one shift per week is allocated to maintenance. The mill staff complement is 120.

Discussions were held with the following personnel:

Managers	2
Miller	1
Supervisor	1
Operators	2
Maintenance staff	2

8.4.2 Water company (Waterco)

The organisation provides water to a number of large towns, small villages and several hundred farmers. While it operates as a cooperative with its members owning the business and is legally bound to function as a profit-making business, it is subject to nationally prescribed standards and regulations. In the past shortfalls in revenue were made up through government subsidies. Most of the company's staff joined when the company was effectively state owned, and managers admitted that it still has a 'government and civil service mentality'. Water tariffs are not regulated, but there is great pressure to keep them low. Water provision targets are set, but penalties for non-availability and non-compliance only come into effect after a significant time has elapsed, and these are not particularly onerous.

The company's head office provides management, engineering and support services to the various regions. Each region has a number of purification works, and is responsible for water distribution in that region. The organisation employs some 200 people, of whom 50 are in the head office. The technology considered in this case is the upgrade of a water purification plant. A degree of automation was introduced (for example, through the installation of dosing pumps, content analysers for a number of chemicals (chlorine, bisulphites and other salts), pH monitoring and control, differential pressure measurements on filters for automatic change-overs). Much of this was done manually in the past, but this was labour intensive, and not always particularly effective.

Discussions were held with the following personnel:

Managers	2
Project staff	1
Supervisor	2
Operators	2
Maintenance staff	2

8.4.3 Cling film manufacturer (Plastico)

The company manufactures PVC cling film for food packaging in the retail and household sectors. Supermarkets continuously demand lower prices in an industry facing considerable local competition. The company identified the need to form long-term relationships with local fast-food customers and to take advantage of the poorly performing local currency by exporting. Fast-food customers are frequently bound by quality standards set by their international franchisers (usually American). Exporting also requires adherence to international quality standards, one of which is consistent film thickness. The factory employs 200 workers.

The company's policy was 'volume is the core business', achieved by low unit production costs, at acceptable quality levels. In order to increase production, bottlenecks in the production process had to be removed, and quality monitoring was essential. During production, compounded PVC resin is heated and passed through an extruder. It is then pushed through an inner die that determines the thickness of the film. When burnt particles are observed on the film from the wind-up machines, operators stop the process and change the screen through which the product passes. The screen requires changing approximately once every 24 hours. Screen problems also cause an unstable bubble on the bubble extruder machines. Lost production and rework reduce the efficiency of the process.

The company installed an automated screen changer. The differential pressure between the screen pack and extruder and the die is monitored, and the screen automatically changed when required. A statistical process control quality monitoring system was also introduced, providing constant monitoring of the thickness of the film. The results are projected on an SPC-type display, and the operator is warned when control limits are reached. The automated screen changer and quality monitoring system are independent and installed by different suppliers.

Discussions were held with the following personnel:

Factory managers	2
Supervisor	1
Engineer	1
Operators	2
Maintenance staff	1

8.4.4 Food processing factory (Foodco)

The factory is a division of a food processing company that processes potatoes for the manufacture of French fries for supermarkets and fast-food outlets. Although the company does not export a great deal of its production, it must adhere to the stringent requirements imposed by South African supermarkets and international quality standards laid down by American fast-food corporations. The variables that primarily influence the quality of the end product are the quality of the raw material and the manufacturing process. The flow process for the manufacture of fries is as follows: from storage, potatoes are washed, peeled and cut. The quality of the cut has a direct impact on the oil intake of the finished product. Blanching removes surface starch, reduces sugars, and gelatinises the cell boundaries to obtain even texture and colour. Moisture control is achieved through a critical drying process. This is essential as fryers only remove a limited amount of water before over-cooking the product. During frying, an oil management system reduces oil oxidation. The product is then frozen, packed and stored. The plant employs some 300 people.

In order to achieve long-term production targets and quality standards, a new production line was installed dedicated to the production of French fries. This incorporated an integrated automatic control system designed to ensure smooth product flow and consistency.

Discussions were held with the following factory personnel:

Managers	2
Supervisors	2
Operators	1
Maintenance staff	1

8.5 MINI CASE INTERVIEWS

Appendix VIII contains summaries of the mini case interviews. In order to avoid repetition, the cases are discussed together under each heading. For reasons of confidentiality, individuals have not been named. Some of the cases operate in highly competitive environments, so plant capacities and suppliers have also not been given. The organisational structures of the cases differ, but in order to attain some degree of commonality, comments have been attributed to managers, site engineering staff, supervisors, operators and craftsmen. Apart from Waterco no head office staff were interviewed, so answers to level 1 and level 2 questions pertaining to strategic issues are the opinions of plant managers. Where appropriate, the race of a respondent is mentioned.

As with the Eskom analyses, interview questions for the mini case studies were derived from Salami and Reavill's framework and the items from the preliminary study. The 5 levels in the framework relating to different levels of decision-making are shown in Table 8.2.

Level	Description (Salami and Reavill)	Location and category of staff in mini cases
1	Decision for selecting technology	Senior management
2	Analysis and survey of technology	Senior management Middle management (Plant)/Factory engineering departments
3	Selecting technology	Senior management Middle management (Plant)/Factory engineering departments
4	Implementation and maintenance	Middle management (Plant) Supervisory
5	Evaluation and modification	Middle management (Plant) Supervisory Operational (operations/maintenance)

Table 8.2 Levels in Salami and Reavill framework and categories of staff in mini cases

8.6 SUMMARY OF MINI CASE INTERVIEWS

Table 8.3 summarises the interviews. For each level in Salami and Reavill's model four elements are shown in the top rows. The second component, derived from the preliminary research, provides the items identified in the left hand columns of the tables. Where appropriate a brief comment in a cell indicates that the interviews revealed a relationship between the elements in Salami and Reavill's model and an item from the preliminary research.

Level 1	Decision for selecting technology			
	1. Identification of needs and demands of acquiring country	2. Identification of limitations, advantages and disadvantages of needs and demands	3. Identification of important macro and micro human factors for use of new technology	4. Identification of acquirer's goals and objectives
ECONOMIC/POLITICAL				
Crime levels in South Africa	Reduction in crime to improve the business climate for investment	Significant management time taken up by crime related issues. Security costs high	Shortages of staff exacerbated by emigration, which occurs partly as a result of crime	Inability to achieve goals through technology because of the broad impact of crime on the business
Low educational levels of labour	Poorly educated workforce affects economic performance	Lack of skills prevents full benefits from technology	Further training and development adds to the business cost structure	Inability to achieve goals through technology; workers unskilled
Effects of globalisation	Businesses must be able to compete internationally	Lack of past exposure to international markets introduces new challenges	Organisations need to be aware how technology can assist in meeting competitive challenge	Exports essential for survival, so technology must provide quality and delivery for competitive edge
Overall level of economic development and infrastructure	Companies find rail transport very inefficient	Low value of Rand encourages exports. Skills shortages	Need for increased training and development	Expansion of exports
General conditions in a developing country	Low levels of education and crime are areas of concern	Shortages of skilled labour reduce technological capabilities	Resources required to improve education and technical training	Ability to use technology without constraints from skills shortages
Government regulations and bureaucracy (planning permission, work permits, etc.)	Encouraging skilled workers from abroad	Relaxation of immigration regulations for technical experts	Assistance with technology implementation through training and development	Availability of financial and human resources for high-tech business applications
STRATEGY				
Statement of clear objectives to be achieved by new technology	Formation of technology 'anchors' on which to build technology base	Developing country conditions restrain high-tech development; limited access to finance	Training and development of a technically proficient workforce	Technology to assist in achieving quality and output targets
Technology implemented because of market demand (demand-pull)	International customer demands determine whether a country becomes a global player	Lack of exposure to global business conditions and customer requirements	Development of workforce in understanding requirements for globalisation	Quality, delivery and production standards to be achieved through technology
Technology as strategic resource for competitive advantage	Global competition will force adoption of world class standards	Technology seen as a mechanism for operational success	Managers fail to emphasise strategic role for technology	Customer driven strategies require technology to meet their demands
Technology to assist in shift from product to process base	Increase in productivity through better facilities and technology	Firms with obsolete technology cannot compete globally	Understanding role of technology in process to meet customer needs	Technology to improve process performance and efficiency

Table 8.3 Summary of mini case interviews

New business climate (global markets)	National boundaries cannot prevent global competition	New quality mindset required throughout organisation	All employees to be aware of what is involved in global business	Exporting is essential for growth of business
Alignment of business goals, systems and technology	Global strategic plans to be supported by technology	Lack of strategic thinking based on technological capabilities	Coordination of corporate, business and operational strategies	Clear objectives for what technology is to achieve

Level 2	**Analysis and survey of technology**			
	1. Identification of appropriate technologies to meet acquirer's goals	2. Identification and analysis of cost and benefits of new technology	3. Evaluation of imported technology on the basis of acquirer's resources	4. Analysis of economic and technical factors affecting TT
TECHNOLOGY				
New technology to meet exact needs of customer	No significant choices of technology available	Cost was main determining factor. Benefits from meeting customer requirements difficult to quantify	Subjective evaluation of technology by acquirers	In some cases technology is essential to meet customer needs
Better quality through technology	Standard technologies required to meet quality requirements	Cost of quality improvements difficult to determine	Acquirers visit technology suppliers to assess quality outputs	If quality standards are not met, companies would not survive
Improved output through new technology	Standard technologies required to meet production output requirements	Not possible to quantify benefits through increased output	Suppliers contractually obliged to meet production outputs	Meeting production requirements essential for survival
ECONOMIC/POLITICAL				
Pressure from labour unions, affirmative action and employment equity policies	Demands from unions for training in new technology	Training should be a cost of technology acquisition, but often excluded from total cost	New technology can result in deskilling of operator jobs	Labour issues not considered
The brain drain - skilled people leaving the country	Skills shortages not considered in technology selection	Additional technician training adds to cost of new technology	Recruitment difficulties not considered in technology evaluation	Skills shortages not considered
STRATEGY				
Distinctive competency to be derived from technology	Technology provides core, not distinctive, competency	Benefits to achieve low cost advantage	Technology required to meet competitor performance	Cost of technology a major factor in acquiring core competences
Technology permits revisit of vertical integration	Companies do not seek vertical integration	Companies do not seek vertical integration	Companies do not seek vertical integration	Companies do not seek vertical integration

MANAGEMENT POLICIES FOR TECHNOLOGY				
Belief in need for and commitment to technology, and establishing clear objectives for technology	Technology selection supported by management to achieve specific objectives	Cost of technology justified if set objectives met	Management support for training human resources in new technology	Technology considered essential for organisational survival. Management support for targets
HIGH-TECH ISSUES				
Novelty of technology	Essential to replace obsolete systems with new technology	Cost-benefit analyses justify choice of new technology	New technology essential despite skills shortages	Upgrading technology likely to introduce high-tech technology

Level 3	**Selecting technology**			
	1. Determination of basic human factors for adopting imported technology	2. Evaluation of final costs and benefits of new technology	3. Determining relevant technology suppliers	4. Estimation of alternative sources of technology
TECHNOLOGY				
Appropriate technology base established from partnership	Companies recognise necessity for training by supplier	Choice of technology limited by cost. Technology considered appropriate	Limited number of suppliers so cheapest supplier often selected	Limited number of technologies can meet requirements, so few alternatives available
Sensitivity of technology in terms of design, fabrication, operation and maintenance	Technology sensitivity not considered in human factor terms	Sensitivity documented in contract requirements	Little difference in suppliers regarding sensitivity	Limited number of technologies available to offer similar functionality
Transfer of core technology from owner to acquirer	Operational expertise transferred, but not maintenance knowledge	Additional maintenance training essential irrespective of costs	Supplier required to offer training to transfer technology as part of contract	Limited number of technologies available to provide core technology
Complexity of technology	Some systems considered unduly complex technologically, and require extensive training	Amount of automation rather than complexity determines final project cost	Standardised technology solutions contain complexity that cannot always be modified	Suppliers claim that less complex solutions do not meet required performance standards
Robustness of technology: installation without adaptation	Technology considered robust. Some adaptation to address interfacing problems	Additional costs incurred because of interfacing and integration requirements	Standardised solutions appeared to offer robust technology to meet requirements	No indication that alternative sources of technology would offer greater robustness

KNOWLEDGE				
Diffusion of intangible knowledge throughout the organisation	Training transferred operational expertise, but little evidence of intangible knowledge diffusion	Not possible to quantify benefits of intangible knowledge or extent of diffusion	All technologies require learning. Suppliers offered only training. Knowledge acquired over time	Not possible to assess what other technologies would result in greater knowledge diffusion
SUPPLY CHAIN				
Changing approach to supply chain management	Supply chain management not evident in relation to technology	No evidence that supply chain approach would add benefits	Relationships and contacts used to discuss technology options	Supply chain approach not used to consider alternative sources
Moves to appropriate local sourcing	No policies require this. Contacts with local suppliers useful to obtain some cheaper services	Local sourcing beneficial for price and availability. Most spares only available from foreign supplier	Supplier with local representative favoured because of easier contact and spares availability	No evidence that local sourcing offers alternative sources of technology (usually imported)
Expertise of international suppliers	Technology acquirers satisfied. Expertise required for training local staff	Acquirers benefit from supplier expertise during commissioning and from training courses	Acquirers assume suppliers are competent, unless other customers recount poor experiences	No evidence that alternative sources of technology would have greater expertise
Use of the internet in supply chain management	Limited use of internet in technology implementation	Costs and benefits of internet use not investigated	Internet not used in supplier evaluation or selection	Internet not used in considering alternative suppliers
STRATEGY				
New relationships with stakeholders	New relationships not established	New relationships not established	New relationships not established	New relationships not established
Nature of technology partnership (FDI, licensing, JV, etc)	Formal technology partnerships not created	Formal technology partnerships not created	Formal technology partnerships not created	Formal technology partnerships not created
OPERATIONAL				
Promoters/champions essential for new technology	Occasional champions emerge if they have technological expertise	Champions do not affect costs and benefits	Champions are not essential for supplier selection	Champions are not essential for investigating alternative suppliers
Change management processes for new technology implementation	Close communication with unions	Intangible benefits accrue from managing change	No evidence that change management would differ with other suppliers	No evidence that change management would differ with alternative sources of technology
Short term operational returns expected from technology	Operational returns delayed because of inadequate operational and maintenance expertise	Increased production output evident soon after installation of new technology	All suppliers expected to ensure operational returns	Alternative sources of technology expected to ensure operational returns
CONTRACTUAL				
Contractual arrangements	Acquirer staff satisfied with contractual arrangements	Scope of work, time, cost and quality of installation determined by the contact	All suppliers subject to similar contractual arrangements	All suppliers subject to similar contractual arrangements

Operational compatibility between owner and acquirer	Satisfactory compatibility, but more training required	Satisfactory commissioning suggests satisfactory compatibility	Compatibility subjectively evaluated when choosing suppliers	Compatibility important with alternative technology sources
INTEGRATION OF TECHNOLOGY				
Integrating new technology with existing systems	Integration difficulties arise because new systems not always compatible and operators did not understand new control systems	Additional costs incurred when integration difficulties delay production and led to other equipment failure	No evidence that other systems present fewer integration difficulties	No evidence that alternatives sources provide systems with fewer integration difficulties
Development of communications and IT systems	Improved communication between different functions and individuals	Difficult to quantify benefits of communications and IT systems	Communications developed irrespective of supplier	Communications developed irrespective of supplier
MAINTENANCE PLANNING				
Lead time to acquire technology/ spares availability	Maintenance delays and reduces production with long lead times. Contacts between acquirer and supplier essential to reduce effects	Effect on production of long lead times or non-availability of spares cannot be quantified	No evidence that lead times/spares availability would be different with other suppliers	No evidence that lead times/spares availability would be different with alternative sources
Features requiring unique spares, specialised maintenance	Unique spares increase dependency on supplier. Some maintenance teams seek alternative suppliers of spares	Specialised spares are invariably more expensive than standard spares	No evidence that unique spares requirements would be different with other suppliers	No evidence that unique spares requirements would be different with alternative sources
MANAGEMENT POLICIES FOR TECHNOLOGY				
Internal support, communication and cooperation	General satisfaction with internal support and communication	Costs and benefits of support and communication difficult to quantify	Support and communication comparable with most technologies	Support and communication comparable with most technologies
General exposure of staff to high-tech equipment and systems	Few staff familiar with installed high-tech equipment	Not possible to quantify effects of non-exposure to high-tech	All high-tech systems would present problems to staff	All high-tech systems would present problems to staff
Internal infrastructure/facilities to accommodate new technology	Satisfaction with infrastructure and facilities	No separate cost-benefit analyses for infrastructure and facilities	Most technologies would require similar infrastructure/facilities	Most technologies would require similar infrastructure/facilities
HIGH-TECH ISSUES				
Use of expert systems/intelligent machines	Expert systems not used	Expert systems not used	Expert systems not likely with other suppliers	Expert systems not likely with other technologies

Process optimisation for full benefit from new technology	Process optimisation not a goal of new technologies	Lack of process optimisation not quantified, or possibly not relevant	Process optimisation unlikely to be an issue with other suppliers	Process optimisation unlikely to be an issue with other sources
FINANCIAL				
Cost a major factor in technology selection	Cost a major factor in technology selection. Training also essential	Cost a major factor, irrespective of (often non-quantified) benefits	Cost would remain important with other suppliers	Cost would remain important with alternative sources
Justification of technology on a cost/benefit basis	Some technology justified. Other installations essential for survival	Some technology justified. Other installations essential for survival	Some technology justified. Other installations essential for survival	Some technology justified. Other installations essential for survival

Level 4	**Implementation and maintenance**			
	1. Importance for suppliers involved in management and implementation of TT	2. Importance for personnel training and other HR issues	3. Importance for selecting alternatives for TT	4. Identification of criteria for better adaptation of new technology
TECHNOLOGY				
Assimilation of new technology	Operational know-how assimilated but maintenance required supplier assistance	Operator training satisfactory but maintenance teams require further guidance and training	Alternatives not considered to ensure greater assimilation	Greater understanding of system functionality
KNOWLEDGE				
Understanding of new technology	Operational know-how understood but inadequate understanding of maintenance requirements	Training and exposure required for maintenance staff	Alternatives likely to present similar difficulties	Further training and working with supplier to improve knowledge of systems
Understanding hardware and software	Suppliers to offer more training in control system software	Training in software systems	Other systems likely to present similar software difficulties	Local staff to work with suppliers during installation/commissioning
Codification and documentation of knowledge relating to technology	General satisfaction. Greater explanations of operating systems	More detailed operating and maintenance manuals	Documentation important	More detailed documentation with operating and maintenance details
Failure data from supplier on which to base proactive maintenance	No failure data supplied to guide maintenance intervention	Maintenance planning departments do not exist to analyse failure data	Alternative technology should be supported with failure data	Detailed failure data applicable to the operating context
SUPPLY CHAIN				
Establishing supplier networks and accessing local infrastructure	Organisations do not see need for supplier networks	Relationships essential. Expand contractual training	Alternative technologies would be considered in the same way	Formal supplier networks not seen to be important
Trust between technology user and supplier	Organisations trust suppliers and this must be maintained	Trust established through formal and informal contacts	Trust essential for any technology supplier	Maintain close contacts to retain trust

Dependence on supplier for long-term technical assistance	Suppliers will remain invaluable to users	Provision for supplier assistance should be formalised	Users will be dependent on all technology suppliers	Retain close contacts between users and suppliers for support
Procedures for problem solving and negotiation with suppliers	Users would benefit from a formal approach to problem solving	Suppliers should be encouraged to formalise assistance	All technologies would benefit from formal problem solving	Formalised contact between users and suppliers
OPERATIONAL				
Lack of labour commitment and productivity/ability to take responsibility	Suppliers to consider cultural and political issues in SA companies	Industrial relations and labour issues to be carefully managed	These issues would apply to all technologies	Adherence to all labour legislation and close contact with unions
Empowerment	Understanding of implications of empowerment	Not widely discussed. Workers sceptical about empowerment	Empowerment would be important irrespective of technology	Discussion and communication about empowerment policies
Cost of training and developing local workforce	Suppliers should include training in quotations	Training is an essential component in TT and should be budgeted for	All technologies will require training	Formalising of training procedures additional maintenance training
Transfer of physical equipment, systems, managerial philosophy, values	Suppliers should emphasise a 'quality culture'	Development of staff should include an understanding of quality and value	Applicable for all technologies	Training and development in more than technical disciplines to understand consumer culture
CONTRACTUAL				
Technical documentation and drawings	Suppliers should provide details of integration with existing systems	Operating and maintenance manuals are required for training	All technologies require training	Regular updating, reflecting new and existing systems
Post-installation back-up and support by technology supplier	Suppliers should attempt to formalise this	Support is required because of poor understanding of systems	Back-up should be provided for all technologies	Formalised assistance and training
MAINTENANCE				
Availability and reliability of equipment	Suppliers need to improve understanding of systems and give guidance for maintenance	Maintenance training and familiarisation are essential to improve availability and reliability	Maintenance guidance for all new systems is essential	Training in plant functionality and maintenance management
INTEGRATION OF TECHNOLOGY				
Training by suppliers in the use of new technology	Suppliers need to improve and expand this	Supplier training should be written in to contracts	Suppliers of all new technologies should offer training	Training programmes for operators and maintenance teams

Difficulties in implementation because of shortage of skilled personnel	Suppliers can offer expertise to counter shortages of skilled personnel	More use of suppliers in maintenance contracts are being considered	All systems suffer from the shortage of skilled staff	Training, development and education are the starting points
Installation and commissioning of new systems	Suppliers should involve operating and maintenance staff in installation and commissioning	Training should commence well before live operation of a system	All operations would be enhanced by additional training	Formalised, contractual training in operations and maintenance
MAINTENANCE PLANNING				
Cost effectiveness of proactive maintenance	Suppliers should be able to justify maintenance recommendations	Training in maintenance management and planning	Maintenance recommendations should be substantiated	Offer training in maintenance, and maintenance planning. Establish a maintenance information system
Problems of 'burn-in' with new equipment and systems	Suppliers should work closely with users during early operations	Familiarisation and training can assist to reduce burn-in	All complex systems suffer from burn-in	Greater matching of needs from technology and existing systems
FINANCIAL				
Quantification of hidden costs of technology (TT, HR, environmental, etc)	Publish estimates of hidden costs	Systems are required to accommodate management reporting systems with such data	All technologies should quantify hidden costs	Provide processes for managing hidden costs
RESISTANCE TO CHANGE				
Resistance to non-local technology	Suppliers can do little	Little evidence of resistance	Little evidence of resistance	Little evidence of resistance

Level 5	**Evaluation and modification**			
	1. Criteria for evaluating performance of entire process based on acquirer's goals	2. Guidelines for redirecting labour force into modification of new technology	3. Evaluating success or failure and efficiency of new technology for the future	4. Introducing innovative programmes through R&D to develop imported technology
KNOWLEDGE				
Understanding of failure modes and effects	Poor understanding of FMEA leads to inadequate maintenance. Necessary to quantify cost of failure to justify maintenance	Modification of technology not considered	Understanding FMEA improves plant performance and efficiencies through more effective maintenance	Innovative programmes not planned
Understanding impact of maintenance/failure on overall process	Impact of failure on process can be quantified. Non-achievement of goals can attributed to failures	Modifications not considered but redesigns could emerge from a study of the impact of failures	Understanding overall impact of failure can improve performance and efficiencies	Innovative programmes not planned

MAINTENANCE				
Safety assurance through maintenance	Little change in relationship between safety and maintenance	Modifications essential if safety related failures cannot be prevented	A safe operating environment is essential	Innovative programmes not planned
Appropriate maintenance policies (intervals and tasks)	Determining correct maintenance policies essential for performance enhancement	Modifications not considered	Appropriate maintenance will improve availability and reliability	Innovative programmes not planned
Failure data generated internally	At present not done	Modifications not considered	Failure data essential to build maintenance history	Innovative programmes not planned
RESISTANCE TO CHANGE				
Difficult to accept other ways of working	No evidence of this item	No evidence of this item	No evidence of this item	Innovative programmes not planned

Table 8.3 Summary of mini case interviews

CHAPTER 9

ANALYSIS OF FINDINGS WITH REFERENCE TO THE RESEARCH QUESTIONS

9.1 INTRODUCTION

This chapter analyses the case study data with reference to the research questions. The main case study and the mini cases are considered together in order to identify similarities and differences between them[1]. Reference is made to the TT and physical asset management literature reviews in Chapters 2 and 3, the South African situation (Chapter 4), the preliminary survey (Chapter 6), the case studies (Chapters 7 and 8), and the interview summaries (Appendices VI and VIII). Conclusions are drawn after the discussion of each research question. These then lead to a modified model derived from the framework of Salami and Reavill (1997), to be discussed in Chapter 10.

9.2 RESEARCH QUESTION 1 - DECISIONS FOR SELECTING TECHNOLOGY

This question relates to technology suppliers and acquirers seeking agreement in the selection of technology, in accordance with the acquiring country's needs, capabilities, limitations and human resources. The literature draws attention to the importance of a sound relationship between supplier and acquirer in TT. This did not take the form of formal alliances, joint ventures or partnerships in the case studies. The closest linkages were supply agreements and technical exchanges (Inkpen, 1998). Leonard-Barton (1995) suggests these can contribute to knowledge-creating activities, but they were, at best, collaborative agreements leading to production improvements, and did not extend to the strategically effective relationships postulated by Irwin et el (1998).

[1] It will be seen that Flourco, Foodco and Plastico, as manufacturing companies, have certain similarities that do not apply to Waterco. For ease of reference these three will be referred to as the manufacturing mini cases.

Research question 1.1: The decision making process of a firm in an acquiring country for selecting technology identifies the needs and demands of the acquiring country

In addressing this question, several differences between the main and mini cases emerged. Decisions made by a large parastatal organisation like Eskom can have a major impact on the acquiring country, whereas technology policies adopted by smaller firms are unlikely to have any effect beyond their immediate environments. Loveridge and Pitt (1990) point to the impact of the external context of decisions on the economy and society. Eskom's choice of technology at the highest level (such as a coal-fired or nuclear power station) has a major influence on regional development: most coal is found in central and eastern parts of South Africa, whereas possible sites for new nuclear power stations have been coastal[2]. Technology choices are intended to support Eskom's goal of being one of the cheapest electricity providers in the world, benefiting South African industry as a whole[3].

Eskom's expansion outside South Africa's borders has only been to other African countries, whereas the global environment has a more immediate effect on the manufacturing mini cases (this was identified in the preliminary research as an important aspect in technology decisions). It is common for firms competing in the global environment, or meeting international standards to be dependent on externally sourced technology in order to compete on cost and quality (Irwin et al, 1998). This was the case in the manufacturing mini cases. However, the choice of such technology was not in response to the needs and demands of the country, as referred to in the research question. According to one supplier of electrical equipment, Eskom's specifications have become the standard in South Africa and certain African countries. Several suppliers of such equipment had been dependent on Eskom for their survival, as they were guaranteed a steady local market during the apartheid era. Sanctions, particularly

[2] When Eskom's nuclear power station was being planned in the 1970s, it was suggested that building a nuclear power station was part of the apartheid government's nuclear weapons programme, since South Africa had no economic need for a nuclear power station, given its plentiful supply of coal. A further reason for constructing the nuclear power station near Cape Town was a fear of terrorist attacks on power lines supplying southern parts of the country. In both instances, Eskom's choice of nuclear technology could be deemed to have been in response to the needs and demands of the country, albeit at the behest of its then political masters.

[3] It should be pointed out that the main reason for Eskom's relatively low electricity tariffs is the cheap, low grade coal used in power generation.

from US companies, meant that Eskom could not buy standard electrical equipment from abroad. However, since global suppliers have entered the South African market, it is no longer bound to purchase from South African companies, although its purchasing practices do favour black empowerment firms.

In terms of Fleury's (1999) categorisation, South Africa operates in a system of 'productive globalisation', having largely deregulated its financial markets (some foreign currency exchange controls are still in place) and removed trade barriers. While firms are at liberty to adopt technology that extends beyond cost-efficient production processes for manufacturing quality goods (Alcorta, 1999), the mini cases were largely still at this stage. They were seeking productivity improvements, but had not reached the situation where innovation follows from knowledge acquisition (postulated by Smit and Pretorius, 1998).

Eskom has a monopoly in South Africa. Since decisions about privatisation and deregulation of the industry have not been finalised, it is not possible to consider Evaristo's (1998) contention that new entrants to a market will select lucrative elements of the South African electricity market, leaving Eskom with a monopoly culture to supply less profitable sectors.

The discussion of this research question indicates that technology decisions in the mini cases did not consider specific needs and demands pertaining to South Africa. To some extent Eskom based its technology decisions on South Africa's needs, in terms of supporting local industries (in the past) and local suppliers (currently), while continuing to supply relatively cheap electricity. The research would therefore partially agree with the research question for the large utility, but not in the case of the smaller manufacturing companies.

Research question 1.2: The decision-making process identifies the acquiring country's capabilities and limitations

Despite skills shortages and the South African education system (discussed in the next question), respondents' technology decisions were not greatly affected by the country's capabilities and limitations. Many respondents commented that their technology was world class, with levels of technology as high as those found anywhere, unless this was too expensive. The fact that South Africa is a developing country did not influence their choice of technology as managers believed that the country had sufficient technological capability to compete through technology-based operations, assisted by abundant raw materials (Table 4.6 shows that 36% of exports come from primary production) and labour costs that were lower than those of many first world competitors (but footnote 6 in Chapter 4 suggests this is not always the case).

Respondents felt that in national terms South Africa had sound infrastructure and high-technology potential, supported by good research institutions, and was thus in a strong position to build on these capabilities. Limitations, or negative aspects, of the country were economic and political. Much of a manager's time was taken up when dealing with factors not directly related to technical matters (such as crime), and government policies, perceived by some managers to be interference (such as affirmative action and employment equity). This agrees with the findings of Chatterji (1996) and Samli et al (1992) pertaining to other countries.

With reference to state-business-management relationships in Figure 2.2, managers divorced government policies from business initiatives, methods of organising and work practices. When discussing technology decisions, they did not agree with suppliers that acquirers were incapable of implementing high-technology projects. Respondents did not consider problems resulting from skills shortages at the technology analysis and selection stage. These only became apparent after technology had been installed.

The research findings do not support the research question that the acquiring country's capabilities and limitations were identified as part of the decision-making process for technology selection. Such limitations did not deter new technology acquisition.

Research question 1.3: The decision-making process identifies important macro- and micro-economic human factors relating to new technology

Shortages of skilled staff were among the greatest challenges facing managers. A lack of suitably trained and experienced staff affected the implementation of high-technology projects (a developing country problem identified by Baranson, 1969, illustrated in Tables 4.9 – 4.11). Although Eskom in particular spent a great deal on training and development, managers acknowledged that poor schooling and tertiary education meant that development programmes would only yield success over time. Training could address immediate deficiencies, but developing a deeper understanding of complex technology was a long-term process.

In seeking to redress poor levels of education, managers in the mini cases instituted training courses, most of which were directed at providing specific skills to operations and maintenance staff. Firms granted some financial assistance to employees seeking to improve their general education. While Williams (1996) advocates that employees should be in a position to control their activities and coordinate training and development, the case studies provided little evidence of this. Managers determined training and development budgets and encouraged staff to apply for development courses, but the managers decided who would attend such courses, what the content should be, and what training should be offered. Managers claimed that developing staff at a more general level and encouraging more students to study science and technology (South Africa's position is shown in Figure 4.3) were functions of the state as part of national education, and firms could only provide limited development programmes.

Government regulations directly affected human resources policies. Eskom in particular was committed to promoting blacks, females and the disabled in accordance with employee equity and affirmative action policies. Some managers complained this meant that highly qualified technical staff were not necessarily utilised in the best possible manner, such as in new technology projects. This was less of an issue in the mini cases because they did not adhere as strictly to (voluntary) government guidelines. In both instances, such issues were racially charged. Accusations that ill-qualified blacks were promoted above more competent whites were countered by pointing out the economic and political necessity of promoting blacks to positions of managerial and technological leadership if the country were to prosper (as espoused by Ramaphosa's (2003) comments in Chapter 4).

Eskom demonstrated a commitment to its macro- and micro-economic human resource policies, but these were not decision-making factors in technology selection as suggested in the question. Likewise, the mini case organisations did not directly take HR matters into account when acquiring technology.

Research question 1.4: The decision-making process identifies the acquirer's goals and objectives to be achieved through the technology

This research question relates to the strategic orientation of TT, as postulated by Phillips et al (1994). The literature suggests that TT is enhanced if coordinated at strategic level and aligned with corporate goals (Leonard-Barton and Deschamps, 1988; Martinsons and Schindler, 1995). Managers did not suggest that new plant had been installed or existing facilities upgraded for strategic reasons. Technology was introduced in the manufacturing mini cases to ensure their survival through improving quality, increasing output, and lowering production costs. Waterco was also obliged to function as a low cost operation. Reduced costs were not a strategic move as suggested by Porter's low cost strategy, but were necessary to meet the production cost levels of competitors and to satisfy the demands of customers. Similarly, better quality and improved deliveries were necessary order-winning conditions.

Managers in the mini cases were not greatly concerned with product versus process technology considerations. Technology was sought to meet externally determined end-product quality requirements. Production output and quality constituted the performance standards used by managers in specifying new technologies. Mini case customers expected conformance to specifications, reliability and flexibility of supply, but were not interested in the manufacturing process, or in long-term innovative capacity (as proposed by Barnes and Kaplinsky, 2000). Competitive advantage attained through product and process innovations, as suggested by Zhang et al (2001), was not part of the technology decision-making process, although respondents accepted the assertion by Lennon (1997) that equipment and processes needed regular updating in order to match competitors' abilities. Technological parity was not an issue, but rather the ability to meet customer requirements, irrespective of the process.

Leonard-Barton's (1995) "knowledge-creating activities" and "technology capability ladder" provide useful descriptions of technology characteristics in the case organisations. Waterco's new plant was a turnkey operation, with limited technological input from its own staff, apart from specifying quality and output requirements. Consulting engineers played an intermediary role in specifying technological standards, but the technology itself was not seen as the mechanism for achieving what was desired. The issue was the provision of an affordable plant that would meet required performance standards.

The second level in Leonard-Barton's ladder refers to adaptation and localisation of components. The technology installed in the manufacturing mini case plants was a combination of the first level (turnkey) and, to some extent, the second (some adaptation to the technology). In Leonard-Barton's terms, adaptation refers to adjustments and alterations to suit local, developing country levels of technological expertise. Managers were adamant that any adaptation required had nothing to do with reducing levels of technological complexity that would be required if their organisations were unable to operate high-technology installations. Rather, engineering adaptation was inevitable when new equipment was installed in an existing plant. Financial constraints caused some levels of technology to be lower than those in the technology suppliers' countries.

Eskom's construction of new power stations and upgrading older stations were not strategic moves for competitive advantage. New plant was installed for operational needs such as additional installed capacity and improving availability.

The findings support this research question that goals and objectives are to be achieved through the technology, but these were not set in strategic terms, and technology was not required to provide competitive advantage.

Overall assessment of research question 1

The analysis supports the overall perspective that suppliers and acquirers reach common accord in the selection of new technology, but not directly as stated in the research questions. Eskom's high-level decisions take into account electricity demands in South Africa, but these are not technology decisions. Common accord between Eskom and its suppliers was technical as performance standards were set in operational terms. Apart from adherence to regulatory requirements, the country's needs and demands were not part of the technology decision-making process. This will change somewhat as suppliers are required to comply with Eskom's black economic empowerment purchasing policies. Mini case requirements were also set in operational terms to which suppliers responded with technology solutions. Neither party devoted much time and effort in considering the acquiring country's or firm's capabilities, limitations and human resource factors.

9.3 RESEARCH QUESTION 2 - SURVEYING AND ANALYSING NEW TECHNOLOGY

This question investigates technology options for meeting the acquirer's goals, subject to a cost-benefit assessment, an evaluation of the acquirer's resources, and basic economic and technical factors. These accord with Samli et al (1992) who emphasise the role played in TT by macro conditions in developing countries, and may be identified as part of the complex picture painted by Alcorta (1999) regarding the interactions and outcomes of technological, economic, institutional and individual considerations.

The resource-based view of strategy suggests that through routines, learning and other variables, resources lead to capabilities (as illustrated in Figure 2.3). These are relevant to items in each subsidiary question in this second research question. Relating the first resource (physical capital) in Barney's (1991) categorisation to the mini cases, plant and equipment were acquired from suppliers. The second component (human capital) was the most difficult to set in place, while the third element (organisational resources) was perceived as part of normal operations, and received little specific attention. The surveys undertaken by firms prior to purchasing technology analysed the features and cost of plant and equipment so acquirers could be confident that desired functionality would be achieved. Apart from the recognition that staff would require training, managers devoted little attention to HR issues. Organisational resources were assumed to be in place, so were not part of an analysis of acquirer goals. Capability aspects in Figure 2.3 were partially addressed during selection and analysis. Managers planned the acquisition of skills as part of overall human resource development.

The preliminary research indicated that technology could be instrumental in formulating strategy through acquiring distinctive competencies, enhancing processes and re-examining vertical integration. There is no indication from the case studies that these items were addressed. Outcomes from technology were seen in operational terms (meeting quality and output demands of customers at a competitive price), rather than in strategic terms.

Research question 2.1: Analyses and surveys of available technology identify appropriate technologies for meeting the acquirer's goals

Analysing and surveying available technology were part of the feasibility studies undertaken by the case organisations. In some instances managers did not have much choice in the selection of technologies. Power station technologies are in many respects similar, irrespective of the supplier, and Eskom has specifically used designs and equipment from earlier power stations (for example, Lethabo was modelled on Matla Power Station, and Tutuka on Duvha Power Station). This shortened the time for design and drawing up specifications, and reduced operator training when staff were transferred between power stations with similar technology. Managers' investigative analyses were often surveys of technology suppliers, rather than of a technology itself. Owners and acquirers did not agree on a technological approach that was deemed 'appropriate' for the level of development in the acquiring country, as advocated by Blumentritt and Johnson (1999) and Plenert (1994), although there was firm resistance to obsolete technology (agreeing with Moor, 1994). Further, acquirers did not determine 'appropriate' levels for proceduralisation and automation on the basis of their level of knowledge of a process (as suggested by Bohn, 1994). The main contractors, not Eskom, specified technologies for auxiliary equipment.

In the mini cases the number of technology suppliers was limited, and acquirers approached those with whom they had had previous dealings, usually in Europe and the US. The questions raised by De Meyer (1992) are relevant in studying technology selection. His first question pertaining to internationalisation of R&D and engineering applies to the extent that all case studies looked internationally for their new technology, because technological knowledge was not available in South Africa. The reason for implementing new technology in the manufacturing mini cases was to strengthen competitive positions through overall cost reduction (not only labour cost reduction as suggested by De Meyer's second question). Indeed, Plastico and Foodco had promised there would be no reductions in the labour force as a result of technology, but managers realised that the effective deskilling of jobs may well lead to changes in payment structures in the longer-term.

With reference to De Meyer's third question about the ease of accessing technology in developing countries, Eskom sourced locally where possible, both directly and through its contractors (in terms of its support for black companies). South African engineering firms undertook most civil design and construction for power stations. Boiler and steam piping, motors, certain mill components, fans and some pumps were produced locally, but control systems, and most high-technology boiler and turbine items were imported. The mini cases preferred turnkey arrangements, rather than having to source selected items locally, and importing the remainder. Regarding De Meyer's fourth point of closer physical proximity of suppliers, this was useful, especially where foreign suppliers had local representatives.

The findings support the research question that analyses and surveys assist in identifying technologies to meet acquirers' goals, but they also indicate that cost was a major factor in technology selection. Details of technological processes were left to suppliers, provided desired functionality was guaranteed. Acquirers did not address what constituted 'appropriate' technology in much detail, but occasionally stipulated what technology would be unacceptable.

Research question 2.2: Analyses and surveys of available technology to take into account costs and benefits of the new technology

The mini case organisations were more concerned with functionality than with the technology itself: what the technology should provide. Once the firms were satisfied with this, cost was the deciding factor, but benefits were not formally quantified. In several instances, technology enhancements were sacrificed because of cost. Promises of lower longer-term operating costs held little sway. One supplier commented that South African organisations only understood capital expenditure, but not operational expenditure, and made no attempt to balance current capital expenditure against longer-term operational costs. The scope of technology was determined by cost, rather than cost-benefit analyses, which are only one option for evaluating technology and measuring the success of TT (Spann et al, 1995).

This was partly because of difficulties in quantifying benefits of different technologies. Another reason was that precise goals were frequently not specified. Applying the thinking of Hackman and Wageman (1995) to new technology, firms sought fewer defects, higher availability of equipment, lower operating costs, and in some cases, a reduction in the workforce. Yet, managers were unable to quantify these in terms of acceptable quality levels, plant availability, or specific operating costs per unit of output. Without such quantification, a true cost-benefit analysis was not possible.

Eskom was more prescriptive in specifying operating costs per kWh sent out, and contractors were contractually obliged to deliver according to these standards. Yet, these were not consistently enforced. Respondents claimed that they did not conduct comprehensive cost-benefit analyses because of many uncontrollable intervening variables. The findings, therefore, do not support the research question that analyses and surveys of technology enabled costs and benefits to be determined.

Research question 2.3: Analyses and surveys of available technology assist in evaluating technology on the basis of the acquirer's resources

Technology was evaluated against acquirers' financial resources, as mentioned in the two previous sections. Respondents discovered during operations the extent to which human resource skills were barriers to new technology implementation, but difficulties in recruiting skilled staff and the slow rate at which staff could be trained and developed internally did not affect the type or complexity of technology selected. Some Eskom staff explained difficulties that had arisen because, in the past, relatively skilled and experienced personnel had been trained as operators, whereas current trainee operators had low levels of technical education. The racial undertones in this comment came from individuals who were often responsible for training and supervising those whose appointment and promotion they resented.

Questions of appropriateness, robustness and transferability arise frequently in the literature. The first of the co-ordinating or bridging mechanisms proposed by Katz et al (1996) to address appropriateness (the suitability of the acquirer's capabilities to accommodate new technology) is the procedural bridge involving joint planning and staffing. The function of project teams set up by the case organisations was essentially to manage projects, rather than attend to how technology should be transferred. Joint planning by suppliers and acquirers was undertaken in all cases, but this did not adequately look at the acquirer's ability to operate the new technology. The second (human) bridge was reasonably successful in establishing interaction between suppliers and acquirers, but again, this was more for design and installation than TT. The purpose behind the third (organisational) bridge is to constitute teams and processes to formalise TT. Again, the teams set up as project teams did not look specifically beyond the project to operational issues. It was clear in most cases that the lack of an individual charged with overseeing TT adversely affected the process.

Grant and Gregory (1997) describe robustness as the condition where a process can be transferred to any environment without adaptation. Respondents felt the technologies they had acquired were robust in not requiring adaptation for local conditions, other than modifications for engineering compatibility (pipe sizes, pressures, temperatures, and so on). In claiming that technology had been transferable, respondents reported what Grant and Gregory (1997) describe as the ideal process: robust and transferable technology.

Despite respondents' claims of their ability to accommodate new technology, in several instances the considerable degree of self-contained and embodied knowledge in the technology indicated that not all technology was appropriate. Grant and Gregory (1997) suggest that such situations, characterised by poor appropriateness and low transferability, require more intensive transfer methods. However, intensive transfer methods were not encountered in the case studies, resulting in limited TT. This would explain the difficulties of the manufacturing mini cases in modifying control systems or amending quality attributes, and the problems encountered with their maintenance.

The technology-push and business needs-pull concept (Martinsons and Schindler, 1995) provides some insight into TT in the cases. Suppliers pushed their technology in a commercial sense to gain business (the 'need' in Zmud's (1984) terminology). In the manufacturing mini cases, there was generally only one broad solution to acquirers' requirements: largely automated production that could meet quality and output requirements (the 'means' using Zmud's (1984) term). This may be construed as business needs-pull. Matching the business needs-pull with technology-push was largely the task of the supplier. This was not an onerous technological exercise as the business needs were fairly standard.

It was more difficult to visualise Eskom's needs in business terms. Greater generating capacity is the reason for constructing new power stations, but once the decision is taken to proceed with construction, business needs are relegated to head office departments with limited influence over TT. The task then becomes one of managing the technology installation at the power station. As Lall (1993) suggests for large organisations, Eskom is better placed than the smaller mini case firms in being able to research, pay for, and absorb advanced technologies from suppliers. Matching technology-push and business needs-pull is rather a distant and abstract issue in Eskom's case.

In all cases technology was evaluated in terms of financial affordability, with little reference to human or other resources. Because technology installation was managed as a project, technology was not evaluated in terms of appropriateness, robustness and transferability. Acquirers assessed technology on the basis of business needs-pull, whereas suppliers viewed technology-push as the driving force. This shows technology was appraised in a number of ways, but the findings do not suggest that analyses and surveys assisted in evaluating technology on the basis of acquirers' resources.

Research question 2.4: Analyses and surveys of available technology consider basic economic and technical factors affecting the TT process

Technical factors were analysed in a number of ways. In Plastico and Foodco investigations were to assess whether prospective new technology could meet customer quality requirements, such as consistent film quality to be measured on an SPC basis (Plastico), or slicing of raw materials (Foodco). Waterco selected equipment on the basis of cost, with little regard for the technology itself as managers claimed that the technology used in water purification was so well known and processes had been perfected to the extent that there was little difference in the technologies offered by well-known suppliers. More complex technology could have improved monitoring systems, and further automated control, but the cost would have been too high. Flourco sought a control system that would integrate with old plant without major adaptation to the new or old equipment.

Eskom's policy was not to seek technology for its own sake, but several respondents at power stations suggested that head office engineers were not aware of operating difficulties at site. Technology was acquired because it was the latest, not because it was necessarily the best. They pointed to high-technology equipment that was difficult to operate and maintain, but which did not appear to offer any special benefits.

The preliminary research suggested that labour issues were important in TT, but there was no indication of unions' resistance to new technology or industrial relations issues affecting technology decisions. Political matters such as affirmative action and employee equity were raised with great vehemence at times, but were not significant when analysing technology.

The findings indicate that analyses and surveys of available technology cover a wide variety of issues, but most are concerned with the technology itself. Decisions were not made on the basis of macro economic or political factors in the sense proposed by Quinton (2002). Although the literature and preliminary research raise a number of non-technical issues, consideration of this research question finds limited evidence of these.

Overall assessment of research question 2

The second research question suggests that technology options do take into account acquirer goals, resources, and economic and technical factors. Operational goals in terms of quality and output, and functional requirements within budgetary constraints were clear in the mini cases. Other factors were of secondary importance. Eskom's performance objectives were set, but cost-benefit analyses were not performed. In Eskom's case, and to a lesser extent in the mini cases, technology and planning decisions were made at higher managerial levels, whereas TT took place at lower levels with insufficient interfacing between them. Contact with suppliers was at a high level until commissioning, so many decisions were taken by those not involved with TT. Technology options investigated at corporate level by senior managers may well have taken acquirer goals and economic factors into account, but human resource and other technical matters seemed to elude decision makers. Technology analyses suffered from a break in continuity, with designers and technology specifiers operating at a different level to receivers of the technology.

9.4 RESEARCH QUESTION 3 - SELECTING NEW TECHNOLOGY

The third level bridges the divide between technology specifiers and designers at corporate or managerial level and users at the operating level, and assesses the extent to which human resource issues are considered in technology adoption. The question further looks at technology evaluation on a cost-benefit basis, surveying suppliers and assessing alternative technologies. Decisions at this level partly relate to Narayanan's (1998: 220) technological paradigm involving a shift from one technology to another "to operate on a different technology frontier through which new and differentiated products can be produced".

Research question 3.1: Final decisions for technology selection take into account human factors pertaining to the new technology

Human factors may be viewed from a skills and an ergonomic perspective, neither of which seemed to have a great influence on final technology selection decisions in the case studies. This agrees with Baranson (1969) that HR issues are of secondary importance when selecting appropriate technology. Control and coordination, training and development, and adaptation of technology to external and internal conditions (Williams, 1996) received attention once installation and commissioning had commenced, but managers did not consider deficiencies in the skills of their staff as reasons for choosing one technology in favour of another.

In their assessment of technology managers failed to differentiate between Lall's (1993) implicit elements in technology that are mastered over a long period of learning through experience, and explicit elements that can be acquired immediately. There was a general impression that output would not meet specified targets immediately as a period of familiarisation was necessary, or in maintenance terminology, for the burn-in or infant mortality phenomenon to settle down (Pattern F in Figure 3.7). Prescriptive operational and maintenance procedures are explicit in Lall's terms, but operators and maintenance staff were not fully capable of following these. This suggests that staff in developing countries carrying out activities that would be construed as routine and explicit in a developed world environment (but which are actually based on a level of implicit knowledge), lack the requisite deeper understanding for competent performance. Lall's differentiation between transfer of technology (supplying equipment and providing instructions) and effective mastery of technology (absorption and deployment) provides an unusual definition of the boundaries of the term TT, but describes the problem encountered in the cases: firms studiously managed the supply of technology and issued operating instructions, but neglected absorption and deployment.

Apart from the handling of raw materials at Waterco where mechanical equipment was installed, technology decisions did not take ergonomics into account. This is in line with Shahnavaz (2000) that many organisations do not cater for changed working practices, and are surprised by high rates of accidents and injuries, low productivity and poor quality.

All cases concentrated on the technology in their selection decisions, so their neglect of human resource issues pertaining to new technology, does not support the notion posited in this research question.

Research question 3.2: Decisions for final technology selection evaluate final costs and benefits of the new technology

As stated in the discussion of the second set of research questions, the cost of new technology was one of the most important issues in final selection. However, head office managers and design teams underplayed cost-benefit analyses as part of the process, and this was not considered a function of operating and maintenance staff. Technology selection was a managerial task where technical and affordability considerations were taken into account, so while some consultation took place in the mini cases, supervisors generally felt managers used a policy of 'decide-and-defend': managers decided on the technology, and defended their decision when challenged about any aspect of it.

The case studies had not considered Sharif's (1997) trade-off between product complexity (for value maximisation) and process complexity (for cost minimisation). The findings therefore do not support the view that evaluation of final costs and benefits are part of the final selection of technology. Issues discussed under research question 2 relating to the difficulty in quantifying benefits also apply to this question.

Research question 3.3: Decisions for final technology selection follow a comprehensive analysis of all possible technology suppliers

Management and engineering staff were involved in reviewing possible technology suppliers, which usually included European, US and Japanese suppliers, reflecting

South Africa's traditional historical and commercial ties with countries that had imposed no or limited sanctions during the apartheid era. While new managerial appointees, and in particular blacks, had not been involved in negotiations during the sanctions era, commercial habits remained strong. Many managers were unaware of the equipment available from other countries.

Once Eskom had appointed a main contractor as technology supplier (of which there are relatively few in the world, and no more than about five appear on the approved list of boiler and turbine contractors), this contractor was responsible for subcontractors, subject to Eskom's approval. On a smaller scale, the mini case main suppliers also chose their own subcontractors. Technology options were investigated at level 2, and once a particular technology had been selected, the number of suppliers reduced.

Findings indicate that final technology selection did not follow a broad review of technology suppliers as suggested by this research question.

Research question 3.4: Decisions for final technology selection assess all alternative sources of technology

Comments made under the previous question also apply here in that proven technologies from known suppliers were usually favoured. Respondents denied passive dependence on imported technology. However, mini case managers were somewhat acquiescent in their technology selection, as a supplier's solution to an acquirer's requirements was frequently accepted with little debate on the applicability of the technology. Some respondents attributed this to a lack of knowledge of available technology, and inadequate research. Where firms had no engineering department, or few competent engineers, managers did not have the time or expertise to investigate technology markets thoroughly.

Managers felt it was preferable to purchase from an experienced foreign supplier with whom they had had previous contact than from an unproven South African firm or an unknown foreign supplier. The lack of credibility directed at some South African suppliers detracted from the likelihood that technology 'anchors' would be developed

(Kumar and Jain, 2001) to establish the technological foundations for expertise in a particular sector. Some managers accepted that this was a short sighted view, as they pointed to local industries such as electrical equipment suppliers and the automotive sector that had successfully established credible technology 'anchors'.

The findings do not support this question that all alternative sources of technology were investigated when making final selection decisions. Managers narrowed the choice to a few suppliers and the final decision between their technologies was usually based on cost and personal preference for one technology and supplier over another.

Overall assessment of research question 3

The issues discussed under this research question were not supported by the case study findings, indicating that human factors were generally not taken into account in final technology selection, cost-benefit analyses were not performed, comprehensive analyses of all technology suppliers were superficial, and not all alternative technologies were assessed.

The divide between technology specifiers and designers, and technology users is again illustrated when discussing this research question. The third step proposed by Salami and Reavill (selecting technology) is not as distinct from the second step (analysis and survey of technology) as their framework may suggest. In many instances the same staff perform these steps: senior managers look at broader technology parameters (level 2), and consider the selection details (level 3). The two activities are carried out in parallel, with selection of technology resulting from a choice between a limited number of suppliers identified at level 2. The research question is further not supported because of the emphasis on technology, and not on its transfer. The purchase of new equipment led the case organisations to believe that they had acquired new technology, but their difficulties in operating and maintenance support Leonard-Barton's (1995) contention that this thinking is misguided because the firms lacked the relevant skills. Again, the lack of a technology champion to bridge the divide between levels was evident.

9.5 RESEARCH QUESTION 4 – IMPLEMENTATION AND MAINTENANCE

The fourth level addresses integration of technology and operations, with specific reference to implementation and maintenance, personnel and training, new approaches to TT, and new technology adaptation. Pressing operational demands did not afford the case companies the opportunity to develop, as Niosi and Godin (1999) suggest, through incremental enhancements, innovation and evolutionary replication.

Research question 4.1: Implementation and maintenance of new technology involve the supplier and acquirer in providing guidelines for management and implementation of the new technology

In Eskom projects, contractors and appointed suppliers provided operating and maintenance manuals for their equipment. The mini cases were less demanding, so manuals were less comprehensive. To some extent this corresponds to the first of Simango's (2000) three levels of TT development, where experts pass on knowledge. Acquirers accepted that it was not possible to operate or maintain a machine only by reading the manuals, since the operating context always played a part in operating and maintenance procedures.

Suppliers complained of a lack of transfer of best practices (Bresman et al, 1999) indicating acquirers' weak information and control capabilities, as well as poor working practices and workmanship. Contractors recalled many instances, where acquirers made no determined efforts to establish the true cause of failures. With reference to the RCM process (Figure 3.11), maintenance was not based on failure modes (let alone functionality), but on addressing failure occurrences. Where operating errors and poor maintenance caused failures, suppliers were frustrated in their efforts to 'educate' their customers in better practice. In this respect the case organisations did not, in terms of Simango's (2000) second level of TT development, share responsibility between owner and acquirer, nor was the technology operated by individuals with adequate knowledge and capability.

One reason for these difficulties was Eskom's project management approach. Suppliers' designers and engineers were in close contact with head office project staff that in turn communicated with project management site staff. When equipment failed during the guarantee period, Eskom's project management site staff were responsible for arranging repairs. Eskom's operational staff sometimes chose not to become involved as this was a 'project site staff problem', while at the same time complaining that they were not fully informed of what remedial action was to take place. On other occasions, technology suppliers implemented modifications in conjunction with Eskom head office and site staff without fully consulting with operations. This demonstrates the need for an improved coordinating function.

The manufacturing mini cases differed from Eskom (where several hundred contractors could be on site at any one time), since more intimate cooperation between suppliers and acquirers was possible. Little formal training took place, but local staff were more closely involved in installation, commissioning and fault finding during the early stages of technology implementation. Waterco was an exception since the consulting engineers were appointed to manage suppliers. Waterco subsequently regretted that they had not taken a greater part in commissioning. The consulting engineering firm was a barrier comparable to Eskom's project management site team. These comments suggest that the case organisations' actions did not follow the suggestion by Irwin et al (1998) that TT is less a task to be accomplished than a set of relationships to be nurtured.

Respondents were slow to recognise the importance of integration of systems and people issues in the new technology context (Burcher et al, 1999), or to identify new forms of social construction (Gergen and Whitney, 1996). There was no evidence of agreement with Gergen and Whitney's (1996: 336) references to "alien beliefs ... undermining of traditions ... colonisation of perceptions, attitudes and actions ... tyrannical effects of globalising organisations".

There was no altruism in the contribution of suppliers to TT. Suppliers hoped for a long business relation horizon with Eskom since there was always the prospect of further future work, but changing conditions, new staff and different priorities meant that Eskom's 'corporate memory' was short. Suppliers commented that acquirers felt the developed world 'owed' developing countries some form of assistance. White managers justified their claim by pointing to the damage caused by sanctions; blacks felt their fight against the evils of racism should be rewarded, and that western countries should pay for their overt or tacit support of apartheid. Compensation was expected in training, technological support and management guidance. Suppliers were unimpressed and not persuaded that anything beyond good customer service was called for.

Respondents volunteered that training offered direct instruction for operating procedures, which were a limited part of overall operational capability, but was no substitute for experience. Restating this in Nonaka and Takeuchi's (1995) terms, explicit knowledge formed a relatively small component of the sum of knowledge vested in the technology required by the case organisations. Experiences in the case organisations supported von Hippel's (1994) contention that design changes required intimate knowledge of the process and high levels of skill. The challenge came at two levels. Firstly, respondents were generally unaware of the relationship between desired performance and equipment capability (as illustrated in Figure 3.5). They were unable to quantify many performance standards, and often sought performance that lay outside the envelope of maintenance capability. Secondly, operators lacked the knowledge and subtle skills that were difficult to codify, and a "plethora of incremental fixes and adjustments" (Katz et al, 1996: 98-99) that were essential for competent operating. The limited extent to which technology was transferred could be gauged by the difficulties experienced by local staff in fine-tuning for optimal performance.

The case organisations did not coordinate the interaction between equipment, operating and maintenance staff, and the organisation itself (proposed by Pitz and Weber, 2001). There was wild disagreement between the critical, economically justified/insignificant, and non-critical components (shown in Table 3.1). In terms of the TPM framework (Figure 3.13) and its five essential features, maximising equipment effectiveness was sought only for maximising production output. The second feature, relating to the development of productive maintenance for the life of the equipment, was not addressed. Where preventive maintenance activities had been introduced, they were directed at preventing immediate failures, without specific efforts being made to establish the root causes of failure. Rather than using a formal maintenance task determination process (such as that in Figure 3.12), solutions were frequently sought in poorly thought out plant modifications. In all case organisations physical asset management was solely the function of the maintenance department, with little involvement by other disciplines, as recommended by the third and fourth TPM features. The only small group activity for addressing maintenance (TPM's fifth feature) was found in the power station using RCM to determine its maintenance requirements. Otherwise an engineer or a supervisor decided what maintenance tasks should be undertaken, on the basis of suppliers' recommendations and personal experience.

While it is accepted that TPM was not specifically guiding the maintenance of any of the case organisations, there was no indication that maintenance thinking followed TPM philosophies such as elimination of all failures, or maintainability improvement. From a managerial perspective, case organisations did not encompass the autonomous maintenance ideas of TPM (shown in Figure 3.13): housekeeping was important, particularly in the mini cases, but cross-training, teams and operator involvement were not utilised. There was limited evidence of information tracking, disciplined planning and schedule compliance.

Many respondents recognised incorrect maintenance practices in their firms, particularly where maintenance was based on simple preventive models or opportunistic maintenance (as illustrated in Figure 3.2). Preventive maintenance usually meant scheduled replacement of items, in the belief that 'more maintenance means better availability'. Where there was a close relationship between age and equipment failure (such as wearing parts in Flourco and Foodco), maintenance history should have enabled to study the impact of maintenance on reliability, as depicted in Figure 3.4. Weekly maintenance at Flourco was aimed at improving reliability from servicing (the upper part of Figure 3.4), but no attempt was made at projecting degradation during an item's lifetime. Poor craftsmanship meant that reliability improvement from overhauls (the lower part of Figure 3.4) was not attained. In most of the cases multi-state models (described in Figure 3.2) would be applicable where the time for the next intervention (replacement or inspection) should be determined at each inspection. Several examples are cited in the appendices where craftsmen's suggestions to follow such practices were derided.

Some power stations had embarked on proactive risk-based and cost effectiveness assessments (simple preparedness models in Figure 3.2). In the mini cases there was limited methodical determination of maintenance in terms of Figure 3.3, suggesting that the basis for most maintenance was the failure rate of equipment, rather than an assessment of failure consequences. Managers preferred design modifications to detailed failure analyses and ways of improving operating procedures.

The findings lend some support to this question, but there was no evidence of inter-company relationships as posited by Fleury (1999) in relation to manufacturing strategy, organisational architecture and management control systems. Guidelines from suppliers were purely technical.

Research question 4.2: Implementation and maintenance of new technology involve the supplier and acquirer in relation to personnel training and human resource issues
This question covers a wide variety of topics relating to human resource management, and technical and non-technical issues, not all of which involve technology suppliers. Neither suppliers nor acquirers envisaged a role for suppliers in day-to-day management affairs. Training and technical guidelines from suppliers discussed under the previous question were integrated to some extent, but the management of other HR and organisational factors relating to TT was considered to lie exclusively with the acquirer.

Operating and maintenance staff lacked a thorough understanding of equipment and system functionality. Functions of individual items were looked at and single failure modes were addressed, without assessing the broader impact. Training could not cover all eventualities, so the challenge was to inculcate a questioning approach to operations and fault diagnosis.

Some firms attempted to implement the idea by Bresman et al (1999) that smooth TT is achieved when recommended operational and maintenance practices and procedures (explicit knowledge) lead to correct operating and maintenance. This requires the acquirer to develop information processing and control capabilities. While TT is of course important in the technical domain, the literature emphasises the role of other organisational and control processes that affect, or are affected by, the technology (Hart and Schlesinger, 1991; Sitkin et al, 1994; Tuckman, 1994). Respondents at supervisory and operational levels did not express opinions about supporting or resisting the new technology as they felt that they had no choice but to accept it. In the mini cases the equipment was installed and their job was to operate it. Operators abided by the procedures set in place. In the Eskom cases, many staff had applied for positions at new power stations and had been transferred from other stations. This was similar to accepting a new job, and one operator remarked 'in a new job, with a new boss, you don't start questioning things'. The technology was 'adopted' without question. There was no evidence that diffusion of knowledge was resisted, although some staff were passive in that they went no further than doing what they were told, nor were they proactive in expanding their depth of understanding of the technology.

From an organisational perspective, managers lacked what Martinsons and Schindler (1995: 11) refer to as the "evangelizing, exploring, motivating, mediating, projecting, planning, problem-solving ... need to examine and enhance organizational practices which are used to introduce, integrate and institutionalize". Eskom respondents did not view the technology as something to embrace. Various examples of planning and problem-solving in this context may be taken from the maintenance literature. The preventive and preparedness models in Figure 3.2 differentiate between simple age replacement (so often practised by the case organisations), and replacement as a result of inspection of monitored and non-monitored components.

Efforts to increase MTBF received some attention through preventive maintenance, but inadequate attention was devoted to operating procedure improvement, failure analysis and operator error reduction (outlined in Figure 3.3). The only factor in Figure 3.3 used to decrease MTTR (mean time to repair) was condition-based maintenance. Failure-finding for hidden functions were seriously (and potentially dangerously) neglected. Training for error reduction was not undertaken, and spares and logistics received little methodical attention. Despite increasing use of condition-based maintenance, this was frequently ineffective because the principle of lead time to failure (illustrated in Figure 3.14) underlying the frequency of inspections was not understood.

Reference has already been made to the importance of relating initial capability of equipment and desired performance (illustrated in Figure 3.5). This was passed off by respondents as a design function, but deterioration or incorrect operating practice resulted in a reduction in reliability operational margins (shown in Figure 3.4).

In the mini cases, there was heightened interest in the new technologies because more staff had been present during installation and commissioning, even if they were not personally involved. The task of "evangelizing, exploring, motivating ..." was essentially one for all supervisors. Operational issues were delegated, as managers did not have sufficient knowledge of the technology to make much technical contribution themselves. This was perceived by some operational staff as a lack of commitment by managers, who suggested that their superiors did not adequately legitimise familiarisation activities (Dimnik and Johnson, 1993). Managers were also unsure of how they should create a learning organisation (Kasul and Motwani, 1995).

Adopting a resource-based view of knowledge management, Helfat and Raubitschek (2000: 961) speak of "the co-evolution of knowledge and capabilities incorporating the vertical chain and the products it supports". Operational and maintenance staff indicated how capabilities improved as they learnt more about equipment functionality. While the literature highlights the role of the supply chain in enlisting the support of suppliers, respondents saw the importance of 'staying close' to the supplier, especially during installation and commissioning. The literature specifically considers the strategic aspects of the resource-based view, but respondents looked at knowledge of plant and processes as a potential core competency. They did not view the creation and transfer of knowledge as a single concept, as suggested by Zander (1991). Some knowledge could be transferred from supplier to acquirer, but it was essential for acquirers to create other components of knowledge themselves. While there were instances of knowledge flowing from supplier to acquirer and back as feedback (Bresman et al, 1999), respondents usually saw one-way knowledge flowing from suppliers.

Project managers were not champions and were not responsible for TT. In fact, no one was responsible for TT. TT had not been viewed as something to be managed, and in most instances, TT had not even been considered. The necessity for training was widely recognised, but TT was a foreign concept. Respondents' comments supported Leonard-Barton's (1995) view that networks of capabilities could play a valuable role in TT, as acquirers saw the benefits accruing from contacts with suppliers, and in some cases, other acquirers. This was easier in Eskom's case where there was no competition between power stations and utilities abroad. In the manufacturing mini cases, sharing technical insights with other users was likely to mean contact with competitors, which was obviously not ideal in competitive business environments.

The influence of culture on TT in general and specifically on human resource aspects of TT receives considerable attention in the literature (Eldred and McGrath, 1997; Gupta et al, 1997; Tyre, 1991). The preliminary research identified national culture as an element in TT, but South African managers did not attach great importance to culture. Respondents complained about how technology was transferred, and commented on a lack of consultation, but there were no accusations of "a failure to understand cultural differences (leading to) misguided assumptions" (Bowmaker-Falconer, 1998: 225). Grievances related to "poor working relations, under-performance and discrimination", but respondents did not ascribe these to cultural differences between suppliers and their organisations, or to the technology.

There was support from a supplier perspective of Hussain's (1998) reference to the necessary absorption capability of an acquiring firm through a combination of work culture, science and technology. Suppliers complained about a poor work ethic in South Africa, South Africans' reluctance to accept responsibility for the standard of their work, and low levels of technological competence. Some suppliers added that their experiences in other developing countries were similar, and by no means unique to

South Africa. Most managers felt that South Africa, as part of the international community, was obliged to compete according to a global, capitalist business model[4].

The contention by Mbigi and Maree (1995) that cultural dimensions in situations of poverty and suffering have a significant impact on the management of transformation was not supported by the research. In relative terms, even the lowest paid operators interviewed lived above the levels of poverty and suffering referred to by Mbigi and Maree. The more anthropological views expressed by Lessem (1998) regarding the authority of 'the north' (western attitudes, practices and beliefs), the community of 'the south' (the African concept of *ubuntu* values of humanity in a social context), and economic forces of pragmatic integration, were inherently appealing to some white respondents, but were not supported by blacks in a TT context.

The comment by Matustik (1998) about the complementarity of African and European modernity was treated with support and derision. Black respondents were adamant that there is no difference between the way blacks and whites do business, or the way they view technology. Others believed that affirmative action and employee equity programmes were part of the South African way of running a business, and that if this resulted in difficulties in transferring technology (because some personnel were not fully technically competent), then this was part of the transformation of the country. These respondents felt that suppliers had a duty to be more understanding of the difficulties faced by blacks in the field of technology. These divergent views support Kuper's (1999: 212) rejection of "cultural wholes", and the acceptance that "cultural boundaries are uncertain and subject to negotiation, and that all cultural fabrications are contested from within". This corroborates the cultural homogeneity discussed by Phillips et al (1994) and Inkpen's (1998) downplaying of the cultural dimension provided the learning organisation is encouraged.

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[4] This sentiment corresponds to Lessem's (1996: 36) contention that South African "economic and educational institutions are modelled on Anglo-Saxon heritage more than any other ... (and that) business has drawn on a "pragmatic 'western-ness' for its material *body* ... and upon a rational 'northern-ness' for its organisational *mind*".

Cultural differences between case organisations were not formally studied in this research, so it is not possible to test, for example, Hussain's (1998) contention that a less 'open' acquirer culture may inhibit TT. Limited evidence from the cases supports the view of Voss and Blackmon (1996) that the influence of corporate culture may be even stronger than the effects of local conditions. With its regular experience with technology projects Eskom has become adept at using suppliers to enhance learning and knowledge acquisition (as suggested by Inkpen, 1998). The mini cases implemented new technology projects less frequently, and had not developed the systems and procedures to derive as much benefit from suppliers as they could have done. Several supervisors commented that managers were not sufficiently demanding of suppliers, suggesting this non-confrontational attitude arose from managers' technical ignorance.

The reference by Phillips et al (1994) to cultural homogeneity and language highlights some communication difficulties between suppliers and acquirers. Although the language of company communication was invariably English, difficulties arose with operators not proficient in English (English was not the first language of most operators and maintenance staff). This was not a cultural difficulty, but a matter of language. Training courses were also conducted in English, but trainees could not always follow the trainer. The problem was exacerbated by suppliers who themselves spoke (poor) English as a second language.

Collaboration between suppliers and acquirers support this question as far as training is concerned, but other human resource issues were considered to be the function of the acquirer, if indeed they were addressed at all in the TT process.

Research question 4.3: Implementation and maintenance of new technology involve the supplier and acquirer in selecting alternatives approaches to TT

Supplier-acquirer discussions took place in order to refine technology issues. Eskom's enquiry documentation provided for many months of negotiations and discussions between head office designers, project managers and suppliers to clarify its requirements and suppliers' technology options. Power station staff were generally not involved until contractors and suppliers had been appointed. Supervisors complained that discussions in the formative and design stages excluded those who would operate and maintain the plant. Because of closer relationships between operating staff and suppliers in the manufacturing mini case organisations, supervisory staff, and sometimes operators and maintainers, were consulted in operational discussions. Generally these concerned practical refinements of the main technology decisions, rather than selecting alternative approaches to TT.

Lall's (1993) differentiation between internalised and externalised TT provides a useful basis for discussion. Internalised TT is evident in the Eskom situation, where control remains with the supplier, typically applying in situations where technology is subject to rapid change, or where R&D are tightly controlled. Technology suppliers claimed not to control their technology deliberately, but where a technology owner supplied the equipment, the acquirer was dependent on that supplier for operating and maintenance expertise and spares. Lall's (1993) contention that internalisation is the preferred mode of TT when the acquirer lacks skills applied in the sense that modification of technology would be done by the supplier or in conjunction with the supplier. It was in the supplier's interests to ensure that as much technology was transferred as possible, as this would assist in achieving desired operating performance targets. Good performance at one power station was invaluable when tendering for further Eskom contracts, but also provided a good source of reference for utilities elsewhere in the world.

Lall (1993) suggests that the more sophisticated the acquirer, the greater will be the externalisation of TT. From interviews with equipment suppliers, Eskom was perceived as a relatively sophisticated buyer, but the expertise lay with head office engineers. Suppliers were critical of technical expertise at the power stations.

The situation in the mini cases reflected internalised TT, with relatively unsophisticated acquirers dependent on suppliers for all aspects of the technology (operations, maintenance and control). The perception of some acquirers was that suppliers were indeed trying to control the technology, or lock the acquirer into the supplier's technology, both in terms of spares and subsequent expansion.

This question raises the issue of suppliers and acquirers considering alternative approaches to TT. Respondents were concerned with technology installation, not its transfer. Belatedly, the appropriateness of technology was sometimes considered as far as this affected training and the ability of the acquirer to take over the new technology. Alternative approaches to the transfer of technology were not considered, so the findings do not offer total support for this question.

Research question 4.4: Implementation and maintenance of new technology involve the supplier and acquirer in identifying criteria for better adaptation of new technology
The contention by Niosi and Godin (1999) that integration develops through incremental enhancements, innovations and evolutionary replication suggests close cooperation between the supplier and acquirer. They worked together in all cases, but not as formulated in the question in seeking better adaptation of the technology. Respondents rejected suggestions of adaptation if this implied simplification for a non-technologically advanced developing country. They claimed that modifications might be required only to accommodate operational or environmental circumstances. There was little evidence of applying Narayanan's (1998) technological paradigm (determining the nature of technology adoption) and Fleury's (1999) configuration. Technological trajectories (problem-solving techniques to diffuse technology and establish manufacturing systems and procedures) and coordination (Fleury, 1999) took the form of suppliers providing informal on-the-job training (at Foodco and Plastico).

Training at Flourco was informal, but greater cooperation between supplier and acquirer was evident. While the supplier had installed control systems in other mills, the Flourco mill presented significant challenges, because of the age of existing machinery. Configuration difficulties required modifications to certain control system design parameters, and while the supplier performed these changes, operating expertise and knowledge by Flourco's operators was frequently called upon. Despite the opportunity of working closely with the supplier, Flourco staff later regretted the lack of attention paid to coordination of technological trajectories.

The lack of involvement by Waterco staff in installation and commissioning, and the intermediary role played by the consulting engineers led to a neglect of configuration. No diffusion took place until suppliers handed over new plant to consulting engineers.

The Eskom cases demonstrated considerable attention to technological trajectories and coordination. Configuration was dealt with in a more generic way: Eskom's standard organisation structures for power stations were applied to new projects. Extensive discussions took place between suppliers and Eskom head office staff. Power station staff commented that they were not sufficiently involved in technology configuration or coordination during the early stages of the project. The complexity of power station projects was such that tender documents were unlikely ever to be fully comprehensive, so points of clarification always would arise.

The literature refers to better adaptation of technology as a result of good R&D infrastructure and indigenous technology capability (Kharbanda and Jain, 1997). Suppliers considered Eskom's corporate technology capability to be good, but lacking at the operational level. Suppliers explored technology issues with head office, but felt that technology adaptation did not occur as TT was seldom discussed with power station staff. In the manufacturing mini cases suppliers worked closely with acquirers, so technology implementation received more attention. However, in none of the cases were specific criteria identified that would lead to better adaptation of new technology.

Finally, the organisations did not appear to address the significance of the social dimensions of TT, and the web of social and cultural relationships suggested by Peppard (1996). While managers certainly publicised the introduction of new technology (corroborating the view of Meyer and Rowan (1977) that by incorporating and institutionalising practices and procedures organisations increase their legitimacy and survival prospects), they did not discuss how TT had progressed and how technology could be better adapted.

From these discussions, experiences in the cases do not support the notion that suppliers and acquirers were closely involved in identifying criteria for better adaptation of new technology.

Overall assessment of research question 4

The case organisations used project management principles to manage the installation of new technology. However, this was not a surrogate for TT. Attention was paid to technical issues, but TT required a broader approach. Training was the only item in this research question that was specifically addressed apart from the technology itself. Other general and HR management issues as well as investigations into alternative technologies and criteria for technology adaptation were not adequately addressed.

9.6 RESEARCH QUESTION 5 – EVALUATION AND MODIFICATION

The fifth level evaluates and assesses TT with reference to the acquirer's goals and performance criteria. This includes operations and maintenance practice and performance, modifications and areas for efficiency improvements and innovation. Effectiveness of maintenance is discussed with reference to the theory in Chapter 3.

Research question 5.1: Evaluation and modification of new technology are based on specific criteria derived from the acquirer's goals

New technology was not formally evaluated. Acquirers' goals were expressed as operational objectives to be achieved through the use of technology, and were evaluated informally by assessing whether their operational needs were met. This supports the views of Baines et al (1999) and Bartlett and Ghosal (1989) that acquirers identify the need for new technology to meet operational requirements such as increased output, improved reliability, lower costs and quality advantages. The lead time for receiving new equipment was a significant factor in the mini cases as their old technology adversely affected their competitive standing. Managers were not specifically concerned with short- and long-term compatibility between the technology supplier and themselves. The technology was to reinforce the core competences of Flourco, Foodco and Plastico, in order to make the firms competitive within their industries.

As Spann et al (1995) have noted, the inter-organisational nature of TT means that a single measure such as cost-benefit analysis serves as only one form of assessment. Cost-benefit analyses were frequently mentioned during interviews, but in none of the cases were these the determining factor for choosing one technology over another, nor were they used to assess the effectiveness of the technology after installation. Acquirers were not easily able to quantify technical or commercial effectiveness (discussed by Bennett et al, 1999), particularly where this involved measuring the loss of business if customer requirements were not met. Financial effectiveness such as return-on-investment or payback periods was not measured. No attempts were made to quantify the 'hidden' costs of setting up and managing new systems, and of lost production during start-up of the new technology.

Several managers questioned the notion of technology evaluation, claiming that once equipment had been installed, little could be done if its performance were unsatisfactory. From a supplier perspective, if the technology did not perform as required, either the specifications were incorrect, or operating and maintenance were inadequate. Suppliers could be called upon to make adjustments, but a radical overhaul of newly acquired equipment was not possible because production could not be interrupted for yet more new technology to be installed. Performance measurements were used by managers for management purposes and comparison, but not for evaluation of the technology.

The complexity of a power station meant that many hundreds of variables could be measured. Contractual requirements were documented, and financial penalties could be imposed, although Eskom seldom resorted to these. Generally, fine-tuning by contractors was sufficient to meet contractual requirements. In some instances, both parties negotiated major modifications. Respondents felt that in certain instances, the measurement of the efficiency, say of a small pump, was not worth the time and effort as its effect on overall power station efficiency was probably negligible. Non-conformance to desired performance constitutes a failure, but no one had specified precise standards for determining functional failures. This resulted in a great deal of discussion and argument about whether technology was achieving its specified goals.

Completing a new technology project on time was particularly important. The cost of delays in achieving full operational status (highlighted by Katz et al, 1999) was not quantified in terms of lost production. While mini case contracts could penalise late installation, suppliers could often blame the acquirer (for lack of access, changes to specifications, and so on), and in any event, respondents believed that maintaining good relationships with suppliers was worth more than alienating them by claiming late installation penalties.

Evaluation was essentially based on managerial intuition (Alcorta, 1999). Difficulties in identifying objectives and evaluating resources, as suggested by Collis and Montgomery (1995), were experienced where evaluation required an assessment of a system consisting of equipment and human resources. Sentiments pointed to a parallel with TQM and BPR which are fashionable yet somewhat indeterminate concepts frequently used as a guise under which almost any management intervention can be implemented, and to which credit can easily be attributed (Farrell 1994; Grover et al, 1994; Guimaraes and Bond, 1996). Managers use them for their own ends, without fear of being challenged or contradicted (Clark and Salaman, 1996). Experiences in the cases suggested that the lack of standardised methods for introducing technologies presented managers with opportunities to select and install new technology, evaluate and measure its outcomes in ways that suited their specific objectives.

Respondents were vague about what new technology entailed, and which parameters should be evaluated. Flourco suggested that its new technology referred to the changes to physical equipment such as installation of motorised valves, measuring devices and the control system hardware. Software was treated as a 'computer system' that did not have the same status as the 'technology'. Typically, evaluation was directed at the performance of control and regulating valves, and hardware, maintained by mechanical and electrical maintenance staff. Problems with software were blamed on a newly formed group of computer and instrumentation technicians.

Supervisors and operators commented that where formal evaluation had been attempted reports would inevitably be positive because managers were the initiators and sponsors of the technology. Managers were not always the implementers and adopters so they attributed faults to those responsible for troubleshooting and operating (as suggested by Spann et al, 1995). Departments to whom blame was not attributed would express commitment to the technology thereby legitimising "all sorts of measures and changes in the name of a self-evident good" (Wilson, 1991: 1). The appeal for management was that their choice of technology was beyond reproach, and suppliers naturally supported such sentiments.

However, commitment to the technology did not equate to operational success, but the lack of formal evaluation methods was helpful in obtaining the commitment of various constituencies inside the organisation. Actual outcomes in some cases were indeterminate. Plant 'uptime' in Flourco was one of the most important performance criteria, irrespective of how much of the product had to be reprocessed. Overall efficiency was therefore not measured nor was the performance of the control system, which should have minimised reprocessing. Much attention was paid to familiarisation and training as part of the TT, and some respondents commented that managers paid more attention to attendance at training courses than to what was being achieved in the plant. This agrees with the comment by De Cock and Hipkin (1997) that sometimes sight of the end goal of new interventions is lost.

A common measure of performance in all cases was downtime, which was closely related to maintenance. In addition to Eskom's CMMS which was intended to provide guidance for maintenance intervention, a firm of reliability consultants had been employed to compile maintenance models at some power stations. Respondents reported that despite extensive work by the consultants, these models had not proved effective. Maintenance staff had not been part of the modelling team, and they admitted that they would not have understood the complexities of the modelling process. The consensus was that the recommendations presented by the consultants held little credibility, and were not practical (supporting the view of Fortuin and Lootsma (1985) regarding quantitative aspects of maintenance).

In most cases acquirers followed suppliers' recommended maintenance schedules and tasks to comply with warranty requirements. From a maintenance perspective, explicit knowledge was lacking in the form of inadequate plant history (supporting the findings of Hipkin, 1996). This was understandable for new plant, but efforts to compile history systems through CMMS were inadequate. A fundamental lack of theoretical knowledge by power station maintenance staff detracted from understanding the true nature of failure in many instances. Although suppliers possessed greater tacit knowledge than case study maintenance staff, they could not be too dogmatic about maintenance recommendations in an unknown operating context. Operating circumstances were 'unknown' both because installations are never identical in different operating contexts (Moubray, 2000), and also because the abilities of the case study operating and maintenance staff were inferior to those in the suppliers' home countries.

A more far-reaching evaluation of technology led to a broader view of new technology. Rapid increases in maintenance costs were partly attributed to the fact that the new technology had not settled in (referring to Pattern F in Figure 3.7), but managers were concerned that costs were not being contained (a common occurrence postulated by Paz and Leigh, 1994). The suggestion by Lofgren et al (1992) that accidents can be attributed to equipment failure also applied at Flourco. Respondents realised how maintenance impacted on their efforts to increase output and improve quality (Campbell, 1999), especially as failures on their automated facilities stopped an entire line. Plastico could operate its line manually, but quality levels would depend on the judgement of operators, which had proved unsatisfactory in the past. Poor maintenance in some power stations had not ensured a high level of availability of the standby items. In using narrow measures such as downtime or maintenance costs in a budgetary period to evaluate maintenance policies, managers were not establishing whether their maintenance was applicable and effective (Nowlan and Heap, 1978), or whether redesigns would be appropriate where failure consequences could not be prevented.

No formal evaluation of technology was carried out, apart from an intuitive assessment of whether quality and output parameters were being achieved. Technology owners and acquirers set widely differing multiple objectives from their technology that extended beyond the stated requirements. The need to lower production costs led managers to assess the performance of the maintenance function, features of which are considered under other questions relating to research question 5.

Research question 5.2: Evaluation and modification of new technology provide guidelines for redirecting the labour force

Knowledge of performance standards was at best vague. Customers set precise standards in all manufacturing mini case firms, but operators were either not fully aware of these, or were negligent in adhering to them. At Plastico, the quality monitoring equipment was set up to meet customer requirements. However, some requirements varied, and equipment was not always adjusted accordingly because maintenance teams experienced difficulty is setting finely discriminating SPC standards.

The miller at Flourco was well aware of quality standards, but most operators accepted broader tolerances. This resulted in product passing through the process more than once. Overall quality was not affected, but the process was less efficient. Maintenance staff were aware of the settings required for the range of quality standards, but became less attentive when they realised that the new control system would compensate for deviations in quality by reprocessing the product. Maintenance staff had differing views of what constituted tolerable wear on sieves, rollers and other equipment. Precise standards had not been laid down, so the failed state, such as that depicted in Figure 3.14 had never been defined exactly. Spontaneous combustion in a flour mill could have devastating consequences of which staff were aware, but there was only a vague idea of exactly what conditions caused combustion. Flourco had a certain amount of redundant (back-up) equipment, yet this was subject to the same preventive maintenance as equipment in permanent service. Some craftsmen had reported that no wear was evident on the standby plant, but had nevertheless been instructed to replace items in accordance with the schedules. This demonstrated a fundamental lack of understanding of the relationships between maintenance and the operating context: respondents were unable to explain the reasons for performing preventive maintenance on equipment where standby plant was available (as discussed in Section 3.3). The result was that despite promises that the new control system would reduce maintenance costs, this had not occurred.

Flourco had the most extensive preventive maintenance programme. This was to be expected as a significant number of moving components come into contact with the product, and the company had years of operating experience. Most preventive action was targeted at replacing items at set intervals. One shift was set aside for maintenance each week, so many replacements were made on a weekly basis. In a number of instances, craftsmen had reported negligible wear on items, and suggested that a two weekly, or even monthly interval would be sufficient. Supervisors or managers had overruled them, and excessive maintenance continued. With reference to Figure 3.7, the failure patterns of certain components were age related (patterns A, B or C), but no attempts had been made to find the point on pattern A where the probability of failure rose to the point of failure, or the point on pattern C at which a functional failure occurred. Little condition-based maintenance was practised, so the concept of lead time to failure (in Figure 3.14) was not appreciated.

The frequent inspections of the knives at Foodco, described in Appendix VIII demonstrated a lack of understanding of the nature of failure and the basis on which condition-based inspection frequencies should be made (again, shown in Figure 3.14).

Eskom's maintenance was based on suppliers' recommendations and experience from other power stations. Engineers did not actively download data from the CMMS of power stations with similar technology, partly because they mistrusted such information, and also because they realised that operational contexts would be different. Yet, some replicated the tasks and intervals that they themselves had introduced at other power stations. Several supervisors and craftsmen commented that preventive maintenance was excessive or inappropriate. There were no attempts or instructions to analyse maintenance schedules, apart from one power station that had embarked on an RCM exercise. This required accurate formulation of functional performance standards, definitions of failed states, and failure modes and effects analyses. Proactive maintenance intervention was evaluated against applicability and effectiveness criteria, and led to considerably reduced preventive maintenance through item replacements, and increased inspection tasks. As the RCM analysis was still underway at the time of the research, no definitive results had been obtained. However several staff reported how much they had learnt about the equipment and processes they had analysed, and they believed that the analyses had produced sound justification for revised maintenance intervention, rather than guesswork, using suppliers' recommendations, or replicating schedules from other power stations with different operating contexts, and where tasks may well have been incorrect.

In many instances it was clear that both Eskom and the mini cases adhered to the type of incorrect maintenance thinking espoused by Pitz and Weber (2001: 223) that "more important devices can be maintained more frequently than those of less importance, leading to reduced maintenance costs but retaining a high level of reliability of the system." As explained in Chapter 3, severity of consequences ("more important devices") is not the way in which maintenance intervals should be determined. Many managers, supervisors and maintenance staff did not understand the notion that frequency of condition based tasks should be based on the lead time to failure, and that restoration and replacement intervals are determined by the age and life of equipment.

Supervisors in the mini cases acknowledged that they had no formal maintenance history for the new equipment, and suffered because of their lack of experience. Inadequate understanding of how the new equipment operated aggravated this. Operators were frequently blamed for poor operating practices, but maintenance staff were equally disadvantaged by their lack of knowledge. Power stations had Eskom's standard CMMS, but failure data was limited, and what was available was not meaningfully analysed. In the mini case companies, CMMS existed in various forms. Flourco had upgraded its old mainframe system, but little data had been transferred. A supervisor commented this had not been a priority because the data was of marginal use anyway. Plastico's CMMS had primarily been set up for another part of the plant, and the film department data had only partially been loaded. Foodco had recently installed a CMMS, but maintenance staff had not been fully trained in the system, so little use was made of it. Waterco did not have a CMMS. It is clear that workers in these organisations were far from being 'knowledge workers'.

Explicit data was seldom available to maintenance staff. Spanos and Liouskas (2000) suggest competences can be acquired through intangible resources such as knowledge and organisational learning. The case studies were slowly acquiring operational and maintenance knowledge. However, several staff commented that with the poor theoretical understanding of processes, everyday analyses would remain superficial with little internalisation that could later be applied for problem solving.

There was no evidence to support the proposition of Lado and Vozikis (1996) that receptivity of technology is largely an issue of corporate culture. No overt resistance to the technology in any of the case organisations was evident, but many operating staff showed no great enthusiasm either. One supervisor commented: "they just consider it their job to do as they are told, and they go no further".

The observation that new technology did not function as well as expected and that maintenance was not always effective led managers to implement further operator and maintenance training. It was assumed that deficiencies lay with poorly qualified and inexperienced staff at these levels. Problems persisted because other issues, such as inappropriate maintenance, based on an incorrect understanding of the determination of maintenance intervals (age of plant as opposed to lead time to failure, referred to in Figure 3.12) were not addressed. The research findings support the question, but managers failed to recognise that they were only addressing part of the problem.

Research question 5.3: Evaluation and modification are assessed by the success, failure and efficiency of the new technology

Respondents had not determined what constituted appropriate and effective technology or successful TT. The mini cases concentrated on the physical operation of the technology without due regard for TT. Qualitative evaluation of the technology was based, to a considerable extent, on ease of adoption, which included the effort expended in installing the technology, and the difficulties encountered in operating and maintenance. It appeared that maintenance performance was quantified when it was easy to take measurements and interpret data. Some of the maintenance performance measures listed in Section 3.6 are considered in the following paragraphs.

The most common form of technology evaluation was measurement of plant availability and utilisation. Reliability was seldom measured as many respondents did not understand the term. Some broadly defined reliability as the probability that an item would consistently perform its intended function under normal operating circumstances, or as the mean time between failures (MTBF). The attitude was that estimating probabilities often entailed guesswork, and was thus not a meaningful management measurement tool. No one had sufficient data to calculate MTBF with much degree of accuracy, and they made no attempt to do so. At best, some experienced Eskom staff could recall the number of times an item had failed in a certain time period (perhaps at another power station), thereby arriving at a rough estimate of reliability. In those few instances where an MTBF was used to determine failure finding frequencies for testing hidden functions and protective devices, this rough estimate proved invaluable.

Problems of definition and inconsistency of meaning obscured discussions of utilisation and efficiency. Difficulties arose because line or machine capacities were frequently unknown. For example, when purchasing its processing line, Foodco specified the capacity in kg per hour, but in reality this capacity was dependent on the size of potato entering the process and the dimensions of the French fry output. Expected capacity differed from the desired performance standards which in turn varied from customer to customer. Utilisation figures were contingent on customer quality requirements that could fluctuate by 3% or more, without any variation in plant availability. Changing effective capacity figures could lead to variable efficiencies that in no way reflected plant availability. Managers were aware of these variations, and questioned whether utilisation and efficiency were meaningful measures of performance. A common way of measuring availability was by subtracting recorded maintenance downtime from overall production time, but such figures were open to manipulation. It was in the interests of maintenance staff to increase the time spent on preventive maintenance tasks (which did not reflect on maintenance performance), but reduce the time reported on a breakdown (since breakdowns indicated poor maintenance execution).

The cost effectiveness of preventive maintenance was not a determining factor when schedules were compiled. Several respondents admitted that the issue was never considered; others suggested that the cost of downtime and lost production would always be greater than the cost of prevention. These statements illustrate that few in the case organisations had a true understanding of all the implications of the new technology. Inventory holding costs were seldom considered. While suppliers' recommended stock holdings were followed, managers arbitrarily reduced these when overall stock levels appeared to be too high.

Plastico experienced similar difficulties in arriving at effective capacity figures. Output was measured in kg per hour, but production depended on the thickness of the film: the thinner the film, the less stable the bubble, and the more likely it would fail. This was a characteristic of the manufacturing process, and could not be attributed to poor operations or maintenance. A supervisor suggested weekly comparisons of utilisation, efficiency, or output (in tons) were only meaningful in the unusual event that one film thickness had been manufactured that week. If the quality monitoring system failed (a detective function), production could continue, so its utilisation was not a useful measure of performance, and no one noted the times during which it was not functioning.

Flourco also experienced variations in production because of differences in wheat quality: protein, 'falling weight', moisture, and so on. Throughput tonnages per hour were therefore not necessarily a measurement of maintenance effectiveness. Settings by maintenance staff were crucial in obtaining good quality, but, as has been mentioned, substandard flour could be reprocessed. The presence of other variables meant it was not possible to attribute these problems to maintenance.

Because of fewer extraneous variables in Waterco's case, utilisation figures could be used as a measure of operational and maintenance effectiveness. Water samples were taken at regular intervals, resulting in early detection of defective equipment.

Management reporting systems in the power stations required measurement of utilisation and efficiencies. Thermal efficiency and heat consumption figures were key indicators, as illustrated, for example, in Appendix VI by the formula for calculating heat consumption. This required a series of other measurements, and the process of taking these measurements effectively monitored the performance of a range of attributes. Plant utilisation figures were indicative of overall performance, but were at too high a level to monitor operational or maintenance effectiveness for individual systems or items of equipment.

Eskom's management reporting system required a record of scheduled tasks completed. Supervisors and craftsmen rejected this as a meaningful measure of maintenance performance, especially as it perpetuated existing scheduled maintenance tasks, many of which were felt to be inappropriate. Because managers expected scheduled tasks to be performed, supervisors pressured craftsmen to complete these tasks, but the 'tearoom tick' syndrome was well known whereby tasks were recorded as having been done when they had not been. Craftsmen claimed that the tasks not completed were the insignificant work that had few consequences should failures occur, or were a waste of time in any event. A further problem was that data entered into the CMMS might indicate that an item had been checked, but its condition had not been noted, or its replacement may not have been recorded. If the CMMS were later used to monitor deterioration, false conclusions would be drawn. Findings from the research support the contention by Pitz and Weber (2001) that CMMS frequently contain "disordered data".

Some of the measures of utilisation and availability were useful, but the number of exceptional circumstances introduced too much variability for these to be sufficiently consistent measures to support this question.

Research question 5.4: Evaluation and modification of new technology lead to innovative programmes through R&D to develop technology

In the mini cases, technology was introduced to meet customer product requirements. There were no plans to develop the technologies further. Some respondents indicated that should product requirements change, it was conceivable that technologies could be modified. Foodco's intention was to process other food products, but recognised that its new line was designed only for French fries. Other fruits and vegetables were processed in different ways, so it would be more sensible to acquire lines for those specific applications. In any event, Foodco was not a manufacturer of equipment, so it would always purchase equipment for new lines from equipment suppliers. Minor improvements were carried out if frequent breakdowns occurred, but this was not development of technology through R&D.

None of the cases intended developing the technology further so this question is not directly applicable to the case studies.

Overall assessment of research question 5

Direct measures were not suitable for re-evaluating TT with reference to acquirers' goals and performance. Intuitive assessments of operating and maintenance performance provide an indication of how well operators and maintenance staff had mastered the technology. Results from the cases suggest that TT was at best partially successful as attention was directed at the technology in each case, rather than the processes of TT.

9.7 SUMMARY OF RESEARCH QUESTION FINDINGS

The findings discussed in this chapter are summarised in Table 9.1, where support, partial support or rejection of each question is indicated. Apart from Level 1 elements (pertaining to Research Question 1) where managers did not see the need for considering technology requirements at national level, managers accepted that TT could be improved by more thorough technology and skills audits and analyses. They recognised the benefits of working closer with suppliers, and appreciated that while cost-benefit evaluations were difficult, a more precise investigation of functionality would ensure a closer fit between technology offered by suppliers and their own requirements.

A general conclusion may be drawn from the case studies that TT was not particularly successful. In summarising the findings, it is useful to refer to points raised by Katz et al (1996) that success rates are highest when TT involves the transfer of procedures and practices; transfer of technology hardware shows the lowest success rates. It has been observed that all case studies concentrated on the acquisition and installation of technology (machines, equipment, control systems, and so on). Katz et al (1996) refer to these as 'hardware', and the findings would agree that the case studies were not successful in transferring hardware. The lack of attention paid to procedures and practices and the human dimension (which Katz et al suggest are essential to successful transfer) could further explain why TT was not successful.

The outcomes in Table 9.1 show a significant number of rejections of the questions. These should be interpreted as evidence that the case studies did not perform certain activities or attend to important issues in TT, rather than a rejection of the questions themselves. This issue is discussed in the concluding chapter.

Research question		Outcome
1. Decisions for selecting technology	1.1 Identify needs and demands of acquiring country 1.2 Identifies acquiring country's capabilities and limitations 1.3 Identify macro- and micro-economic human factors 1.4 Identify acquirer's goals and objectives	1.1 Partial support for utility Reject for mini cases 1.2 Reject 1.3 Reject 1.4 Support operational goals, but not strategic objectives
2. Surveying and analysing new technology	2.1 Identify appropriate technologies to meet acquirer's goals 2.2 Cost-benefits of new technology 2.3 Assist in evaluation on basis of acquirer's resources 2.4 Consider basic economic and technical factors affecting TT	2.1 Support 2.2 Reject 2.3 Partial support in relation to financial resources, but not HR 2.4 Support of technical issues
3. Selecting new technology	3.1 Take into account human factors 3.2 Evaluate costs and benefits 3.3 Analyse all technology suppliers 3.4 Assess all alternative sources	3.1 Reject 3.2 Reject 3.3 Partial support 3.4 Reject
4. Implementation and maintenance	4.1 Involve supplier and acquirer in setting guidelines 4.2 Relate to training and other HR issues 4.3 Involve supplier and acquirer in selecting alternative approaches to TT 4.4 Involve supplier and acquirer in identifying criteria for adaptation	4.1 Support for technical issues 4.2 Support for training 4.3 Partial support as emphasis is only on technology 4.4 Reject
5. Evaluation and modification	5.1 Are based on criteria derived from acquirer's goals 5.2 Provide guidelines for redirecting labour force 5.3 Are assessed by success, failure and efficiency of new technology 5.4 Lead to programmes to develop technology	5.1 Reject 5.2 Support, recognising limited understanding of plant 5.3 Reject. No measurement of technology efficiency 5.4 Reject. Question not applicable to case studies

Table 9.1 Summary of research question findings

CHAPTER 10

CONCLUSION

10.1 INTRODUCTION

This study into technology transfer in a developing country context prompted a number of research questions to be answered using South African case studies. The broad approach to the study is stated in the introduction (Chapter 1). The literature on TT in developing countries (Chapter 2) and physical asset management (Chapter 3) form the two theoretical components of the research. The South African situation (Chapter 4) contextualises the environment in which TT is transferred. The methodology (Chapter 5) explains the phenomenological, theory building approach adopted in relation to the case studies. The preliminary survey (Chapter 6) was carried out in order to obtain basic parameters for the empirical work. Details of the main case study (Chapter 7) and the mini case studies (Chapter 8) are presented with summaries of interviews in the appendices. Findings are analysed (Chapter 9) with reference to the TT and maintenance literature, the South African context, and the preliminary study. This final chapter (Chapter 10) revisits the research questions, and attempts to derive theory building conclusions for TT in a developing country context.

The framework by Salami and Reavill (1997) provided the basis for the research questions and, in combination with the preliminary research items, the structure for the interviews. This chapter draws conclusions from the research questions. It then evaluates the framework, and proposes a revised model for TT in the light of the outcomes of the research. The contribution and limitations of the study are discussed, proposals for further research are made, and some final conclusions drawn.

10.2 REVISITING THE RESEARCH QUESTIONS

The literature provides a sound basis for research question formulation, but an under-researched topic and a changing context may prompt different questions, the answers to which may support, modify or reject findings in the literature. In using the Salami and

Reavill framework, it soon became apparent that certain issues were not applicable to the South African case studies. The task now is to consider each question and its implication for TT in the light of the analyses presented so far.

The views of Cole (1934: 9) quoted in Chapter 1 are referred to again in revisiting the research questions. Although referring to an analysis of Marx, his ideas are broadly applicable to all social science research:

> "We run the risk of assuming that precisely the questions Marx asked are the questions that need asking now, and that the answers will be merely modifications, or perhaps negations, of the answers which he found. But in fact the questions that it is important to ask may be different questions, and the answers may have to be stated in radically different terms".

Reflecting on Cole's views in the application of the literature in general, and Salami and Reavill's framework in particular, the researcher is confronted by several possible misgivings:

- is the Salami and Reavill framework 'correct'? If not, should it be modified, and how?
- if organisations do not follow the actions proposed in the framework, are they at fault, and would TT be more effective if all steps were followed and all elements addressed?
- are there instances where the framework is not applicable in the South African situation?

The South African political, economic and industrial environment differs from other developing countries and is characterised by pressures that may not apply elsewhere, but South Africa is also subject to influences affecting all developing countries, as they attempt to respond to globalisation and new technology. In order to understand this, the researcher must acknowledge that the TT process has a different set of dynamics in South Africa, which is only intelligible with an appreciation of the country's history and present circumstances. To address these issues, we turn again to the research questions.

Research question 1

Do technology suppliers and acquirers reach common accord in the selection of technology, in accordance with the acquiring country's needs, capabilities, limitations and human resource factors?

Subsidiary questions

Does the decision-making process for selecting technology by a firm in an acquiring country identify

1.1 the needs and demands of the acquiring country?

1.2 the acquiring country's capabilities and limitations?

1.3 important macro- and micro-economic human factors relating to new technology?

1.4 the acquirer's goals and objectives to be achieved through the technology?

The Salami and Reavill framework stresses the importance of the needs and demands of the country for TT (Question 1.1). These could affect Eskom's vital role as the main electricity supplier and a technology leader in South Africa. The choice of technology at the highest level (coal fired, nuclear, renewable energy, and so on) was not considered in this research. Such decisions are taken by Eskom in conjunction with government departments, local authorities, and other interested parties. At a lower level, selection of one technology in preference to another (such as roller mills or ball mills, steam or electric feed pumps) was based on the merits and costs of the technologies. In neither Eskom nor in the mini cases, did the country's needs or limitations influence the selection of technology.

The research suggests that more attention should be paid to a country's capabilities and human resources (Question 1.2). This is a recurring theme that impacts at all levels. The desire to be a technological leader, the engineering competence of specifiers, and the lack of awareness by designers and engineers of operational conditions play a role. While planning for technology installations occurs at a later stage, decision makers should heed Alcorta's (1999) warning that intervention is required during earlier decision-making stages to address the implications of the lack of skilled workers and the limited depth of knowledge for advanced automation in developing countries.

Alcorta (1999) introduces an important limitation (his application was in a Brazilian context, but the idea is useful in a South African context) when a country is locked into older technology, and needs to break out of this mould. South Africa's isolation during the latter apartheid years deprived it of much new technology. The country has yet to bridge the technology gap between equipment installed 20 years ago, and the most modern machines now available. Eskom's case was different in that it was able to acquire technology during the isolation years, but its power station building spree in the 1970s and 1980s resulted in the installation of systems that were modern at the time, but which have dated. This was exacerbated by Eskom's policy of replicating the designs and specifications of the 1980 power stations in those constructed in the 1990s. Further, the long construction phases of a power station mean that the last unit, commissioned more than 10 years after contracts are awarded, will inevitably not have the latest technology by the time it is commissioned.

In selecting technology, managers did not consult suppliers regarding macro and micro issues (Question 1.3) or the role of advanced technology and TT in economic and industrial development. With reference to Salami and Reavill, managers were not concerned whether its adoption and adaptation would enhance South Africa's productivity and efficient use of natural resources. In the form in which it is stated, the first three questions would be more applicable to a national technology policy and would be useful to official policy formulators.

Question 1.4 considers the identification of an acquirer's goals and objectives from a strategic perspective. Managers were preoccupied with internal (micro) matters, and not broader (macro) factors pertaining to politics and the national economy (infrastructure, crime, and so on). Rather than looking at technology as a strategic resource, they considered only the operational side of technology. This limited perspective seldom looks beyond existing products, and only seeks operational efficiencies. The implication for developing countries is that while this may meet low cost demands of consumers, it results in limited innovation and inhibits the search for competitive advantage through process technology. Operational efficiencies may thus support strategic objectives in a passive and neutral way.

The common accord with technology suppliers, referred to in the first research question, took place at a lower level. Some suppliers, but few acquirers, recognised the danger that technologies could be too advanced for the South African context, with its generally poorly educated and low-skilled labour force. They felt strongly that technology selection should take human resource factors into account at an earlier stage in transferring the technology.

The conclusion regarding this research question is that for private organisations (and from a technology selection perspective Eskom is effectively an independent organisation), the needs, capabilities and limitations of the acquiring country are not taken into account in technology selection. Objectives are largely operational. Suppliers have little influence at this stage of TT.

Research question 2

Are technology options investigated taking into account the goals of the acquirer, costs and benefits of the technology, the resources of the acquirer, and economic and technical factors in technology transfer?

Subsidiary questions

Do analyses and surveys of available technology

2.1 identify appropriate technologies for meeting the acquirer's goals?

2.2 take into account costs and benefits of the new technology?

2.3 assist in evaluating technology on the basis of the acquirer's resources?

2.4 consider basic economic and technical factors affecting the TT process?

This question is concerned with technology options, as part of the investigation of available technologies to achieve the acquirer's goals. These were stated in operational terms (reliability, quality and consistency of supply). Objectives of the manufacturing mini cases were to meet local and, more importantly, international standards.

The choices of technology available to meet the requirements of the case organisations were limited. Process technologies from international suppliers were well established and standardised. While differentiating features certainly existed, acquirers' 'surveys' were essentially investigations of the quality of suppliers rather than assessing the extent to which technologies were appropriate (Question 2.1). 'Appropriate' meant 'could the technology do the job?', and did not consider local operating constraints to any significant degree.

Managers based their technology decisions on technical evaluations, cost and service, but benefits were not quantified (Question 2.2). At this stage of analysis, no attention was paid to resources other than financial (Question 2.3). The emphasis was on technology, with no consideration of economic factors (Question 2.4).

Research question 3

Do final decisions for using the most appropriate technology consider basic human factors for adopting new technology, include an evaluation of final costs and benefits, require knowledge of possible suppliers, and compare alternative sources of technology?

Subsidiary questions

Do decisions for final technology selection

3.1 take into account human factors pertaining to the new technology?

3.2 evaluate final costs and benefits of the new technology?

3.3 follow a comprehensive analysis of all possible technology suppliers?

3.4 assess alternative sources of technology?

At Level 3 decisions did not consider human resource competencies and skills (Question 3.1). Managers conceded that only after installation of their new technology did they fully appreciate the extent to which more complex technology and control systems imposed burdens on the maintenance function. This supports Swanson (1999) that automation of human effort still requires an ability to monitor and self-correct through human activity, but the degree of intervention is often beyond their capability. Acquirers acknowledged that they had neglected this aspect of their new technology.

One of the prime requirements from the technology was cost reduction. Costs of new technology were known, and production costs were carefully documented in the mini cases. Eskom's power stations' reporting systems contained detailed production costs, but these were not easily attributable to individual technology items. Functionality was not measured in terms of comparative benefits between different suppliers, so technology acquirers were unable to produce detailed cost-benefit analyses (Question 3.2). Comparisons between technologies and suppliers leading to final decisions for adopting technology were based on functionality and cost. Acquirers' comparisons did not evaluate a great variety of technologies (Questions 3.3 and 3.4), as processes used essentially similar technologies. Possible suppliers were identified at Level 2.

Research question 4

Do technology suppliers and acquirers agree on implementation, adaptation and maintenance by providing guidelines on management and implementation, personnel and training, selecting new technology, and identifying criteria for improved adaptation of new technology?

Subsidiary questions

Do implementation and maintenance of new technology involve the supplier and acquirer in

4.1 providing guidelines for management and implementation of new technology?

4.2 personnel training and other human resource issues?

4.3 selecting alternative approaches to TT?

4.4 identifying criteria for better adaptation of new technology?

Installation and commissioning of the technology were contractually agreed between acquirers and suppliers. Eskom had a fully documented process for witnessing preliminary testing of items, taking over from the supplier (installer or contractor) by Eskom's site engineering department staff, and handing over to Eskom operations. The mini cases followed a less formal process, ending with taking over by factory staff. These processes were concerned with accepting fully functional physical assets. Performance and equipment availability were contractually guaranteed, but implementation, as the process of operating and maintaining the assets, was not managed through agreements between technology suppliers and acquirers (Question 4.1). Acquirers expected that the technical support provided by suppliers should enable them to operate technology efficiently (agreeing with Olayan, 1999). In the short term this entailed a commercial demonstration of what to expect during start-up, operations and shutdown. In the longer-term acquirers wanted technology updates and assistance on modifications.

Operations and maintenance staff attended a variety of formal and on-the-job training programmes. Eskom has extensive training facilities, and favoured formal instruction as a transparent way of demonstrating its commitment to skills upliftment, particularly among black employees. The mini cases limited classroom-type training courses in the new technology to familiarisation sessions, and favoured on-the-job training. This was partly because only two or three operators were deemed to require training, and partly because the manufacturing mini cases did not have a training culture that addressed specific skills (Question 4.2). The case organisations established what Alcorta (1999) refers to as external linkages for learning through supplier-acquirer relationships, and these formed a valuable basis for subsequent knowledge acquisition by the case organisations. No alternatives to TT were addressed (Question 4.3), and where adaptation of technology was required, this was considered solely an engineering function (Question 4.4).

Research question 5

Is the TT process assessed and re-evaluated with reference to the acquirer's goals and performance criteria, the necessity for modifications of technology, analysis of success and failure, and R&D innovations for further development of the technology?

Subsidiary questions

Are evaluation and modification of new technology

5.1 based on specific criteria derived from the acquirer's goals?

5.2 based on guidelines for redirecting the labour force?

5.3 assessed by the success, failure and efficiency of new technology?

5.4 instrumental in leading to innovative programmes through R&D to develop technology?

As the cases undertook no formal evaluation of technology, effectiveness was subjectively assessed in terms of meeting surrogate goals, set in operational terms (Questions 5.1 and 5.3). Only a portion of cost-reduction items like inventory holding costs, flexibility and shorter response times are captured in evaluation and accounting systems. The majority of benefits remain invisible. Further labour force training was undertaken on an informal basis (Question 5.2). Modifications, like adaptations of technology, were an engineering task, not considered part of TT. There were no instances of innovative programmes derived from the technology (Question 5.4).

10.3 ASSESSMENT OF THE SALAMI AND REAVILL FRAMEWORK

The Salami and Reavill framework has been used extensively in this thesis. The definitions of TT in Chapter 2 are useful in assessing its effectiveness. Salami and Reavill provide a number of perspectives, which corroborate Kahen's (1997) definitions of TT, and the descriptions of technology by Adjibolosoo (1994). Technology is referred to as a body of knowledge:

- retained by individual, specialised personnel
- resulting from accumulated experience in design and operational activities
- that is mostly tacit, and not explicit in any collection of blueprints and manuals
- acquired in problem-solving and trouble-shooting activities within the firm
- in a substantially uncodified state

The features of TT include:

- the movement of technology from one physical location to another
- the application to make an end product, or provide an end-user service
- a continuous process of planning and decision-making about technological options
- the choice of the appropriate technology for local characteristics and available resources
- utilising and developing technology to achieve particular goals at some time in the future
- the capability to produce goods and services
- the design and development of new capabilities when appropriate
- application to meet the specialised needs of the customer
- installation and service of technology

The Salami and Reavill framework utilises many of these attributes, omits some and introduces others. It is clear from activities in the case studies that they broadly followed the levels in the framework, but that several elements were either not applicable, or should be modified for the South African situation. The framework contains a bias towards countries that are constrained by government intervention in technology policies, and in this sense it is not fully relevant to the South African situation where the state plays no role in technology decisions at the level of individual firms. A revised model is proposed in Figure 10.1 on the basis of the research findings. The following paragraphs consider each level of the framework. Where the research findings do not support an element, it is necessary to assess whether its inclusion can be justified even though the case studies indicate that it is not applicable. This requires distinguishing between what is done or not done in practice, and what action should be taken. The fact that managers ignore a certain issue is no reason in itself for claiming that the item should be excluded. In the final analysis, it is a question of whether TT would be enhanced through its retention or modification.

Level 1 - decisions for selecting technology

Managers did not see the necessity for taking demands of the country into account. This is not surprising in a market-oriented economy where businesses operate independently from the government, and are only accountable to it for issues such as affirmative action and black economic empowerment. Where firms have to survive through their own abilities and resources, it would seem appropriate for a TT model for independent and private businesses to ignore the needs and demands of the acquiring country. Such firms do not act as surrogates for government intervention, and technology suppliers are unlikely to be drawn into such roles, unless through lucrative joint venture government-funded contracts. Cooperation between technology suppliers and acquirers follow the normal course of negotiations.

The lack of vision concerning human resources adversely affected TT. With political intervention in human resource management, and an acute shortage of skills, human resources should be an essential aspect of technology selection from the outset. The revised model in Figure 10.1 shows only two elements at Level 1: identification of strategic and operational goals and objectives, and the identification of important human factors, through an audit that assesses current skills and those that can reasonably be accessed where required.

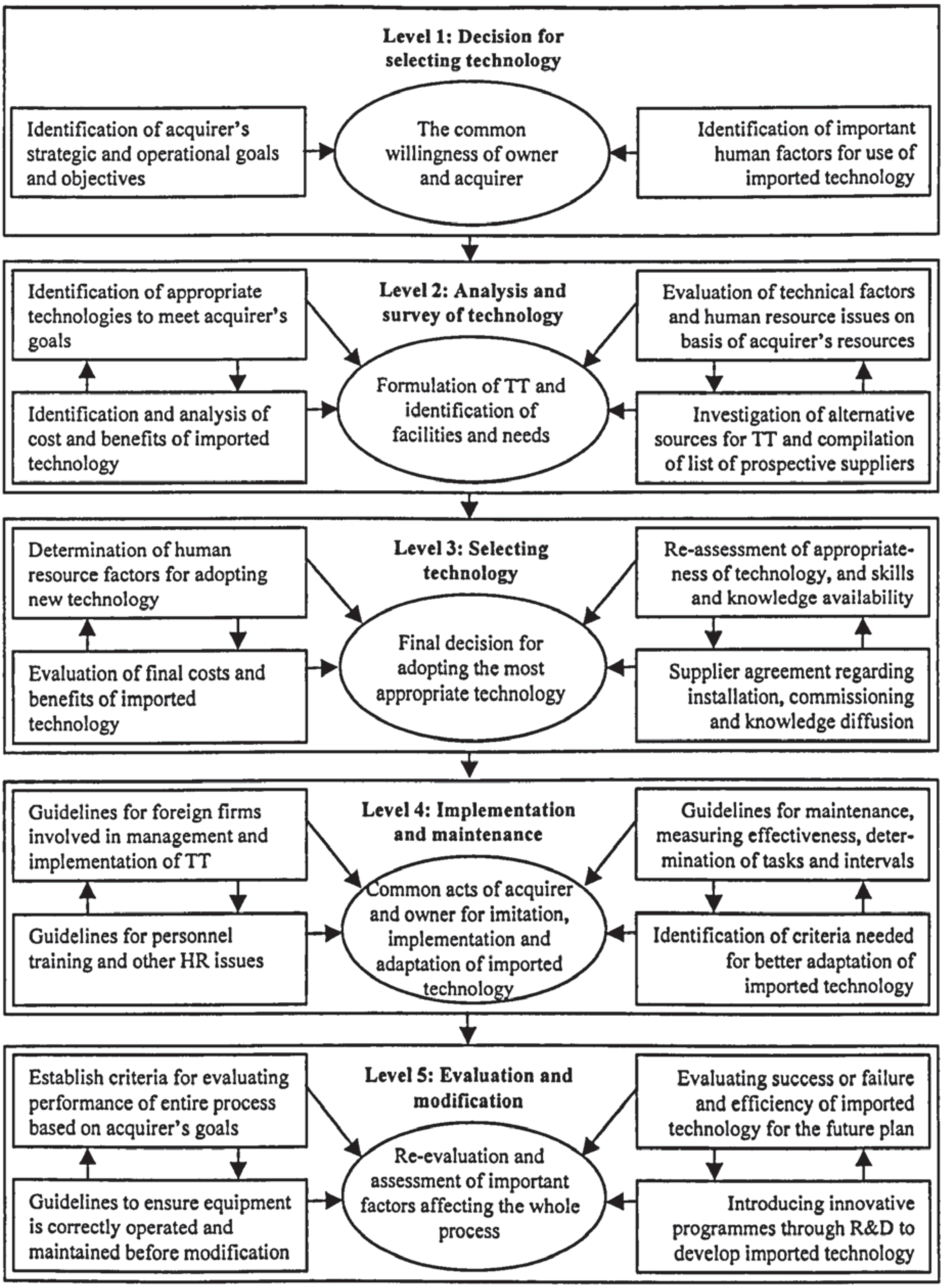

Figure 10.1 Revised model of technology transfer

Operational goals were the driving force behind the selection of new technology, yet managers did not see technology as a strategic resource. It is not only in developing countries that firms are restricted to a follower position in world competition. Where requirements are exclusively operational (such as Eskom and Waterco) technological goals are set in functional terms. In other instances (such as the manufacturing mini cases), a more creative approach to technology application can lead to competitive advantage, so goals and objectives should be set in strategic terms. This requires an assessment of the competitive environment from a strategic perspective and an evaluation of the price-quality nexus and management challenges in cost-quality strategy, as illustrated in Figure 2.5. These concepts are difficult to apply in some industries. As discussed earlier, Eskom's 'quality' lies in reliability of supply, with few consumers concerned, say, with frequency fluctuations. The vertical line in Figure 2.5 therefore largely applies to an electrical utility. In Waterco's case, while most consumers are unable to quantify quality, and would also specify an important component of quality as reliability of supply, legislation provides for a minimum quality. The manufacturing mini cases are in a position to apply the value concept through the use of technology.

As discussed in Chapter 2 common technology among competitors moves all firms towards a point of ultimate value (UV), necessitating high quality and low price products. Figure 10.2(a) illustrates the move to ultimate value under conditions of pure price competition, applicable to Eskom and Waterco. Figure 10.2(b) shows a situation where quality considerations are taken into account for the manufacturing mini cases. The vertical downward movement in Figure 10.2(a) may be achieved through the application of a range of technologies. In a power station context, these might be a chain grate boiler, roller mills and ball mill technology. The new technology lines depicted in Figure 10.2(b) enabled Plastico and Flourco to catch up with competitors. Their challenge is to acquire more technology in order to move to a lower value line if they are to become leaders towards UV.

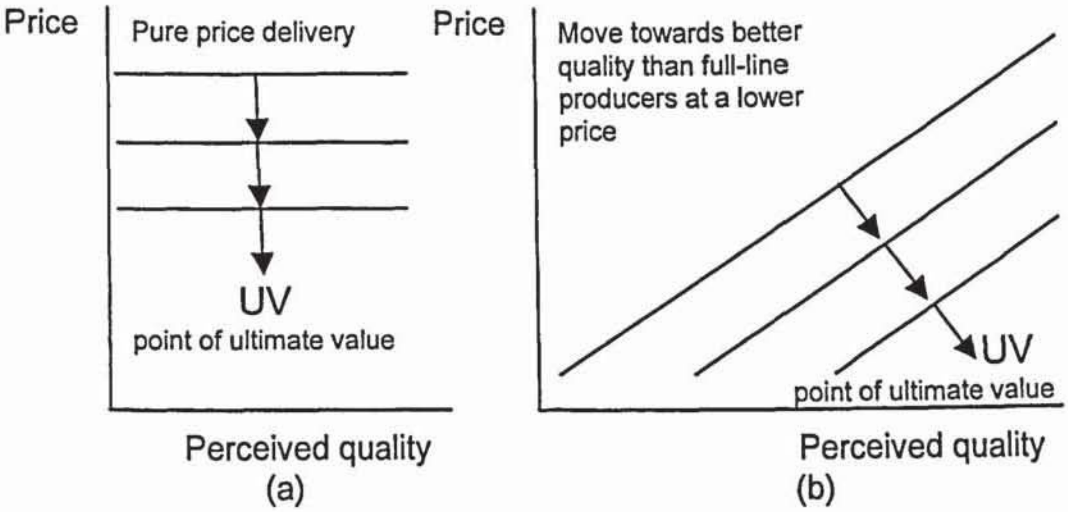

Figure 10.2 Ultimate value for price and quality delivery

Figure 10.3 suggests various possibilities, which eventually require the strategic use of technology to take a firm beyond the price-quality competition circle. Foodco had the opportunity to use the features offered by its technology to enter fast-food and more expensive supermarket niches.

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Figure 10.3 Moving beyond price-quality through technology (D'Aveni, 1994)

Level 2 - analysis and survey of technology

Initially, the necessity for this level was questioned. It contains elements that could be addressed at Levels 1 and 3. Decisions for selecting technology (Level 1) include analyses of available technologies, and economic assessments. An important reason for retaining Level 2 is its identification of appropriate technologies to meet an acquirer's goals. Appropriateness was almost entirely ignored by the case organisations, resulting in a lack of appreciation of the implications for integrating high-technology equipment (not only from a human resources perspective). Technical interface management was left to the supplier, who naturally only assumed responsibility up to a certain point. Acquirers were unable or unwilling to manage the interface further. In not addressing appropriateness, managers failed to conceptualise the link between technology and the affected processes (Kelley, 1994). Although technology changes had company-wide effects, the new technologies in the mini cases were process-specific and benefits were confined to the process in which the technology was employed. There was uncertainty about how quickly and easily gains from deploying technology would be realised, because managers were unaware of how much new knowledge was necessary and how drastic would be the change from the new configuration of equipment and people.

The task-technology fit (TTF) construct illustrated in Figure 2.8 as a surrogate for appropriateness (Goodhue, 1995) is expanded in Figure 10.4 to include some Level 2 issues. If acquirers use a technology because of its instrumentality in their task, its appropriateness may be seen as a function of the task (producing the product), technology, and human resources (individual operators and maintainers). Appropriateness may be seen as functionality, ease of use, ability to meet customer requirements, and strategic contribution (Goodhue, 1995). As a surrogate for appropriateness, the task-technology fit is used to evaluate whether technology will lead to improved performance. Instead of looking solely at the technology (as occurred in the case studies) managers and engineers should view appropriateness as a combination of the three components.

Superimposed on the TTF idea are the co-ordinating or bridging mechanisms proposed by Katz et al (1996): planning and staffing transfer of knowledge (relevant for evaluating human factors), establishing direct contact between organisations (for investigating alternative suppliers), and transfer teams and processes (to co-ordinate the analysis and survey of technology).

The revised model in Figure 10.1 retains elements that identify appropriate technologies. Analysis of the human resource implications is added to the study of technical factors. Technology should be evaluated on the basis of these factors, and at this stage alternative sources of technology should be investigated and a list of relevant suppliers drawn up (previously in Level 3). It may be difficult to undertake cost-benefit analyses, but these constitute sound business practice, so they are retained in the modified model in Figure 10.1.

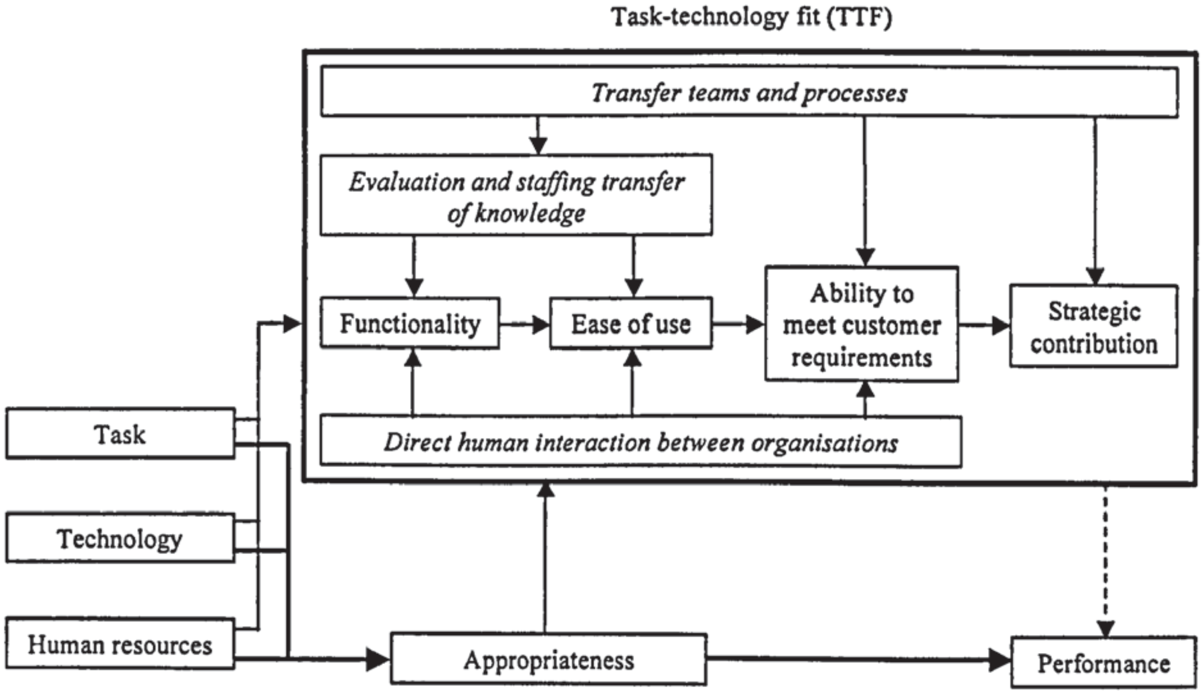

Figure 10.4 Task-technology fit as a surrogate for appropriateness

Level 3 - selecting technology

Level 3 was perceived as the stage at which TT activities actually commenced. Although managers considered the planning and surveys at higher levels to be too far removed from the factory floor for meaningful consideration of TT, the reality was that they made little provision for TT at any stage. The case organisations concentrated on technology, and not on its transfer. Even those firms that had made some effort to facilitate TT had barely embarked on it at Level 3. The revised model retains the reference to human resources. This is reinforced by a new element calling for a reassessment of the appropriateness of the technology under consideration. Such actions should revisit the extent of automation in relation to current and future skills, and knowledge availability, in accordance with Bohn's (1994) demonstration that high proceduralisation (automation) is only appropriate if the organisation has a high stage of knowledge of the process, as illustrated in Figure 10.5.

Managers in the mini manufacturing cases were asked to provide a score for the stage of knowledge of their organisations in terms of Bohn's definitions, and to state their degree of proceduralisation. These subjective estimates have been plotted in Figure 10.5, and broadly suggest that Plastico and Flourco lie in the zones of ineffectiveness, that is, their degree of automation is greater than their stages of knowledge would suggest in terms of proceduralisation. Foodco lies in the zone of inefficiency, indicating that further automation may be appropriate. The difficulty with this broad approach is that if individuals are at a high stage of knowledge, then they can cope with greater proceduralisation, even if their colleagues have poor knowledge.

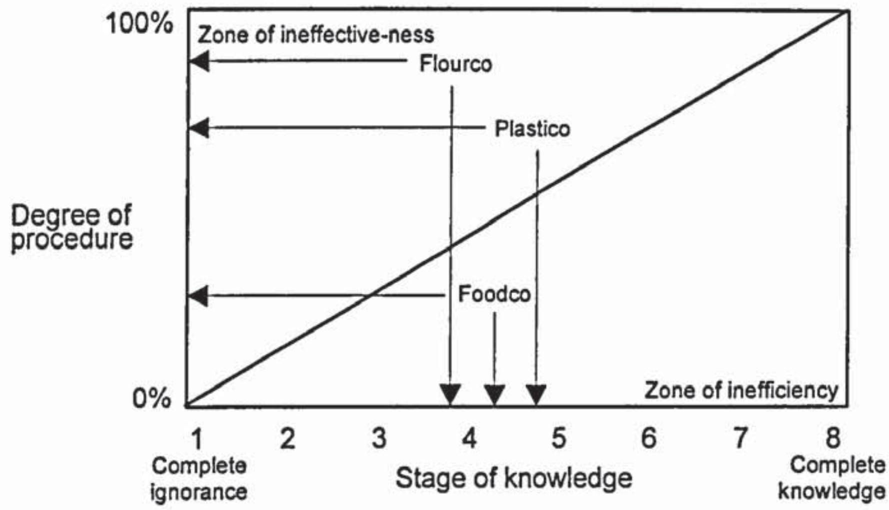

Figure 10.5 Degree of procedure and stages of knowledge

Managers failed to recognise that high-technology operations require rapid learning about multiple variables in new products and processes. These are difficult to control, so effort should go into raising knowledge as quickly as possible (Bohn, 1994). The low stage of knowledge in the manufacturing mini cases, in particular, resulted in a low stage of knowledge overall. Since staff did not understand the process, they could not handle unanticipated situations, nor could they do much to improve the process (other than revert to manual operation, as was frequently the case in Flourco and Plastico).

The second new element of the revised model introduces an activity to ensure agreement with (potential) suppliers regarding installation, commissioning and knowledge diffusion. This should be done in conjunction with the human skills audit (part of the first element at Level 3) that matches individuals' experience and qualifications with those recommended by suppliers. This should not be left until Level 4 as a clear lack of available skills may render the selected technology inappropriate, and remedial action can more easily be taken at an earlier stage.

Level 4 - implementation and maintenance

The case organisations did not plan implementation and maintenance as part of TT. As a result they suffered many operational and maintenance difficulties that might otherwise have been avoided. The original framework emphasises cooperation between suppliers and acquirers. Adaptation of imported technology should be retained as appropriate adaptation may well facilitate TT. Although respondents insisted that little, if any, adaptation was required in their installations, it emerged that later modifications would have been beneficial if they had been carried out earlier as part of the TT.

Guidelines for suppliers, training, and human resource issues are retained, but those for selecting alternative sources for TT have been removed in the revised model. These should be investigated long before the implementation and maintenance phase. A new element pertaining to physical asset management has been introduced at Level 4 in the revised model. Because maintenance fundamentals were poorly understood, maintenance was often incorrect, potentially dangerous, and ineffective. Typical maintenance activities are shown in Figure 10.7.

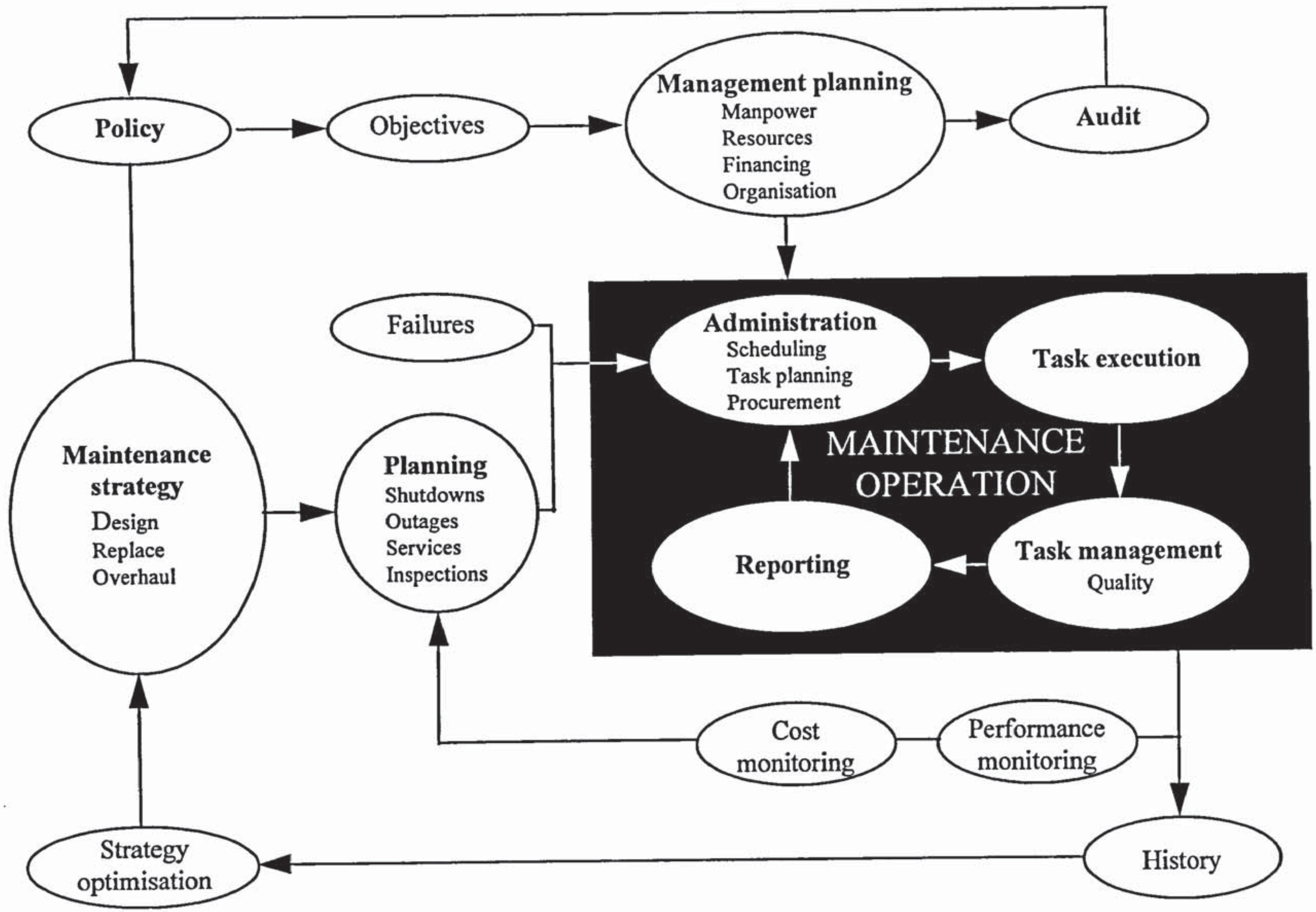

Figure 10.6 Activities of the maintenance function

Although power stations carried out most of these, maintenance was not as effective as it could have been if staff had been aware of some basic tenets of maintenance. Few of the activities were evident in the mini cases, apart from the basic maintenance operations, but even these were poorly executed. Within each 'box' in Figure 10.6 a large amount of preparatory work is required if maintenance is to deliver what operations is entitled to expect from it. The theoretical concepts in Chapter 3, such as determination of desired performance standards, mechanisms for seeking root causes of failure, evaluating consequences of failure, and maintenance intervals should form an essential part of Level 4 activities.

Level 5 - evaluation and modification

Apart from one element, the original framework is left unchanged for Level 5. Although the case studies did not evaluate their new technology or assess the effectiveness of TT, and no innovative programmes developed the new technologies further, these activities should be retained. While guidelines for redirecting the labour force into modification of technology are potentially significant, this element is revised to provide directions for ensuring that technology is correctly operated and maintained.

The maintenance decision-making process presented in Chapter 3 appears in Figure 10.7. Additional features have been added to explain some of the issues that managers and supervisors should attend to during the process of determining whether maintenance is applicable and effective. If the applicability and effectiveness criteria cannot be fulfilled, the default action is modification to plant, systems, operating and maintenance procedures, and enhanced training (Moubray, 2000). The process in Figure 10.7 requires that functionality should be well understand and quantified, in order to classify the consequences of failure. Only after a rigorous process of seeking to prevent failures should redesigns and modifications be considered. A tendency in the case studies was to seek equipment modification before all other possibilities had been exhausted, particularly as far as ensuring correct operating and maintenance procedures were followed.

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Figure 10.7 Maintenance decision-making process (Moubray, 2000)

Integration of activities: TT champion

From an organisational perspective, a number of issues will facilitate implementation of the recommendations made in the above discussions. They cover a wide variety of hierarchical levels, functional disciplines, and an array of decision-making processes.

Jelinek (1996: 808) speaks of the persuasive and enduring power of a strong and ingrained corporate culture and paradigm. The challenge is to show the "cognitive reality experienced by organisational members ... (understanding) is social, not solitary ... ambiguous data needs joint interpretation because many members embrace the new view for an organisation to change". Technology gains support with management commitment or at best 'benign neglect' and a receptive audience. One of the main problems in the case organisations was the lack of responsibility for TT.

The success of TT in power station PSZ was attributed to the appointment of a project manager who emerged as a technology champion. This new technology project was unusual in Eskom terms in that it involved only the power station. All managers were demonstrably supportive, and the supplier totally committed.

Decisions made at Levels 1 and 2 in the framework were divorced from activities at lower levels, so a champion appointed from, say, supervisor level would not normally be involved with earlier technology decisions. Involvement in the needs assessment and technology selection stages is essential, and a champion should have a clearly defined role and decision-making powers. This position would be complementary to the engineering function, would provide a bridge between operations and maintenance departments, and would require a broader range of skills than a project manager entrusted with new technology installation.

10.4 CONTRIBUTIONS AND LIMITATIONS OF THE RESEARCH

The aim of this research was to contribute to the TT literature, with specific reference to South Africa. While the country has its own unique problems, it also represents one of the most advanced of the developing countries, and lessons learnt from this study will be useful to countries in a comparable stage of development. The results show that the emphasis in the literature on economic and political intervention by governments of developing countries is only partially relevant to South Africa (in terms of affirmative action and black economic empowerment). This is an important finding because it shows that transferring technology is not the duty of the state in an open and free market economy, and firms cannot blame their government for low levels of technology. A significant charge can be made against the government for the country's poorly educated workforce, which is exacerbated by emigration of skilled people, and in the longer term by HIV/Aids. While part of the poor state of South Africa's education system can still be attributed apartheid, the country suffers economically because of the government's inability to address inadequate technical skills.

The findings suggest that South African managers do not fully utilise technology for competitive advantage and make little provision for transferring technology. Their interest is in acquiring machines to meet operational demands, but their problems lie in their inability to make the technology perform. Lack of technical knowledge and experience featured many times as the reason for poor operational performance: many operators and maintainers simply did not understand how their equipment functioned, why it failed, and how to repair it. Because maintenance concepts are poorly understood, physical asset management does not support operations as it should. In many respects these issues also apply to firms in developed countries, but they are more serious in the developing world, and only concerted action will begin to address them. The revised TT model in Figure 10.1 provides a structure for this, and further recommendations have been made at each level for addressing the important deficiencies in TT.

From a theoretical perspective, the research has used several sources to reach its conclusions, as described in Chapter 5, and illustrated in Figure 5.1. The literature is an essential starting point, and provides a basis from which to formulate research questions. This was done using Salami and Reavill's framework. The preliminary surveys of managers provided a useful insight into the South African situation. The case studies included Eskom, as a technological leader and parastatal organisation that is recognised as being competent in dealing with large technology projects. While its vast resources and the size of some of its projects make it untypical, much can be learnt from its project management skills and technical expertise. Additional views of TT were obtained from the mini case studies. Many of their challenges were similar to those of Eskom, although the latter was more subject to political pressure regarding black empowerment, and economic issues pertaining to overall infrastructure.

Limitations of case study research were discussed in Chapter 5. Generalisability remains one of these, since generalising from a limited number of cases leads to a set of working hypotheses, and not definitive conclusions (Cronbach, in Patton, 1980). However, as suggested above, "the domain to which a study's findings can be generalised" (Steenhuis and de Bruijn, 2003: 792) would not, in any event, have included all developing countries. The range of developing countries is such that TT to the least developed countries is totally different from that in the more 'advanced' developing countries, such as South Africa and Brazil. From a methodological perspective, case study research can be expanded to include more cases, across a broader industry spectrum.

A number of difficulties were experienced with the interviews in that access in some plants was limited, and certain respondents were reluctant to speak freely on sensitive topics. Along with many management investigations the research suffers from the problem highlighted by Gummesson (1991) regarding access to reality and insight. Discussions and interviews were standardised in order to enhance the reliability of the research. Interpretation of findings may affect validity (Steenhuis and de Bruijn, 2003), which will depend on the researcher's understanding of details and the inferences obtained from the literature and interviews. Various instances (as envisaged by Van Maanen, 1979) were experienced where respondents were incorrect about certain issues, or they were unaware of aspects underlying many of their firm's activities. This was not always at lower levels in the case organisations, but difficulties were experienced when individuals were being questioned about concepts which were foreign to them: many respondents were unaware of the concepts of TT and knowledge, so surrogate descriptions of the terms were used. Interviews with different levels in the case organisations and with a selection of suppliers did support Van Maanen's (1979: 545) view that "... the secrets of one group are revealed most readily by members of another group".

In terms of triangulation, the research combined a broad range of inputs, and research approaches (multi-methods) (Gummesson, 1991): the TT and physical asset management literature, the preliminary surveys of South African managers, and the main and mini case studies which provided data from a number of organisational levels in different industries and locations (Bryman, 1988). These led to the conclusions, which, as a contribution to theory building are summarised in the revised model for technology transfer, and supported by the additional models described at each level (Figures 10.2–10.7).

10.5 FURTHER RESEARCH

Findings from this research using Salami and Reavill's framework for TT in Eskom and four mini cases have led to a revised model for TT in developing countries. Because results from intensive research are not fully representative, several areas for further research can establish how general the findings are (Sayer, 1992). The first is the divide between parastatal organisations which can influence macro-economic conditions in the acquiring country, and smaller, private sector organisations that individually have no impact on the national economy. Secondly, the introduction of technology for strategic and operational reasons could present further challenges for TT, with particular reference to developing the technology through R&D for innovative purposes. Thirdly, the research was undertaken in process industries, and could be extended to product and service sectors. Fourthly, a wider TT study of countries at a comparable stage of development as South Africa could yield interesting similarities and differences.

10.6 FINAL REMARKS

The role of technology in economic growth and development, and in assisting firms to survive in a competitive environment is widely recognised (Lall, 1992; Kumar and Jain, 2001). Developing countries are subject to the same global pressures as their developed counterparts, but face the additional burden of dealing with domestic conditions which place them at a significant, and perhaps, insurmountable disadvantage, as they struggle with new technology, limited intellectual capital, inadequate learning experience and insufficient organisational competence (Fleury, 1999). Developing countries must acquire a technological base in order not to be subjugated to permanent dependence on imported technology. As regulatory and protective barriers are removed and new firms enter developing country markets, existing organisations face competition that is often incompatible with existing company cultures (Evaristo, 1998).

First-world technology is unlikely to provide a satisfactory technological base when infrastructural support and workforce skills are lacking. Local conditions influence technology choices and the degree of operational adaptation. As developing countries abide by international trade agreements in removing regulatory and protective barriers, local companies are confronted by formidable competition from international firms entering their markets (Narayanan, 1998).

This research has addressed many issues in its attempt to understand TT in South Africa. The literature, preliminary research and case study analyses have provided data and information for drawing some final conclusions. The country's history, stage of economic and political development, and other special circumstances clearly play a role in selecting and analysing technology. At the early stages firms must ensure the technology is appropriate for their requirements and commensurate with skills and knowledge of their staff. Lack of attention to this is the most serious barrier to successful TT. A TT champion should address human resource needs and should be fully involved with technology selection, and supplier negotiations. The case organisations failed to manage the interface between existing plant and systems, and the new technology. Understanding functionality and physical asset management is a further neglected aspect of TT. Evaluation of TT should not be an end in itself, but part of an on-going process to improve performance so that, through technology, South African firms can assume a competitive position in the global marketplace.

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REVIEW OF METHODOLOGIES USED IN THE TECHNOLOGY TRANSFER LITERATURE

The following table summarises the topics covered in TT publications and selected in order to assess the research methodologies in the literature.

	DC	TT/ MoT	Devel- opment	Strategy / policy	Other *	Research based survey	Research based case	Concep- tual	Descrip -tive
Adjiobolosoo	x	x	x						x
Al-Ali	x	x							x
Al-Ghailani	x	x							x
Alcorta	x	x					x		
Amin	x				x				x
Barbosa	x		x				x		
Bartlett	x			x	x			x	
Baruch		x							x
Bassolino	x	x		x		x			
Beruvides	x	x						x	
Bennett	x	x		x			x		
Chaudhurri	x		x			x			
Corbett	x				x	x			
Erel	x				x		x		
Estanislao	x				x		x		
Evaristo	x	x							x
Fleury	x			x		x			
Hemais		x						x	
Husain	x	x				x			
Jegathesan	x	x				x			
Jelinek		x			x	x			
Kahen		x		x				x	
Kharbanda	x	x		x			x		
Kim	x	x		x				x	
Kumar	x	x		x		x			
Lockett				x	x	x			
Motwani	x				x				x
Narayanan	x	x			x	x			
Padgett	x	x							x
Pandit	x	x		x		x			
Prochno	x	x		x	x		x		
Sabourin		x		x			x		
Salami	x	x		x				x	
Sambasiva Rao	x	x		x				x	
Samli	x	x							x
Sharif	x	x		x			x		
Sikka	x	x		x					x
Simango		x		x		x			
Steele	x	x		x					x
Veiga		x			x			x	

DC = developing country, TT = technology transfer, MoT = management of technology

*Other includes innovation, entrepreneurship, quality, supply chain, JIT, IS, culture, etc.

Summary of publications used to review methodological approaches in the TT literature

Author	Title/Contents	Contents/methodology	Conclusions/criticisms
Adjibolosoo (1994)	Promoting technology transfer for African development	Paper discusses the importance of social and institutional infrastructures. Several necessary conditions for TT are proposed in conjunction with a model	An exploratory paper using topics from the literature to propose a procedure for TT in African countries, containing several infrastructural requirements
Al-Ali (1995)	Developing countries and technology transfer	Technology is discussed as an essential factor in the industrialisation process. Paper defines TT, discusses technology as a concept, levels of technology, channels of TT with reference to the literature	Paper is descriptive with no research findings. The conclusions are a series of comments which define TT and give some recommendations for successful TT
Alcorta (1999)	Diffusion of advanced automation in developing countries	Paper presents extent of advanced automation in 6 developing countries. Factors underlying diffusion of CNC machines identified and the process of diffusion is described. Techno- and macro-economic factors were found to be important	Numerical count of CNC machines and workers in different types of firms. Conclusions are based on these numerical counts plus some conjecture regarding advanced automation. Paper reveals some interesting country differences
Al-Ghailani and Moor (1995)	Technology transfer to developing countries	A general model is developed presenting activities related to TT in Developing countries. The source of the model is from another conference paper. Types of technology transferred, channels of TT, factors affecting TT, are discussed with reference to the literature	The model is "applied" to Oman as a case study by studying the developmental progress caused by new technology and the effects of TT on aspects of Oman society, giving an idea of the pace of technological change. The case study does not prove the validity of the model, but specific recommendations are made
Amin and Kamel (1992)	Exploiting technological innovation in a developing nation	Paper proposes a code of conduct for encouraging innovation in Egypt. Several models are proposed, with a simple evaluation process	Paper is not a research paper, and proposes prescriptions for encouraging and evaluating innovation. There is little reference to the literature
Barbosa and Vaidya (1997)	Developing technological capabilities in an industrialising country: the cases of two Brazilian steel companies	The acquisition of technological capabilities by two Brazilian steel companies is described, illustrating a number of aspects of TT in an industrialising country	2 cases used to draw conclusions of complex, long-term process of TT. Paper differentiates between advanced and intermediate stages of TT. Two (limited) conclusions are long-term approach to developing capability and long-term external links in industries with complex and changing technologies and high R&D and investment costs
Bartlett (1994)	Strategic issues in energy policy formulation for developing countries	Paper looks at the importance of strategic marketing, human resources and strategic choice issues in energy policy formulation in Trinidad and Tobago	Paper is a description of some strategic issues in energy policy formulation, with no reference to the TT literature
Baruch (1997)	High technology organization what it is, what it isn't	Paper reviews classifications of the term high technology organization (HTO) by analysing 24 academic works, opinions of 100 top level managers in 60 organisations in Israel and the UK	By analysing categories for the definitions of HTO, investment in R&D as a proportion of sales, and authors opinions, some conclusions are drawn
Bassolino and Tse (1999)	Leveraging technology in the PRC	Description of regulatory issues in China. Some strategic considerations regarding TT, paying for technology, taxation and IP protection	Possibly useful for an organisation considering China as a business opportunity. The paper offers no methodological insight
Beruvides MG (1999)	Management of technology in developing nations: a survey of stakeholders	Paper addresses the most crucial issues in technology management in developing countries. There were 17 respondents from a MOT conference. Most important issues were understanding MOT and education/ knowledge	Author states that survey was an informal, non-scientific, fact-finding instrument, constituting exploratory research. Small, biased sample reduces validity and generalisability of findings

Bennett (2001)	Technology transfer through collaborative partnership arrangements: issues and considerations	Paper examines issues associated with partnership arrangements for international TT, focusing on questions arising when collaborative arrangements are being considered. The focus is on the machinery and machine tools, electronics and telecommunications industries, where China's economic policy has encouraged TT transfer through foreign investment for the purpose of upgrading these sectors	Paper uses cases of TT between Europe and China. Case study data are drawn from a study of success factors for joint ventures funded by the EU-China Higher Education Co-operation Programme
Chaudhuri (1992)	Technological development in technology exporting firms in a typical developing country	Paper describes insights into technological capability development in India. Discussions were held with officials in government departments and bodies, revealing a numerical count of 12 motives for technology export. 3 cases are briefly discussed	Although the paper sets out to investigate technological capability development, it is essentially a description of the activities of 3 firms, and what technology they exported to other developing countries. There is little reference to the literature
Corbett et al (1998)	A study of quality management practices and performance in Asia and the South Pacific	Survey of 599 managers in 5 countries. Literature used to derive components of TQM. Research questions used to test a number of hypotheses relating to quality performance and practice (*t*-test, factor analysis, regression)	Rigorous statistical analysis reveal country specific divergence regarding quality practices and performance
Erel and Ghosh (1997)	ISO 9000 implementation in Turkish industry	Study of status of ISO 9000 in Turkey. Survey of 73 large companies. Number of interviews not specified. Sought reasons for ISO 9000, obstacles, benefits and focus	Simple numerical counts of number of companies in each category reveal ISO 9000 motivated by quality considerations. Obstacles are procedural and organisational difficulties. Limited reference to the literature in assessing conclusions. Little insight into details of problems of introducing a new intervention
Estanislao-Clark (1998)	Implications of cultural differences on the implementation of JIT in garment countries in the Philippines and the UK	Paper uses Hofstede's country categorisation to investigate values for identifying a smooth implementation of teams and knowledge of work-force values. 2 UK and a Philippine companies are used as case studies. Implementation proceedings of team working were documented in each. Interviews were conducted, focusing on orientation and preparation, interaction, supervision and control, and compensation schemes	Comparisons are drawn from the 3 cases, regarding the smoothness of transition, congruence of values and team- working, power-distance, and individualism/ collectivism. Case studies provide useful substantiation of findings
Evaristo (1998)	Impact of privatisation on organisational information needs	Discussion of privatisation and deregulation in Brazilian telecommunications, with specific reference to information and intelligence needs	Steps in the privatisation process are described and how information needs change. Limited critical reference to the literature and paper remains largely descriptive
Fleury (1999)	Operations management in developing countries	Review of Brazilian companies to identify different roles played by subsidiaries in global competitive strategies	Based on a sample of 21 companies, strategies adopted by Brazilian companies are identified in terms of global partnerships, global chains and non-globalised industries. Ways of reorganising productive networks and productive networks were identified
Hemais (1995)	International transfer of technology - development of a model	A model is developed showing interaction between several dimensions affecting the international flow of technology. This is based on the literature and 6 UK case organisations	It is not clear how the model was derived. Discussions of the home market, the technology, government barriers, company attributes are intuitively obvious, the paper does not show how the interrelationship fits together

Husain and Sushil (1997)	Management of technology: learning issues for seven Indian companies	Paper analyses corporate practices concerning TT in 7 technology-driven Indian organisations. Interviews and observation techniques were used, and the situation-actor-process paradigm was used to analyse the cases	A generally consistent approach used for cases (present situation, technology strategy, S-A-P analysis, learning issues). Differences in industry sector highlighted. Comparisons of the situational factors, roles of actors, technology management processes, etc. are presented
Jegathesan et al (1997)	Technology development and transfer: experiences from Malaysia	Experiences from Malaysia and the literature are used to develop a model for technology development and transfer considering external and internal factors in ASEAN countries. The model relates the technology supplier through TT to the technology recipient	Strategic options for promoting technology development in Malaysia are looked at, based on an extensive discussion of local conditions. These illustrate the model, and discuss the role of government
Jelinek (1996)	'Thinking technology' in mature industry firms: understanding technology entrepreneurship	A discussion with reference to the literature is followed by 3 accounts illustrating the role of cognitions in helping or hindering technological entrepreneurship	Although the paper does not deal specifically with developing countries, it discusses on strategic configurations and the persuasive power of ingrained cost-reduction paradigms, the necessity for new technology to transcend past limitations, etc. which affect all TT
Kahen (1997)	Technology transfer and a conceptual model for technological planning and decision making	Paper aims to define major issues involved within the technological policy planning system for TT. A conceptual model of technological planning for TT is proposed and explained with reference to the literature	Models of a comprehensive system of TT, institutional infrastructure for TT and industrial development taking account of government involvement are proposed at a conceptual level
Kharbanda and Jain (1997)	Indigenisation and technological change at firm level	Study analyses technological change at firm level, looking at processes of absorption and adaptation of imported technologies. Learning by doing assists absorption an adaptation of imported technologies	Case study describes processes of absorption and adaptation. Detailed sales and production figures, and imported vs. indigenous performance discussed
Kim (1998)	Technology policies and strategies for developing countries: lessons from the Korean experience	A number of analytical frameworks are presented, with reference to the literature. The implications are discussed in relation to Korean public policy. No formal cases are analysed, although reference is made to organisations and current practice in Korea	Paper makes recommendations (better tertiary education, improved quality, export-orientation, etc.) which could be generalised, with the caveat that different approaches apply to newly industrialising and less developed countries. No formal research methodology
Kumar and Jain (2003)	Empirical study of perceptions of technology institutions	Paper focuses on parameters that influence decisions regarding commercialisation practices in India, the success of new technology ventures, and efficacy of existing financing/support mechanisms	Field research study of 500 firms and institutions undertaken to establish status and practices of commericalisation of new technologies, with some statistical analysis
Lockett and Palmer (1992)	Organising for change: managing an IS project across countries	Introducing IS technology in a manufacturing context into other European countries. Single case (ethnographic) used to understand how company transferred technology (communications, systems, computers, procedures)	Methodology was to talk to people. Systems and procedures were set up. The paper is largely descriptive in the style and content of a consultant's report, with little reference to theory, hypothesis testing or theory building
Motwani et al (1999)	Supplier selection in developing countries: a model development	With critical reference to the literature, supplier evaluation issues are identified from a strategic perspective. A model, derived from the literature, is developed for determining purchasing quality from developing countries in South America	While not dealing specifically with TT, paper contains points relating to problems in developing countries. These are derived from the literature (no survey or case analyses)
Narayanan (1998)	Technology acquisition, deregulation and competitiveness	Effects of deregulation on technology acquisition and competitiveness are analysed in India. Study makes some valuable comments about Indian industrial practices and how technological paradigm and trajectories have shifted under a more liberal economic regime	Reference to published data (annual reports, balance sheets) provides basis for statistical analysis (essentially an econometric exercise) and results

Padgett (1996)	Technology transfer to developing countries	Paper compares strategies used for protection and commercialisation of technology developments in developing and developed countries. A number of models proposed by the author are described and discussed	This is not an academic paper, and contains no bibliography. The paper is purely descriptive, reflecting the author's view on a number of topics (which do, in fact, concur with the literature)
Pandit and Siddharthan (1998)	Technological acquisition and investment	Study investigates influence of technology acquisition on investment behaviour, modernisation, and expansion plans, and finds that capability of firms to acquire technology differs considerably	Sample of 325 large firms in various industries selected to examine interfirm differences. Statistical and mathematical analysis of results
Prochno and Corrêa (1995)	Development of manufacturing strategy in a turbulent environment	With reference to the literature propositions aim to contribute to manufacturing strategy process research in one case organisation, looking specifically at manufacturing proactivity and inter-functional integration	Case study analysis used to suggest criteria for breaking barriers through the internal customer-supplier approach, to discuss the role of contingency models and replanning. Final conclusions made with reference to the literature
Sabourin and Pinsonneault (1997)	Strategic formation of competitive high technology	Paper examines role of highly qualified manpower, technological infrastructure, knowledge resources and capital in the competitiveness of 3 high technology clusters in Canada. 4 hypotheses drawn from the literature are evaluated	From a thorough analysis of information drawn from the cases, the paper shows that strategic resources follow a sequential path of causality
Salami and Reavill (1997)	International technology transfer policies and the industrialisation of developing countries	Paper analyses key success factors of international TT and their effects on economic and industrial development of developing countries, with reference to the literature. TT policies are discussed	Factors leading to successful experiences in newly industrialised countries are listed. A structured model is proposed consisting of five steps, ranging from macro to internal aspects of TT
Sambasiva Rao and Deshmukh (1993)	Implementing flexible manufacturing systems in India	Paper discusses necessity and scope of FMS with some reference to strategic issues. A four-stage approach is proposed (objective setting, planning, implementation, evaluation)	Some reference is made to the machine tool industry in India, with tabulations of figures (growth rates, imports and exports, number of CNC machines produced). No empirical work is presented; no analysis with reference to the literature
Samli, Grewal and Berkman (1992)	Macro aspects of technology management in the third world countries	Paper has an economic focus looking at TT as one way for developing countries to develop, exploring conditions for managing at a micro level (skills, resources, abilities to use, maintain and replenish) and macro (power structures, culture, priorities) level	Paper is entirely descriptive, with useful reference to the literature to illustrate interaction of variables. The conclusions appear intuitively useful, but are essentially conjecture
Sharif (1997)	Technology strategy in developing countries: evolving from comparative to competitive advantage	With substantial reference to the literature the paper develops a framework for establishing an integrated technology-based competition strategy by firms in Developing countries. 4 case studies from South Korea and Indonesia are selected	Paper shows that as markets deregulate and trade is liberalised, competition is more intense, but companies have opportunities in global markets, provided they have a strong technological capability
Sikka (1996)	Indigenous development and acquisition of technology	Description of support policies and strategies adopted in India for development of a technology base, and foreign collaboration, and TT	Paper describes issues relating to policy directives, technological self-reliance, R&D, with reference to the literature. No empirical work or theory building from the literature
Simango (2000)	Corporate strategy R&D and technology transfer in the European pharmaceutical industry: research findings	Paper looks at TT from various multinationals to Ireland. Survey results from 42 questionnaires are analysed. 10 interviews were conducted with CEOs. Results are tabulations of activities of, and R&D by multinational subsidiaries	Conclusions are drawn from tabular information (no statistical analysis) TT is associated with (unspecified) modes of entry, local R&D, infrastructure in Ireland, local skills

Steele (1998)	External technology sought during complex transition	Description of characteristics in India relating to technology	Findings are author's perceptions regarding self-sufficiency, government sponsored research, intellectual property concerns. No reference to any theory
Veiga and Floyd (1998)	The technology acceptance model: toward a cross-cultural perspective	Paper explores the relationship between national culture and IT acceptance by extending the technology acceptance model (TAM). Literature is cited to study effects of cultural dimensions on the TAM	A number of propositions are discussed with reference to the literature. Author suggests that TAM has predictive utility, and claims paper offers an approach to bridging the gap relating to national culture

APPENDIX II

MODEL OF TECHNOLOGY TRANSFER (Salami and Reavill, 1997)

Aston University

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APPENDIX III

SELECTION OF DEFINITIONS OF MAINTENANCE TERMS

The maintenance literature is characterised by an extensive and sometimes contradictory array of definitions and measurement concepts. This appendix contains a selection of these. Some comments are made where direct contradictions lead to different interpretations of the terms. Where definitions are essentially the same, these have been attributed to more than one author. The sources used for these terms are: Gits (1984), Jacquot (EdF) (1994), Kelly (1984), Moubray (2000), Smith (1993), US Army (1995), US Army (1992).

Absolute failure: a failure resulting in the physical impossibility of a part to fulfil its function (Gits)
Availability: the functional state in which a technical system is fulfilling its production function, or can fulfil its production function when called upon (Gits)
Availability: the time that a SSC (structure, system or component) is capable of performing its intended function as a fraction of the total time that the intended function may be demanded (this is the numerical complement of unavailability). Availability includes reliability (US Nuclear Regulatory Commission)
Breakdown: the transition of the technical system from the available into the unavailable state, due to absolute failure (Gits)
Condition-based maintenance: maintenance based on the mechanistic model, prescribing maintenance primarily based on assessing the value of a failure prediction property, and if a predetermined norm has been reached, the remedial activities to be executed (Gits)
Condition-based tasks: checking for potential failures so that action can be taken to prevent functional failures or to avoid the consequences of functional failures (Moubray)
Conditional probability of failure: the probability that an item entering a given age interval will fail during that interval (US Army, Moubray)
Condition-directed maintenance: aimed at detecting the onset of a failure or failure symptom (Gits)
Corrective maintenance: the actions performed, as a result of failure, or potential failure, to restore an item to a specified condition (Gits, Kelly, Moubray, US Army)
Degradation: the loss of performance or characteristics within the limits of the specifications; knowledge of the failure and degradation mechanisms provide information of the principles for on-condition maintenance (EdF)
Effective maintenance: prescribes when and what maintenance should be performed, either regarding:
- maintenance activation in view of the correctness at the prescribed moment, or
- the maintenance operation to be carried out in view of its achievement of the desired physical state (Gits)

Evident failure: a failure, the occurrence of which signals itself directly during operation of the technical system (Gits)
Evident function: one whose failure will on its own eventually and inevitably become evident to the operating crew under normal circumstances (Moubray)
Failure-based maintenance: maintenance generated by the event of failure only (US Army)
Failure cause: the physical or chemical processes, design defects, quality defects, part misapplication, or other processes which are the basic reason for failure or which initiate the physical process by which deterioration proceeds to failure (US Army)

Failure consequence: the damage inflicted upon a technical system and its environment as well as functional consequences concerning the effect of failure on the function of the part, and eventually, on the production function (Gits)
Failure consequences: Moubray divides these into hidden consequences (occurring as a result of the failure of a hidden function), safety consequences (occurring where a failure mode can cause a loss of function or other damage which could hurt of kill someone); environmental consequences (occurring where a failure mode can cause a loss of function or other damage which could lead to the breach of any known environmental standard or regulation); operational consequences (where a failure has a direct adverse effect on operational capability – typically, affecting total output, product quality, customer service, and increased operating costs in addition to the direct cost of repair); non-operational consequences (where failures affect neither safety nor production, and involve only the direct cost of repair)
Failure effect: the consequence(s) of a failure mode on the operation, function or status of an item (US Army)
Failure effect: describes what happens when a failure occurs (Moubray)
Failure mode and effects analysis (FMEA): a procedure by which each potential failure mode in a system is analysed to determine the results or effects thereof on the system and to classify each potential failure mode according to its severity (US Army)
Failure mode, effects, and criticality analysis (FMECA): an analysis to identify potential design weaknesses through systematic, documented consideration of the following: all likely ways in which a component or equipment can fail; causes for each mode; and the effects of each failure and may be different for each mission phase (US Army)
Failure mode: the manner by which a failure is observed, generally describing the way the failure occurs and its impact on equipment operation (US Army)
Failure mode: an event that causes a functional failure (Moubray)
Failure: an interruption of the component function, creating a loss of performance, below the threshold defined in the functional specifications (EdF, US Army)
Failure: the transition of a part from an operable to an inoperable state (Gits)
Failure: unintended cessation of function of a SSC (structure, system or component), classified as: immediate (catastrophic) where failure of equipment is both sudden and complete; degraded where a failure is gradual, partial, or both; the equipment degrades to a level that, in effect, a termination of the ability to perform its required function (US Nuclear Regulatory Commission)
Failure: the inability of any asset to do want its users want it to do (Moubray)
Failure-finding: aimed at discovering a hidden failure before an operational demand (Kelly)
Failure-finding: checking a hidden function at regular intervals to find out whether it has failed (Moubray)
Function: the characteristic actions of units, systems, and end items (US Army)
Function: a statement of what a user wants an item to do (Moubray)
Hidden failure: a failure which is undetectable during operations by operator/crew (US Army)
Hidden function: a function which is normally active and whose cessation will not be evident to the operating crew during performance of normal duties, or a failure which is normally inactive and whose readiness to perform, prior to its being needed, will not be evident to the operating crew during the performance of normal duties (US Army)
Hidden function: one whose failure will not become evident to the operating crew under normal circumstances if it occurs on its own (Moubray)
Incipient failure: a deteriorated condition that indicates that a failure is about to occur (US Army)
Incipient failure: an imperfection in the state of condition of equipment that could result in a degraded or immediate failure if corrective action is not taken (US Army)
Maintenance activiation distinguishes between:
- failure based maintenance

- use based maintenance
- condition-based maintenance (Gits)

Maintenance task: an action or set of actions required to achieve a desired outcome which restores an item to or maintains an item a in serviceable condition, including inspection and determination of condition (US Army)

Maintenance: a technical process which aims at keeping a technical process in, or returning it to, the available state by means of altering the physical properties of its parts (Gits)

Maintenance: the aggregate of those functions required to preserve or restore safety, reliability, and availability of plant structures, systems and components. Maintenance includes not only activities traditionally associated with identifying and correcting actual or potential degraded conditions, i.e. repair, surveillance, diagnostic examinations, and preventive measures, but extends to all supporting functions for the conduct of these activities (US Army)

Maintenance-preventable failure: an unintended event or condition such that a structure, system or component is not capable of performing its intended function and that should have been prevented by the performance of appropriate maintenance actions. Under certain conditions a structure, system or component may be considered to be incapable of performing its intended function if it is out of specified adjustment or not within specified tolerances (US Army)

Normative failure: a failure due to the passing of a specified threshold relevant physical property (Gits)

Operable condition: the physical state of the part that is considered sufficient for fulfilment of its function (Gits)

Preventive maintenance: maintenance with the objective of retaining a part of the technical system in the operable state (Gits)

Preventive maintenance: the aggregate of all those actions necessary to maintain the intended function of a structure, system or component, and reduce the probability of its failure in subsequent service by preventing unacceptable degradation. Preventive maintenance activities are expected to include periodic or predictive maintenance activities, as well as diagnostic testing, trending of failures, or trending of unacceptable degradation, as appropriate (US Army)

Preventive maintenance: the care and servicing by personnel, for the purpose of maintaining system/equipment safety and reliability levels, through systematic inspection, detection, lubrication and cleaning, etc (US Army)

Preventive maintenance: the performance of inspection and/or servicing tasks that have been preplanned (i.e. scheduled) at specific points in time to retain the functional capabilities of operating equipment or systems (Kelly)

Proactive tasks: tasks undertaken before a failure occurs, in order to prevent them from getting into a failed state - embraces predictive and preventive maintenance (Moubray)

Probabilistic model: forecasting of the event of failure based on the distribution of the duration of failure free operative periods (Gits)

Reliability: a measure of the expectation (assuming that the structure, system or component is available) that it will perform its function upon demand at any future instant in time. For an active system or component, reliability can be expressed as the probability that the system or component will start on demand, continue to run, and will perform its intended function. For a passive structure, system or component, reliability can be expressed as the probability per unit time that the structure, system or component will continue to fulfil its intended function. Note that reliability is a component of availability (US Army)

Reliability: the probability of an object performing its purposes adequately, for the period of time intended, under the operating circumstances encountered (Gits)

Running maintenance: maintenance that can be performed while the technical system is in the available state, or that requires the technical system to be operative (Gits)

Run-to-failure: a deliberate decision to run to failure because other options are not possible or the economics are less favourable (Gits)

Scheduled maintenance: periodic prescribed inspection and/or servicing of equipment accomplished on a calendar, mileage, or hours of operation basis (US Army)

Shutdown maintenance: maintenance that requires the technical system to be inoperative, and consequently in the unavailable state (Gits)

Shutdown: the transition of the technical system from the available into the unavailable state, due to a maintenance control decision (Gits)

Time-directed maintenance: aimed directly at failure prevention or retardation (Gits)

Unavailability: the functional state in which the technical system cannot fulfil its production function due to maintenance to be carried out (Gits)

Unavailability: how long an item is out of service when it fails (Moubray)

Unscheduled maintenance: those unpredictable maintenance requirements that had not been previously planned or programmed, but which require prompt attention and must be added, integrated with, or substituted for, previously scheduled workloads (US Army)

APPENDIX IV

FACTOR AND ITEM IMPORTANCE AND CONTROL SCORES

Code	S&R Level	Factor loading	Factor average importance/control scores in bold	Importance now	Control now	Importance 3 years	Control 3 years	z-score importance	z-score control
			TECHNOLOGY (% of variance explained 9.8)	**4.3**	**3.0**	**4.4**	**3.2**		
T1	4	0.891	Assimilation of new technology	4.3	3.1	4.5	3.5	*-1.22*	-3.21
T2	2	0.844	New technology to meet exact needs of customer	4.4	4.0	4.5	4.6	*-0.99*	-4.45
T3	3	0.708	Appropriate technology base established from partnership	4.3	3.8	4.4	4.0	*-0.71*	-2.35
T4	3	0.684	Sensitivity of technology: design, fabrication, operation and maintenance	4.2	1.5	4.2	1.7	*0.17*	*-1.56*
T5	3	0.663	Transfer of core technology from owner to acquirer	4.0	3.0	4.3	3.5	-2.19	-4.11
T6	3	0.662	Complexity of technology	4.6	3.2	4.8	2.4	-1.98	6.21
T7	2	0.619	Better quality through technology	4.6	3.4	4.6	3.9	*-0.09*	-4.65
T8	2	0.615	Improved output through new technology	4.4	3.6	4.6	4.1	*-1.62*	-4.37
T9	3	0.417	Robustness of technology: installation without adaptation	3.9	1.6	3.8	1.3	*0.95*	2.64
			ECONOMIC/POLITICAL (% of variance explained 7.9)	**4.5**	**1.8**	**4.6**	**1.8**		
E1	1	0.923	Crime levels in South Africa	4.8	1.4	5.0	1.4	-2.32	*0.60*
E2	2	0.858	Pressure from labour unions, affirmative action, employment equity	4.7	2.0	4.4	2.4	2.42	-3.41
E3	2	0.849	The brain drain - skilled people leaving the country	4.6	1.3	4.9	1.4	-2.65	*-0.91*
E4	1	0.791	Low educational levels of labour	4.8	1.7	4.9	1.6	*-0.86*	*0.20*
E5	1	0.708	Effects of globalisation	4.2	3.0	4.5	3.3	-2.01	-1.97
E6	1	0.696	Overall level of economic development and infrastructure	4.2	1.4	4.5	1.3	-2.63	*1.63*
E7	1	0.696	General conditions in a developing country	4.4	2.0	4.5	2.0	-5.58	*-0.17*
E8	1	0.608	Government regs/bureaucracy (planning permission, work permits)	4.0	1.2	4.4	1.3	-3.42	*-1.04*
			MAINTENANCE (% of variance explained 7.9)	**4.4**	**3.2**	**4.6**	**3.6**		
M1	3	0.892	Lead time to acquire technology/spares	4.3	3.0	4.4	4.2	*-0.43*	-9.97
M2	4	0.857	Cost effectiveness of proactive maintenance	4.3	2.8	4.3	3.0	*0.37*	*-1.28*
M3	3	0.825	Spares availability from suppliers	4.4	2.5	4.6	3.3	-2.15	-6.47
M4	3	0.823	Features requiring unique spares, specialised maintenance	4.2	3.6	4.3	3.2	*-0.87*	3.38
M5	4	0.799	Availability and reliability of equipment	4.7	3.6	4.8	4.2	*-0.82*	-5.74
M6	5	0.743	Safety assurance through maintenance	4.6	3.2	4.8	3.5	-1.94	-2.38
M7	5	0.685	Appropriate maintenance policies (intervals and tasks)	4.6	3.4	4.8	3.8	-2.76	-4.16
M8	4	0.677	Problems of 'burn-in' with new equipment and systems	4.2	2.6	4.4	2.9	-1.81	*-1.54*
M9	5	0.623	Understanding impact of maintenance/failure on overall process	4.2	3.4	4.6	3.9	-3.65	-3.46
M10	5	0.608	Failure data generated internally	4.3	3.6	4.5	4.0	*-1.50*	-3.08

FACTOR AND ITEM IMPORTANCE AND CONTROL SCORES

Code	S&R Level	Factor loading	Factor average importance/control scores in bold	Importance now	Control now	Importance 3 years	Control 3 years	z-score importance	z-score control
			KNOWLEDGE (% of variance explained 7.5)	**4.3**	**3.3**	**4.6**	**3.7**		
K1	4	0.926	Understanding of new technology	4.4	3.5	4.8	3.9	-3.31	-3.12
K2	4	0.865	Understanding hardware and software	4.3	3.8	4.5	4.0	-1.69	-2.08
K3	4	0.828	Codification and documentation of knowledge relating to technology	4.5	3.6	4.7	4.0	-1.65	-3.74
K4	3	0.776	Diffusion of intangible knowledge throughout the organisation	4.1	2.5	4.3	2.8	-1.97	-1.72
K5	4	0.727	Failure data from supplier on which to base proactive maintenance	4.4	3.1	4.6	3.6	-2.13	-4.54
			PEOPLE AND SYSTEMS INTEGRATION (% of variance explained 6.8)	**4.5**	**3.4**	**4.6**	**3.6**		
I1	3	0.919	Integrating new technology with existing systems	4.6	4.0	4.7	3.9	*-0.57*	*1.04*
I2	3	0.887	Development of communications and IT systems	4.5	4.1	4.1	4.2	2.82	*-1.18*
I3	3	0.883	Internal support, communication and cooperation	4.5	3.3	4.6	3.4	*-1.18*	*-0.90*
I4	2	0.872	Commitment to technology, and establishing clear objectives for technology	4.7	4.0	4.8	4.3	*-1.36*	-2.91
I5	4	0.825	Training by suppliers in the use of new technology	4.3	4.1	4.5	4.5	-1.81	-3.18
I6	4	0.747	Difficulties in implementation because of shortage of skilled personnel	4.8	1.7	5.0	2.0	-2.72	-2.55
I7	3	0.667	General exposure/experience of staff to high-technology equipment and systems	4.3	2.0	4.4	2.5	*-0.70*	-4.27
I8	4	0.658	Installation and commissioning of new systems	4.2	3.7	4.4	3.6	-1.83	*0.91*
I9	3	0.637	Internal infrastructure/facilities to accommodate new technology	4.4	3.6	4.5	4.3	*-1.25*	-6.55
			SUPPLY CHAIN (% of variance explained 6.3)	**3.6**	**3.2**	**4.0**	**3.5**		
Sc1	4	0.904	Establishing supplier networks and accessing local infrastructure	3.5	3.2	4.3	4.0	-7.42	-5.95
Sc2	3	0.804	Changing approach to supply chain management	3.6	4.0	4.0	4.3	-3.93	-2.49
Sc3	3	0.767	Moves to appropriate local sourcing	3.3	3.2	3.0	3.5	2.89	-2.34
Sc4	4	0.758	Trust between technology user and supplier	3.6	2.2	4.1	3.0	-4.52	-5.94
Sc5	3	0.732	Expertise of international suppliers	3.6	1.7	3.6	1.5	*-0.18*	2.14
Sc6	3	0.688	Use of the internet in supply chain management	3.8	4.0	4.4	4.2	-5.14	-2.12
Sc7	4	0.565	Dependence on supplier for technical assistance on a long term basis	3.9	3.0	4.4	3.6	-5.04	-4.92
Sc8	4	0.475	Procedures for problem solving and negotiation with suppliers	3.7	4.0	3.8	4.0	*-0.75*	*-0.18*

FACTOR AND ITEM IMPORTANCE AND CONTROL SCORES

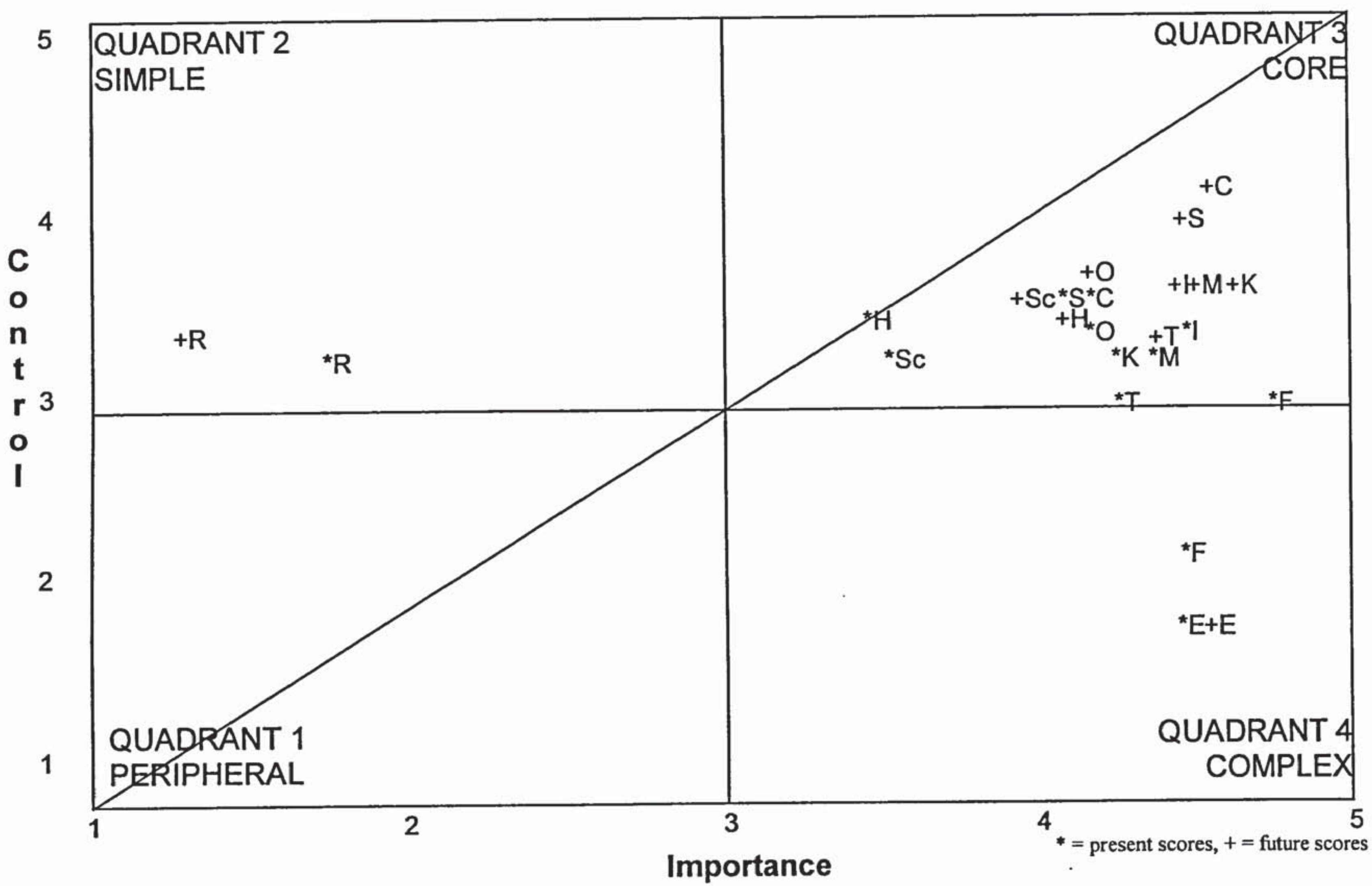
Code	S&R Level	Factor loading	Factor average importance/control scores in bold	Importance now	Control now	Importance 3 years	Control 3 years	z-score importance	z-score control
			STRATEGY (% of variance explained 6.2)	**4.1**	**3.6**	**4.5**	**3.9**		
S1	2	0.901	Distinctive competency to be derived from technology	4.2	3.9	4.6	4.3	-3.58	-3.69
S2	1	0.839	Technology implemented because of market demand (demand-pull)	4.3	3.9	4.6	4.2	-2.03	-2.75
S3	1	0.802	Technology as strategic resource for competitive advantage	4.4	4.2	4.7	4.5	-2.45	-2.92
S4	4	0.787	Ways of managing new technology (FDI, licensing, JV, partnership, etc)	3.9	3.7	4.3	4.0	-3.65	-3.03
S5	3	0.746	New relationships with stakeholders	3.7	3.1	4.4	3.4	-6.09	-2.58
S6	1	0.744	Technology to assist in shift from product to process base	3.9	3.2	4.3	3.8	-3.04	-5.24
S7	1	0.656	New business climate (global markets)	4.0	2.0	4.4	1.8	-3.41	1.67
S8	1	0.633	Alignment of business goals, systems and technology	4.4	4.2	4.6	4.4	*-1.27*	*-1.51*
S9	2	0.558	Technology permits revisit of vertical integration	3.9	3.7	4.4	4.0	-4.04	-2.95
S10	1	0.497	Statement of clear objectives to be achieved by new technology	4.4	4.3	4.6	4.6	-2.29	-3.55
			OPERATIONAL MANAGEMENT (% of variance explained 5.2)	**4.2**	**3.3**	**4.2**	**3.7**		
O1	4	0.884	Lack of labour commitment/ability to take responsibility, poor productivity	4.6	2.0	4.8	3.0	-2.63	-8.69
O2	4	0.858	Empowerment	3.7	3.8	3.9	4.2	*-1.52*	-3.36
O3	4	0.784	Cost of training and developing local workforce	4.5	3.0	4.5	3.9	*0.28*	-8.01
O4	3	0.773	Promoters/champions essential for new technology	3.8	4.3	4.0	4.4	-2.54	*-0.83*
O5	3	0.705	Change management processes for new technology implementation	4.3	3.6	4.2	4.0	*0.64*	-3.61
O6	4	0.587	Transfer of systems, managerial philosophy, values	4.2	3.2	4.5	3.7	-3.31	-4.12
O7	3	0.587	Short term operational returns expected from technology	4.0	3.0	3.3	2.7	6.40	2.27
			CONTRACTUAL (% of variance explained 4.7)	**4.2**	**3.6**	**4.6**	**4.1**		
C1	4	0.878	Technical documentation and drawings	4.2	3.4	4.5	4.0	-2.77	-4.74
C2	3	0.874	Contractual arrangements	4.4	4.3	4.6	4.6	-2.52	-2.72
C3	4	0.857	Post-installation back-up and support by technology supplier	4.2	3.5	4.7	4.1	-4.09	-5.68
C4	3	0.740	Operational compatibility between owner and acquirer	4.1	3.1	4.5	3.6	-3.11	-4.23
			HIGH-TECHNOLOGY ISSUES (% of variance explained 2.5)	**3.5**	**3.5**	**4.1**	**3.6**		
HT1	3	0.867	Use of expert systems/intelligent machines	3.5	3.1	4.1	3.4	-5.51	-1.90
HT2	2	0.839	Novelty of technology	3.4	3.6	4.0	3.2	-5.18	3.32
HT3	3	0.748	Process optimisation for full benefit from new technology	3.7	3.7	4.2	4.3	-4.17	-5.05

APPENDIX IV (cont)

FACTOR AND ITEM IMPORTANCE AND CONTROL SCORES

Code	S&R Level	Factor loading	Factor average importance/control scores in bold	Importance now	Control now	Importance 3 years	Control 3 years	z-score importance	z-score control
			FINANCIAL (% of variance explained 2.3)	**4.5**	**2.2**	**4.7**	**3.0**		
F1	3	0.881	Cost a major factor in technology selection	4.5	2.2	4.6	2.5	*-0.87*	-2.68
F2	3	0.876	Justification of technology on a cost/benefit basis	4.6	2.0	4.7	3.0	-1.19	-8.15
F3	4	0.755	Quantification of hidden costs of technology (TT, HR, environmental, etc)	4.5	2.4	4.8	3.5	-2.35	-9.21
			RESISTANCE TO CHANGE (% of variance explained 2.1)	**1.7**	**3.2**	**1.3**	**3.3**		
R1	4	0.811	Resistance to technology because it is not local	1.7	3.4	1.2	3.2	4.47	1.88
R2	5	0.770	Difficult to accept other ways of working	1.7	3.0	1.3	3.4	3.52	-3.77

APPENDIX V



The importance-control grid - current and future factor scores

APPENDIX VI

ESKOM INTERVIEW SUMMARIES

This appendix summarises the Eskom interviews in five sections, corresponding to the levels of the Salami and Reavill framework. The items from the preliminary research pertaining to each level are discussed in the five sections. In order to avoid repetition comments from respondents at different power stations have been combined rather than discussing each power station separately. Some repetition of comments is evident as respondents at different levels made the same points.

1. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 1 (HEAD OFFICE)

The following paragraphs discuss the items categorised at Level 1 in Appendix V. Level 1 refers to head office management levels where policy decisions are taken.

- *Level 1: Economic/political*

Crime levels in South Africa

Crime was recognised as having an extremely debilitating effect on South Africa, although it did not have an immediate influence on technology decisions. It affected the South African economy, and respondents largely attributed high emigration of skilled personnel to crime. Eskom was not able to quantify its losses through theft and dishonesty, but felt the figure must be millions of Rand. Additional security measures at installations increased the cost of engineering projects.

Low educational levels of labour

South Africa's low levels of education were widely recognised. Technology policy did not specifically take this into account as respondents selected technology on its technological merits. Eskom was committed to upgrading the skills of its staff by ensuring the necessary skills for present and future needs. It offered generous bursaries for tertiary education (universities and technical colleges). Its practical training programme for newly qualified engineers was recognised by the South African Council for Professional Engineers. Many training courses were offered, ranging from technical to human resource management skills, and staff at all levels were encouraged to attend these. Eskom's policy of transformation was accompanied by leadership development programmes. The training refund from the skills development levy paid by all employers to the Inland Revenue was fully utilised by Eskom.

Examples were cited where an inadequate grasp of equipment functionality had discouraged its subsequent use, and poor education certainly contributed to the lack of understanding. To address this significant use was made of supplier expertise, and this was expensive. Respondents realised that abilities of operating and maintenance staff were, in some cases, lower than would be found in first world countries, but these did not affect the choice of technology.

Effect of globalisation

Respondents differed in their assessment of globalisation. Some contended this did not directly affect Eskom's technology decisions as South African organisations conducted business throughout the world, unlike during the apartheid era when Eskom was obliged to source its technology from a limited number of European suppliers. Others suggested Eskom's extended influence in Africa was a form of global expansion. There was consensus that Eskom's sources of technology supply were global, and that the markets for its products and services lay in the African continent. One respondent quoted a policy statement that pointed to Eskom's becoming "a pre-eminent African energy and relative services business of global stature".

Overall level of economic development and infrastructure
Respondents felt that Eskom contributed significantly to South Africa's generally sound infrastructure. Some of Eskom's performance standards on its sustainability index were:

- generation:	energy availability factors 90% unplanned automatic grid separations of 1.7 per 7 000 hours
- transmission:	zero supply interruptions with a severity greater than or equal to one system minute were 6.2 system minutes per year
- environment:	water consumption 1.26 l/kWh particulate emissions 0.33 kg/MWh sent out
- frequency:	between 49.85 and 50.15Hz in normal conditions, an estimated 95% of the time (comparable figures for the UK are between 49.8 and 50.2Hz, and Norway between 49.9 and 50.1Hz)

Eskom has greater distribution expansion plans than utilities of comparable size (such as the UK and Norway), with the electrification of 600 000 homes between 2000 and 2002. With surplus generating capacity, Eskom would concentrate on increasing electrification in rural areas in South Africa, and increase its presence in neighbouring countries (particularly Mozambique, Namibia and Zimbabwe).

Respondents pointed out that Eskom's testing facilities at Rotek (established from Eskom's central maintenance function as an independent business) are comparable to developed world standards, such as the impulse generator for high-voltage transformers, and balancing equipment for turbines. Generally South Africa's economy could accommodate and sustain a high level of technology, and to that extent, its infrastructure far exceeded that of most developing countries.

General conditions in a developing country
While there is good infrastructure this contrasts with areas of poverty where roads, telecommunication, education and health facilities were similar to those found in some of the poorest countries. Low levels of education and poor productivity were cited as being comparable with other developing countries. South Africa's economic growth was lower and its inflation higher than those in most industrialised countries, which placed the country at a trading disadvantage.

Government regulations and bureaucracy
Eskom, as a parastatal organisation has always been subject to the political whims of the government of the day. Eskom pursued apartheid policies to the letter, particularly in its exclusion of blacks to senior positions. Before the ANC came to power in 1994, Eskom had changed dramatically, and in keeping with the ANC government's policy, it now actively promotes black economic empowerment and women enterprise developments.

Respondents perceived this to be the way in which government influence was felt, rather than its regulations and bureaucracy. They felt that financial arrangements were now far easier than under the previous government. There were frustrations with government policies, for example, with the difficulties experienced in granting work permits for skilled staff from abroad. With the great shortage of skills in South Africa, Eskom knew that there were few local individuals able to perform many skilled functions, but the Department of Home Affairs took months, if not years to approve work permit applications.

- ***Level 1: Strategy***

Statement of clear objectives to be achieved by new technology

Eskom's corporate objectives fall under four headings: finance, restructuring for growth, the customer, and human resource alignment. While technology does not appear in these, respondents suggested that technology plays a role in each. For example, in terms of achieving financial goals, an information systems strategy was in place, and e-business initiatives were being introduced. Respondents indicated that the only way Eskom could achieve its performance targets was by making use of the latest technology. Eskom's proposed entry to the telecommunications market would require the acquisition of a great deal of new technology.

Technology implemented because of market demand (demand-pull)

Market demand did not directly affect the choice of technology in Eskom. Respondents indicated that the customer was not aware of, or interested in, the technology used (apart from growing concern with environmental pollution, and the debate over nuclear power).

Technology as strategic resource for competitive advantage

Being a monopoly Eskom did not have competitors in South Africa in its core areas of activity. Distribution was done by municipalities, so they could be perceived as a competitor, although the distribution network was being restructured into Regional Electricity Distributors.

Technology to assist in shift from product to process base

Although the product and process base did not apply from a customer perspective, Eskom has always sought to increase the efficiency of its production processes. Views of its 'product' included availability and reliability of supply, at the correct frequency and voltage. Increasing efficiencies of power stations have been achieved through improved technology and better operating and maintenance.

New business climate (global markets)

The new business climate in which Eskom operates includes expansion through its subsidiary Eskom Enterprises into African markets. Restructuring of the electricity industry requires definition and implementation of a holding and subsidiary company structure, with generators being positioned for competition, transmission remaining as a parastatal, consideration of the implications of restructuring and transformation on human resources related issues, and communication with stakeholders, especially lenders.

Alignment of business goals, systems and technology

Technology was not specifically mentioned in the changes envisaged in the previous paragraph. Respondents did not feel that technology was the driver of these goals. Rather, technology would play an essential, but supporting role.

2. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 1 COMPONENTS

The following paragraphs discuss the Level 1 elements in the Salami and Reavill model.

- ***Level 1: Identification of needs and demands of acquiring country***

Respondents saw Eskom's role as one of providing a vital service to South Africa. Continuity of supply was Eskom's main task, and technology needs concentrated on this. It was also felt that Eskom was a technology leader in South Africa, and other parastatal organisations, mines and a range of private companies use Eskom's specifications, and, increasingly, Eskom's testing facilities. It therefore had a responsibility to maintain contacts with new technology suppliers, as these would help South Africa's technological advancement. Respondents discussed its many stakeholders as being the direct beneficiaries of its technology policies.

- ***Level 1: Identification of limitations, advantages and disadvantages of needs and demands***

Finances limited the technology available to Eskom. Although other firms looked to Eskom for technical specifications, respondents indicated that these firms could not always afford to acquire technology at these levels.

Eskom's approach to generation was also changing. Environmental pollution in the areas with plentiful coal suppliers (in Mpumalanga province, east of Johannesburg) meant that it was unlikely that permission would be granted to construct new large coal fired power stations in this area. Water shortages exacerbated the situation, despite one of the newest power stations being dry cooled. The nuclear option presented several possibilities. Another large nuclear power station, similar to that at Koeberg, near Cape Town, was thought unlikely. Pebble bed nuclear reactor technology was under development by Eskom and interested parties from Germany, and the UK. Solar powered generation was also being tested.

Eskom's need for technology thus extended beyond traditional coal fired power station technology, although these power stations would continue to supply most generating capability.

- ***Level 1: Identification of important macro and micro human factors for use of new technology***

Training and education were amongst the most important issues in considering new technology. Eskom has led the world in dry cooling. The pebble bed reactor was being developed in South Africa. Respondents claimed that Eskom possessed world-class engineering expertise, but insufficient technicians, operators and maintainers to accommodate some new technologies. Poor school education presented a considerable burden on companies' training departments that were forced to provide numeracy and literacy training. Eskom suffered further with inadequate numbers of students studying science and engineering.

- ***Level 1: Identification of acquirer's goals and objectives***

Eskom identified its goals as being the pre-eminent African energy and related services business, of global stature. Technology would be partly instrumental in achieving this.

3. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 2

The following paragraphs discuss the Level 2 items in Appendix V. Level 2 refers to head office management and engineering.

- ***Level 2: Technology***

New technology to meet exact needs of customer

The nature of the contracting process with power stations was that Eskom would generally set broad design parameters on which suppliers would tender. Eskom stated standard specifications applicable to various categories of equipment (such as IEC, British Standards, DIN, ISO, etc), and also specified exact needs in terms of performance criteria. For example, electrical generation requirements included: generator rated voltage, continuous maximum output at rated voltage and power factor (CMR), power factor at CMR, short circuit ratio, and speed. Mechanical requirements and conditions were based on electrical output of the generator, with a given steam pressure and temperature at the high pressure turbine emergency and stop valves.

Selected suppliers would then present their detailed designs to Eskom, and provide technical performance information, material descriptions, specifications, and properties 6 months after authorisation to proceed with the contract. Eskom verified these during fabrication, installation, commissioning and acceptance testing.

Better quality through technology

As discussed above, the quality of Eskom's output was measurable in terms of availability and reliability. Greater efficiencies could be achieved through technology, but Eskom was not fully competent to accommodate all technologies. Experiences and considerations regarding hydrogen generating plants and steam driven feed pump turbines are discussed under levels 3 and 4.

Improved output through new technology

Respondents equated output with quality in the context of Eskom's 'product'.

- ***Level 2: Economic/political***

Pressure from labour unions, affirmative action and employment equity policies

Eskom's commitment to affirmative action and black economic empowerment affected the entire organisation. Its non-negotiable affirmative action policies aimed for 50% of management, supervisors and professional employees to be black, and 20% to be women. Respondents noted that affirmative action and black empowerment policies were overtly accepted at head office. Preferential treatment offered to black empowerment companies changed the nature of purchasing, and introduced an additional link in the supply chain. Even where equipment could only be obtained from Europe or the US, Eskom invariably required an intermediate black empowerment company to be involved in the supply chain.

The brain drain - skilled people leaving the country

Respondents maintained that this posed enormous difficulties. This affected Eskom directly with the number of its own engineers who had emigrated, but also because many suppliers' staff had also left. While European suppliers usually sent installation and commissioning experts, they were only available during that period. With the emigration of suppliers' South African, or South African-based employees, Eskom found it increasingly difficult to turn to suppliers for immediate assistance. Respondents felt that it would take many years for local engineers to acquire the knowledge and experience lost through emigration.

- ***Level 2: Strategy***

Distinctive competency to be derived from technology

Technology offered Eskom the ability to operate more efficiently, but further than that, technology was not an integral part of strategy, and did not offer a distinctive competency in a coal fired power station context. Technology did potentially grant Eskom competitive advantage in other generation processes, such as the pebble bed nuclear reactor, and would possibly do so when solar power generation had been further developed.

Technology permits revisit of vertical integration

Respondents' only illustration of increased vertical integration was Eskom's specialised centralised maintenance organisation, Rotek, that could undertake large maintenance tasks that were previously performed by contractors. Outsourcing of other aspects of maintenance (such as valves) effectively meant less integration. Eskom also effectively outsourced much of its design work by setting broad parameters within which suppliers provided the appropriate technology.

- ***Level 2: Management policies for technology***

Belief in the need for and commitment to technology, and establishing clear objectives for technology

Respondents were adamant that Eskom was committed to the most appropriate technology for a particular application. During the phase of extensive power station construction in the 1980s, there was a view that Eskom was less financially constrained than at present. Ironically, this was a time when sanctions against apartheid made access to funds difficult, yet it found itself able to invest in new technology. Today, it was far more accountable to its stakeholders. Although Eskom still remained fully aware of available technologies, and maintained its high technical specifications, respondents felt that financial constraints had some beneficial effects in more cost-effective designs. Examples were given of dispensing with coal staithes at certain power stations, changing the layout of power stations back to a common turbine hall, rather than individual turbine halls for each unit, new configurations for feed pumps, and so on. These are examples of improved designs, rather than technology driven improvements.

- ***Level 2: High-tech issues***

Novelty of new technology

One respondent felt that in the past Eskom had sought new technology for the sake of novelty, rather than basing designs on sound engineering judgement. Others disputed this, and suggested that it was rather conservative in wanting to witness new technology in operation elsewhere in the world before introducing it in South Africa. It was generally felt that Eskom's new boiler and turbine control systems were amongst the best in the world, and these resulted in direct benefits in operational efficiency.

4. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 2 COMPONENTS

The following paragraphs discuss Level 2 in the Salami and Reavill model.

- ***Level 2: Identification of appropriate technologies to meet acquirer's goals***

Respondents did not believe Eskom had to be content with inferior technologies appropriate for a developing country. Technology was not adapted to local conditions, other than for environmental reasons. Eskom specified performance standards, which were comparable to those in the developed world, and suppliers were obliged to provide plant that could meet these standards. Some engineers acknowledged that plant was taken over, the original performance standards were not always met and could not be sustained, and gave the example of the effective derating of all coal fired power station units throughout Eskom. Arguments for and against this decision indicated a wide diversity of opinion.

- ***Level 2: Identification and analysis of cost and benefits of new technology***

Engineers felt that Eskom had not in the past been strict in its cost control. Decisions favouring one design or technology over another were taken on engineering judgement, and cost was a secondary factor. In reality, it was not possible to conduct true cost benefit analyses. While lack of adherence to performance standards could be quantified, say by calculating losses, or inefficiencies, these were at best estimates. Comparative estimates were made, but engineers felt that final decisions were based on intangible factors, Eskom experiences, and the experiences of users in other countries.

- ***Level 2: Evaluation of imported technology on the basis of acquirer's resources***

Eskom's policy favoured local suppliers. It was possible to source items such as electric motors, transformers and switchgear locally (apart from generator transformers and generator breakers, as these were too large for South African manufacturers). Most manufacturers were a subsidiary of a European firm, or had close alliances with foreign technology suppliers. The depreciation of the Rand obliged suppliers to source imported materials from low cost producers. One example was given of a transformer manufacturer who obtained the material for transformer cores from Russia, as this was considerably cheaper for comparable quality from suppliers in Europe who would typically buy their equipment from European manufacturers. With Eskom's new policy of favouring black empowerment companies, these firms would have to establish partnerships with foreign suppliers. The most important resources from the acquirer's perspective were financial.

- ***Level 2: Analysis of economic and technical factors affecting TT***

In the past Eskom was bound to acquire technology from firms in countries whose financial institutions offered to finance new projects. Because of sanctions against apartheid, Eskom was essentially limited to negotiating with European suppliers. This has changed, but respondents indicated that relationships with these suppliers had generally been good, and that there were no technical reasons for changing. They also pointed out that many of the large power stations contracts had been placed during the apartheid era, so the occasion had not arisen for appointing large contracts under the new political dispensation.

5. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 3 (POWER STATIONS)

The following paragraphs discuss the Level 3 items in Appendix V. Level 3 refers to power station management.

- ***Level 3: Technology***

Appropriate technology

Managers did not evaluate technologies or items of equipment in terms of being appropriate to South African conditions as the main boiler and turbine contractors determined much of the technology. They felt that equipment was suitable and compatible with operating circumstances and rejected suggestions that less complex technology might be more appropriate for South African conditions.

A manager pointed to a clause in the power station contract documentation: "during the design stage, the contractor shall embody such modifications as experience with similar current turbo-generator units shows to be necessary, (and must) provide the best availability and utility of plant ... any tenderer may also propose optional items which contribute towards safety, ease of operation and efficiency not envisaged in the specification" (Tutuka Power Station contract with GEC, 1980). Respondents felt that Eskom should be offered the latest technology, although cost considerations would be a deciding factor once technological options had been evaluated.

It was pointed out that Eskom was the seventh largest generating undertaking in the world, and had been a major purchaser of generation equipment since the second world war. Further, Eskom's standards were derived from British Standards, although Eskom frequently prescribed higher specifications than other utilities. Financial constraints may require a lowering of future technical standards, such as the reduction in the frequency target from 49.70Hz in 2001 to 49.50Hz in 2002 following an international benchmarking exercise. Eskom's Annual Report 2002 claimed that the reduction resulted in cost savings and the reduction of movement of generators by some 80% without any adverse impact on customers.

Managers at PSZ (the power station that had installed a new boiler control system) condemned their original boiler control system: it constituted new technology the time, but did not provide adequate boiler stability. The new control system, piloted initially on one boiler, was chosen as the new supplier had provided attractive performance guarantees. The output of the new system was considered to be appropriate for the power station. Managers had no control over the technology itself as the supplier developed this.

Sensitivity of technology
Certain equipment did not function as originally intended, and was considered insufficiently responsive to South African conditions. The true reasons were frequently not TT issues, but attributable to errors in specifications. For example, coal from one mine was too abrasive for the original mill specifications; load reductions at another power station were required when the temperature of cooling water rose above the maximum temperatures specified in the contract; exceptionally dusty conditions necessitated revising many filter specifications.

Considerable attention was paid to control systems to accommodate automatic control of the main boiler, turbine and feed heating plant variables over the whole operating range. Managers saw sensitivity as relating to Eskom's operating philosophy whereby the primary function of the control systems was to increase the availability of a unit by increasing the safety of operation during start-up and shut-down procedures, to provide continuity of generation under normal conditions, and instigate correct switchover procedures to reserve auxiliaries under fault conditions. While managers acknowledged that these were standard requirements, they were aware of the additional advantages of relieving operators of routine operations, and ensuring regular automated checking of systems and circuits.

Although the new boiler control technology at PSZ had been tested in applications in other parts of the world, local modifications were necessary to accommodate unique features of the boiler itself. This was not an issue of adapting for the South African situation, or a developing country environment, but a process of adjustment that would have been required for every boiler.

Transfer of core technology

A common problem was the inability to attract sufficient graduates, or technically qualified staff to power stations. There was little deep understanding of power station technology. Operating staff were 'programmed' to operate. Because much of the operation was automated, it was possible to achieve satisfactory production with lower skills levels. Some staff had many years of experience, with a good feel of how to operate, but managers doubted that operators understood much of the underlying thermodynamic theory pertaining to power stations. It was suggested that many managers and senior supervisors themselves had insufficient theoretical understanding of the operation. These deficiencies in core technology transfer were frequently encountered.

Respondents at this and other levels commented that operators experience difficulties in bridging the gap between theory presented during formal training, and its practical application. Operators knew immediate performance parameters such as temperatures and pressures, but their knowledge went little deeper than this. This meant that subtle improvements were unlikely, and that the considerable on-the-job training that took place resulted in a perpetuation of current practice, rather than improved operating. Because of the relatively low levels of technical skills among operators and maintenance staff, it was difficult to ensure complete transfer of power station technology. Systematic training programmes were offered, but in many instances Eskom had to contend with poor literacy, inadequate knowledge of English, and low mathematical ability. The advantage of automatic control of a unit was that less than total operator proficiency could be accommodated, but managers accepted that expensive mistakes were made, and that fault diagnoses were poor.

Several managers criticised Eskom's policy of not insisting that acceptance testing of equipment should be witnessed by its staff before hand-over. Contracts stated that every opportunity should be afforded to Eskom's operating and maintenance staff to obtain first-hand knowledge of plant erection and equipment installation. However, some testing was done off-site (such as overspeed and balancing of the generator and exciter rotors), as Eskom was prepared to accept test certificates provided tests were done in accordance with CEGB and Eskom standards. In such instances core technology was not transferred.

A PSZ manager commented that core technology had been better transferred with the new control system than in previous instances because the design, project management, installation, commissioning and initial operational testing were done in close conjunction with power station staff. There was none of the usual conflict between Eskom's commissioning and operating departments, which resulted in a far greater sense of ownership by operators. Formal training was offered, and this was immediately followed by on-the-job observation and training. In conventional new power station construction, technology suppliers were more aligned to Eskom's commissioning teams than to the operating and maintenance functions, so there was a distant relationship between the technology supplier and the final technology user. In the case of PSZ, the absence of a head office appointed Eskom commissioning team meant that the supplier communicated directly with the user from the start of the technology project.

Complexity of technology

Modern power stations are highly complex. Amid this complexity, it was a head office function to achieve a balance between achieving world-class efficiencies and lower operating costs, and initial capital expenditure. A different design philosophy and fewer financial constraints applied to the power stations designed several decades ago in the apartheid era of profligate spending for politically inspired infrastructure. Cost considerations now determined whether sophisticated plant and systems were introduced. Better systems were available but these were sometimes too expensive. One manager questioned the true extent and validity of cost benefit analyses, which were undertaken at head office. Managers believed that Eskom could operate and maintain any good systems of whatever level of sophistication. Some Eskom respondents and suppliers questioned these contentions (this is discussed in level 4).

Contract documentation gave suppliers considerable choice in the equipment they supplied. For example, following experiences elsewhere, the turbine contractor was given the option of providing a hydrogen generating plant or hydrogen cylinders. In other instances, Eskom specified engineering solutions. One supplier commented that Eskom's technical specifications and acceptance testing were exceptionally demanding, and that head office was well informed of available technology options. For example, the preferred excitation system at one power station was an AC exciter and stationary rectifiers. In this case, Eskom was effectively determining the level of complexity of the technology. By specifying a design philosophy, Eskom also excluded certain technology. So, by having no 22kV generator breaker between the generator and the generator transformer (which had been introduced in other power stations), Eskom excluded complex and expensive items. This decision also had implications for high voltage protection systems. Managers felt that problems with technology lay not with excessive complexity, but with ill-equipped staff.

Several managers felt that some maintenance work was too complex for Eskom maintenance staff, and so such work was outsourced. This was in line with worldwide trends in outsourcing maintenance.

Robustness of technology

Managers felt that technology owners assumed their technology was more robust than was the case in reality. High summer ambient temperatures meant that certain items of plant operated on their outer limits under maximum load conditions, because of inadequate designs by technology suppliers, or inadequate conformance to technical specifications. Eskom's derating of output of most units was interpreted by some managers as accepting that the plant was not always able to meet its specifications. Low mill availability meant that units were frequently operating with two mills out of service (where full load requirements permitted only one mill to be out of service). Several managers ascribed this to shoddy maintenance rather than poor mill technology.

One supplier commented that some Eskom staff 'operated like cowboys', and did not understand the complexities of a modern power station. He mentioned that after a particular unit had been handed over to Eskom operations, the unit had tripped and had been run-up more times in two months than would be expected for such a unit in two years. This would adversely affect the life of the boiler, as no technology had the level of robustness to accommodate such poor operating.

- ***Level 3: Knowledge***

Diffusion of intangible knowledge

Managers did not relate to the concepts of explicit and tacit knowledge. The question pertaining to the diffusion of tacit knowledge was interpreted as how technical staff could acquire a broad knowledge of power station operation. Examples were provided to illustrate a lack of knowledge, an instance where specialised knowledge is only reasonably expected to lie with the technology supplier, and a situation where knowledge diffusion did take place. Failures on generally reliable equipment caused concern as Eskom maintenance staff had no knowledge of such equipment. One instance was a series of excitation disturbances and faults on an automatic voltage regulator (AVR) that had caused considerable downtime. Defective sections of the AVR were sent to Switzerland for repair. When returned to service faults were still indicated on the AVR panels, but as the AVRs appeared to be working satisfactorily, they were left in service. It was necessary to send a representative from the AVR supplier in Switzerland to address the problem as neither Eskom staff nor the AVR supplier's local agents were competent to do so. This illustrated that no technology transfer had taken place when the AVRs had been installed years ago (as complete units assembled in Switzerland and commissioned by the supplier). Even after this event when failures occurred, control cards were replaced on a trial and error basis to clear faults.

A second example was when an engineer was given the task of specifying the requirements for a replacement oil tank and associated pipework that had been damaged. His theoretical calculations suggested a certain size of tank and this was duly installed. Soon it was discovered that the tank was too small as it did not comply with the commonly accepted standard that the capacity of an oil tank in this context should be the total nett quantity of oil delivered by the oil pump in ten minutes under normal operating conditions. A further error was ordering 3-way change-over valves that did not operate from the same integral spindle. The manager suggested that an experienced engineer would have known why such valves were not suitable as it was so easy to assemble and install them incorrectly.

The third example illustrates the installation of additional control equipment and the benefit of specific training. A faulty solenoid caused a safety valve to open. In the past it was likely that the resulting instability would have caused the unit to trip, or that the operator would not have intervened to prevent the tripping. The fact that the unit did not trip was attributed both to the new, improved control system, and the fact that the operator had noted that the boiler pressure had been satisfactory despite the spurious opening of the safety valve.

A fourth instance illustrated that certain intricate tasks would always be best undertaken by specialists. This concerned the inspection of rotor forgings, where non-destructive testing procedures involved visual examination, sulphur printing, magnetic particle inspection and ultrasonic flaw detection. There were accusations that Eskom staff were unable to be perform such tests, until it was ascertained that few electricity utilities in the world possessed the knowledge to perform these tests. Such specialised levels of knowledge were only to be found among technology suppliers.

Managers equated knowledge with skills and abilities. Without extensive technical backgrounds some operators could perform only in a programmed manner, requiring maintenance and operations supervisors to be more interventionist. One manager recognised that some supervisors were themselves not fully technically competent, but great efforts were being made to enhance the skills of supervisory staff.

Managers at PSZ were confident that operating and maintenance staff had a better understanding of the new boiler control system than was previously the case. However, the lack of theoretical knowledge of boiler technology prevented a deeper understanding of the precise function of the control system. The supplier provided good documentation for the system, so more explicit knowledge was available, but replacing control cards on a trial and error basis indicated that corrective maintenance to clear a fault was not based on knowledge.

- ***Level 3: Supply chain***

Changing approach to supply chain management

Supply chain management was not used in a power station context. Power station managers were free to source equipment and spares from whichever suppliers they wished within the constraints of Eskom's purchasing policies. These favoured black economic empowerment local suppliers. Price competition and technical support played a role, but the mechanism awarded points to companies depending on the number of black managers and employees. Support from the original owners of the technology was essential, so at a technical level, close contacts were maintained with technology owners, and particularly those that had formed alliances with black empowerment companies.

Expertise of international suppliers

Comments on international suppliers were favourable. One recent incident was a persistent problem with a 100% boiler feed pump (a steam driven feed pump turbine) that was ascribed to faulty expansion indicator instrumentation. Eskom did not have expertise in such systems and only the overseas supplier could install additional shaft eccentricity and measuring devices to assist operators and mechanical maintenance staff increase the availability and reliability of the pump. The example given earlier of rotor forgings inspections was cited as the level of expertise expected from suppliers. As an illustration of Eskom's total dependence on international suppliers, a manager listed some of the sub-contactors that supplied associated equipment: generator rotor forgings (Corus, UK), generator rotor bells (Krupp, Germany), stator and casing (GEC, UK), LP cylinder (Sulzer, Switzerland), main condenser tube plates (Japan Steel), HP feed heater header boxes (Diedwick, Germany), and so on.

Managers noted that shortages of technical skills in South Africa meant that local representatives of international suppliers had limited expertise, and frequently acted as no more than a link between Eskom and suppliers from abroad. Intermediary black empowerment companies contributed little in terms of technological expertise.

Moves to local sourcing

Eskom sourced locally where possible, such as: main condenser shell and waterboxes, boiler feed pump turbine condenser shell and waterboxes, HP and LP feed heater bodies. A manager noted that while manufacturing tolerances and metallurgical standards for these items were important, the levels of manufacturing technology were not particularly high. In addition to the policy of using black empowerment companies, local contractors were supported where possible for generally low-technology work: small motors rewound by local rewinders, minor building work undertaken by local builders. Again, preference was given to black managed small businesses.

PSZ had agreed with the control systems supplier that local contractors would be used where possible. Contracts awarded locally did not require particularly high levels of technology, such as cabling and new panels were manufactured in South Africa and installed by local contractors. Some electrical protection was imported because it was not available in South Africa.

Use of the internet

The internet was used to obtain prices and availability, but Eskom's purchasing procedures made limited use of B-2-B purchasing.

- ***Level 3: Strategy***

Relationships with stakeholders

Managers did not consider strategic issues relevant at power station level. They described Eskom's responsibility to stakeholders in terms of environmental standards, re-landscaping land after opencast mining, water requirements, and ash dam and effluent pollution control. Eskom as an organisation was greatly aware of its commitments to local communities as stakeholders. Addressing black empowerment issues, education, expanding electricity distribution to the poor were office and distribution department matters, and social issues were coordinated by regional offices. From a power station perspective, the important relationships with stakeholders were those relating to black suppliers.

Technology partnerships

At a broader level Eskom supported South African R&D, and participated in technical projects with research institutions and universities. Managers did not view these as strategic issues, and dealt with them as they arose. Head office dealt with issues such as licensing and joint ventures.

- ***Level 3: Operational***

Promoters and champions for technology transfer

Managers felt the process of TT should take place during commissioning and handover, when arrangements were made for training and familiarisation. Champions were not formally appointed. Although the introduction of new systems or modifications were treated as projects. The project manager's job was to introduce the technology, which was adopted in most cases for operational reasons. Managers agreed that Eskom did not think in terms of technology transfer. It trained its staff formally, and relied on on-the-job training. One area where champions emerged was condition monitoring. Several individuals at a number of power stations expanded condition monitoring activities considerably further than regional office engineers had intended.

Change management

With Eskom's commitment to affirmative action, there was considerable pressure to empower black employees. Although technology was frequently not the driving force for change, change management initiatives had a major impact on many aspects of power station management. One manager indicated that the current structure of the management team derived from adherence to affirmative action policies. This was a sensitive issue with which Eskom was still coming to terms. The views of other power station staff are considered in the level 4 discussions.

Managers did not see that new technology required organisational change. Change management related largely to the implementation of Eskom's personnel policies. One black manager commented that Eskom had vigorously implemented the previous government's apartheid policies in the past, so white employees should not be surprised that it was now leading the way in following the present government's approach to black empowerment. He accepted that some individuals were not fully capable of doing their current jobs, but was adamant these individuals would grow into their positions with appropriate support. He believed an evolutionary approach would be too slow to rectify the distortions of apartheid in the economy and society.

While some whites argued that plant performance was deteriorating and that maintenance was poor, they produced no specific evidence for this. Managers suggested that possibly the greatest resentment among white employees was that they had effectively to train blacks who would soon be their managers or supervisors. Some were concerned that so much time and effort were spent on 'political' issues that sight was lost of their real challenges in running the power station.

Managers at PSZ suggested that because much of the technology was new, those exposed to it had a great deal to learn. There was a collegiate attitude where trainees helped each other. Some comments suggested that individuals did not have the requisite skills, but managers had gone to great lengths to minimise this. One manager accepted that this had only been possible because the scope of the project was limited, and had not involved everyone in the power station.

Short term returns from technology

It was difficult to measure the effects of changes in technology directly, and attribute these to a single intervention. With new power stations, the question of short-term returns did not arise, and it was not the task of power station management to determine the cost effectiveness of new technology introduced during the construction of a power station. Managers conceded that investigations for the best solution through modifications were not always as thorough as they would like, because 'pressures for megawatts' at times reduced their ability for extensive cost-benefit analyses. Once new technology had been introduced, performance was monitored, but justification for modifications was usually sufficiently clear from an operational perspective to convince head office that formal evaluations were unnecessary. Several managers commented that where safety was at stake, questions of cost effectiveness of technology should not arise. The issue was whether technological intervention would prevent a dangerous situation from arising.

One manager suggested that Eskom's parastatal history still persisted in that returns on investment were not part of management thinking. A technology was chosen if it was felt this would improve performance and safety, or enhance working conditions. With the conversion of Eskom into a company, financial reporting systems were more demanding, and tighter financial controls would introduce more discipline into financial decisions.

At PSZ it had not been possible to isolate extraneous variables (such as a number of unexpected turbine and ash handling faults) in order to quantify the direct effect of the new control system. However, the number of boiler trips had reduced. Managers felt this could be attributed to both the new control system and the enhanced knowledge of the operators. Managers were satisfied, from a qualitative perspective, that the new system had improved overall performance.

- ***Level 3: Contractual***

Contractual arrangements

Operational managers did not enter into contracts for original equipment for new power stations. Once plant had been commissioned and handed over, operational managers could agree contracts for additional work. These might typically be lubrication surveys and services, and outsourcing maintenance on various items of equipment on a contract basis. Some of these are discussed under level 4 items.

Operational compatibility between owner and acquirer

Comments under this heading were diverse. Several managers mentioned difficulties with language, communication and documentation. Some international suppliers were not particularly proficient in English, and documentation, drawings and technical manuals were sometimes only available in foreign languages.

Many of the contractors' managerial and technical staff had been working for Eskom at previous power stations for several years. Managers felt that most contractors understood Eskom's performance and operational requirements. It was to be expected that differences of opinion would arise in large power station projects, with hundreds of contractors on site during the construction phase, but managers were satisfied with compatibility between contractors, as technology owners, and Eskom, as the acquirer. Contentious issues were typically non-compliance with contracts, or damage done to plant during installation. Managers did not feel that this represented technological incompatibility.

Suppliers saw a number of compatibility problems, some of which were sensitive from a cultural and attitude perspective. A poor South African work ethic and lack of commitment were frequently mentioned. Eskom staff were not prepared to take material home and study this in their own time. 'Clock-watching' was a great source of irritation to suppliers in that Eskom staff were not keen to remain at work to solve a problem unless overtime or time off were guaranteed. This meant that suppliers would continue to work on a problem after Eskom staff had gone home. Complaints the following morning would typically be that the suppliers were not sharing their technology with Eskom.

Part of the success of the project at PSZ was attributed to the relationship between the supplier and power station staff. Once contracts had been awarded, considerable work was required to update drawings and identify cables that had not been correctly handed over during the initial construction. Assistance by the supplier demonstrated a desire to make the project succeed.

- ***Level 3: Integration of technology***

Integration with existing systems

Condition monitoring and additional performance measurement activities were introduced later as modifications. Selected equipment was kept under surveillance, which was expanded to other units where this proved useful. An example at one power station was the tripping of cooling water pumps on high thrust bearing temperature. The bearings were inspected on a number of occasions and returned to service. Once a trend had been obtained through a substantial amount of data collection, the cause was attributed to an incorrect lubricant. Inspection (by Operations) and lubrication (by maintenance) were not integrated, and no communication mechanism had been established with the main control room. Regular management intervention was required to ensure that the tasks were carried out. Managers indicated that they were unable to keep track of many such actions, and that their data collection was not as comprehensive as they would like.

Efforts were made in some departments to measure certain performance parameters. This required additional measurements and the installation of appropriate equipment. One such measure was heat consumption from the formula:

$$H = \frac{M_1(H_1 - h_f) + M_3H_3 - M_2H_2 - M_4h_a}{P_e}$$

where H = guaranteed heat consumption at CMR (kJ/kW)

H_1 = enthalpy of steam at high pressure turbine combined emergency and stop valve (kJ/kg)

H_2 = enthalpy of steam at high pressure cylinder exhaust (kJ/kg)

H_3 = enthalpy of steam at intermediate pressure cylinder interceptor valves (kJ/kg)

h_f = enthalpy of feed water at discharge from final heater (kJ/kg)

h_a	=	enthalpy of water for reheater attemperation (kJ/kg)
M_1	=	steam flow to high pressure turbine (kg/hour)
M_2	=	steam flow to reheater (kg/hour)
M_3	=	steam flow from reheater (kg/hour)
M_4	=	water flow to reheater attemperator (kg/hour)
P_e	=	net electrical output of generator (kW)

One manager explained that the thinking behind taking such measurements was to encourage operating staff to understand details and integration of the boiler and turbine operations and the overall process, and to appreciate the effect of sub-optimal operating in any one area on overall performance. In this way he wished to integrate several aspects of power station operation. He recognised that at present many operators took readings as instructed, but did not understand what the results meant, and how to make use of them.

Eskom has long recognised the importance of technical interface management. Contractually, boiler and turbine suppliers are obliged to foster close relationships. In other instances, Eskom provides the interface through the appointment of other suppliers. So, there is a busbar contractor, a cable contractor, an electrical panel contractor, a number of transformer suppliers, and so on. Managers felt that good design and thorough contract documentation could solve most integration problems. Installation problems had arisen in cases where civil work had been carried out and months later, after the civil contractor had left site, it was discovered that access points had not been catered for. Managers did not see this as a technology transfer issue.

At PSZ the greatest difficulty was the problem of integration of the new control system with the existing operation. Eskom had been adamant that the boiler itself was not to be modified. It was the supplier's task to ensure that the new system would control the boiler in its current state. The supplier seemed fully capable of doing this, but difficulties arose with out-of-date drawings and descriptions of functionality in the boiler manuals that did not reflect exactly how the boiler was configured. Managers suggested that this had not been a problem in the past because few people read the operating and maintenance manuals in any event. It was clear that Eskom staff had more work to do than anticipated at the outset of the project because of poor documentation (explicit knowledge), and because their knowledge of the existing boiler functionality was not fully understood (a lack of explicit and tacit knowledge).

Communications and IT systems
Managers felt that these systems were generally good, but they were not always fully used. One example was the maintenance information system, where insufficient attention was paid to comprehensive data entry, and limited real use was made of the data. This is discussed in some detail under level 4.

At a person-to-person level, managers recognised there was always room for improved communication between individuals and firms. They gave examples of difficulties that had occurred with some control systems not being compatible with others. In another instance a manager described how Eskom had refused to accept a transformer because it did not meet technical standards. It transpired that Eskom's definition of 'percent impedance voltage' in transformers with tap changing was based on a nominal system voltage, whereas the supplier referred to rated tap voltage. This seemed a relatively trivial issue to the supplier, but Eskom's insistence that the impedance remain constant regardless of tap position meant that commissioning of a section of plant was delayed, while additional cables were run to provide temporary power. The manager gave this as an example of where the transformer supplier did not appear to understand the technology.

- ***Level 3: Maintenance planning***

Lead time for spares acquisition

Maintenance planning has a number of components in a power station. A planning department was responsible for day-to-day planning of preventive maintenance schedules. A maintenance foreman allocated tasks to individual craftsmen. Shutdown planning referred to short shutdowns (such as over a weekend) or long shutdowns (as in a general overall of several months). Maintenance activities are discussed in level 4, but an important component of maintenance planning at level 3 was inventory and spares management. A head office spares function offered advice to power stations, but the power stations themselves were responsible for all spares management. Clearly, equipment suppliers remained the most important source of spares, particularly for imported spares.

Although there was pressure to reduce spares stock holdings, managers aimed to stock items specified as 'Contract spares', delivered in terms of the original contract. There were concerns with the new purchasing dispensation that acquiring spares through black empowerment companies would lengthen the lead time for spares delivery, because of the additional administrative process. Attempts were made to categorise maintenance spares in terms of their usage: stock and non-stock items, project spares, and insurance inventory. These classifications assisted in ordering spares on a dependent demand basis where possible, taking into account long lead times for imported items. Although condition monitoring was in a relative early stage of implementation, managers were trying to use it as the basis for ordering.

On-line facilities at Eskom made it possible to establish what spares were held at other power stations, and, where plant was similar, increasing use was made of this facility. Experience had shown that the lead time for spares from Europe was reasonable, but lead times from Japan and the US were unacceptably long. Fortunately not many spares were sourced from these countries.

Unique spares and specialised maintenance

Eskom aimed to have as much commonality of equipment as possible so that spares holdings could be minimised, but changes did occur, say, between certain equipment used in units 1-3 and in units 4-6, where two different sets of contracts were awarded[1]. Eskom's centralised maintenance function, Roteck, was involved with large overalls of say, a turbine, where specialised equipment and testing facilities were required. These were planned on a project basis, often in conjunction with the equipment supplier.

The policy was also to have as few unique spares as possible, and that similar wearing parts should be interchangeable with each other and with their spares, so that replacement of a worn part could be carried out with minimum adjustment. Equipment suppliers were required to ensure complete interchangeability of rotating parts, particularly major items such as turbine shafts and generator

[1] One respondent described the problems of having different suppliers by relating the situation of a power station in Botswana which had been constructed using aid from a number of different countries. The power station had five units, each of which was supplied by suppliers from five donor countries. Different spares were therefore required for each of the five units, resulting in massive stocks and extremely high inventory values.

rotors. Insofar as they were able, contracts insisted that rotating parts should have identical journal and coupling dimensions, and that stationary parts should be machined to close tolerances where mating with interchangeable parts was required. Increasingly, Eskom required suppliers to record precisely the dimensions of all wearing and rotating parts, and to identify jigs and fixtures used in the manufacture of components, so that future orders for corresponding parts of similar machines would ensure complete interchangeability.

- ***Level 3: Management policies for technology***

Internal support and communication

Eskom has standard practices and reporting structures for all power stations. Power station managers introduced additional policies to improve their management information requirements. There was a fine dividing line between the functions of certain departments. For example, electrical equipment could fall under the electrical maintenance department (such as, electric motors, voltage and current transformers, battery chargers, and inverters), the control and instrumentation maintenance department (variable speed feeder motors, control systems), or the test department (electrical protection on transformers, electrical distribution boards). With increasingly complex control systems, the interface between these three departments became blurred. Clear lines of demarcations were desirable, but managers felt these had become too rigid. One manager commented that this was a management rather than a technology issue.

Considerable effort had been made to facilitate communication between maintenance departments through technical interface management. When a valve did not open, the intention was for mechanical and instrumentation departments to work closely to assess whether mechanical problems or transmitters and limit switches had caused the failure. Technological complexity was such that many failure modes were possible. Some managers were resolved to reverse trends towards departmentalisation of maintenance frequently found in power stations.

General exposure of staff to high-technology equipment

Managers were concerned that many employees had not experienced sufficient exposure to a high-technology working environment. The extreme case was found with labourers from surrounding communities who in many cases were barely literate. They may well not have had electricity or running water in their own homes prior to joining Eskom. They had no understanding of how a power station operated, and the vast majority would never have seen a personal computer.

At operator level the lack of general exposure to high-technology equipment was aggravated by the appointment of non-technical staff to positions of responsibility where they were working with high levels of technology. An example was given of one individual who had worked in the local post office after school, had joined Eskom and after a few years was the principal plant operator for a large boiler and turbine. He had been through all the training, and was therefore theoretically qualified to do his job. However, one manager was concerned that with no technical background or formal technical education, such an individual could not be expected to have a 'feel' for high-technology equipment. Appointment policies meant that more individuals would be promoted without sufficient depth of technical expertise.

Low levels of education of some staff meant that delegation of tasks had to be carefully considered. This placed a burden on supervisors who spent increasing amounts of time training and explaining to their staff how equipment functioned. One manager expressed reservations with this practice because some supervisors were also not technically proficient. This was a problem with which Eskom would have to contend with the tremendous shortage of technically qualified staff in South Africa.

Internal infrastructure and facilities
New testing and monitoring facilities offered great potential for improved operations and maintenance, but managers did not find it easy to insist on their use. So for example, oil condition monitoring techniques such as ferrography, X-ray fluorescence and spectrometric chromatography required cooperation between mechanical, electrical, and instrumentation maintenance departments who were responsible for assisting contractors in installing the technology, and the laboratory who were involved in analyses of condition monitoring data. Power station managers were still setting up communication processes for interpreting results and acting thereon on a more informed and formalised basis.

Managers believed that a great deal of technical expertise existed within Eskom, but recognised that communication between power stations, the central maintenance department (Roteck) and head office was poor. Examples were given where power station staff had called upon suppliers to assist with maintenance work, when in fact other Eskom departments were fully capable of offering assistance. Roteck's testing facilities were the best in South Africa, but insufficient use was made of these because of the belief that technology suppliers knew better.

Power stations were limited in the extent to which they could perform on-going verification of plant performance. When acceptance testing was done for a new unit, suppliers installed many additional measuring devices, but removed them after a unit had been accepted. Some managers felt that insufficient detailed measurements were taken to ensure functionality of the plant. This was essential for detecting inefficiencies, and for transmitting knowledge among operating and maintenance staff.

- ***Level 3: High-tech issues***

Use of expert systems
Managers regretted that levels of technical awareness were severely lacking, so any move to even more sophisticated systems could be counter-productive. Staff were keen to have the latest equipment, but without the technical background and knowledge, some systems were underutilised. Condition monitoring was a valuable intervention, but establishing base conditions, taking measurements and interpretation of results required skills that few staff possessed. Appropriate maintenance intervention had so far been limited, so it was clear that some staff 'went through the motions' by claiming to use it, but managers felt that it was not being used to its full potential. Many computer and diagnostic systems were available, but Eskom lacked suitable people to utilise these.

Concern was expressed with the availability of protective systems that were so important for safe operation of highly automated equipment. One manager had studied certain items, and found that testing was in accordance with the law, but that the functionality of other items, not directly covered in the statutory regulations, was not being verified.

Process optimisation
This should be addressed at the design stage of a power station. The example given earlier about the calculation of heat consumption was cited as an attempt at achieving higher process efficiencies. Changes in operating practices and modifications were introduced to improve overall

performance, but process optimisation was too broad an issue to be dealt with by single interventions. Measures of Eskom's overall performance were comparable to other first world utilities, such as the generation energy availability factor (EAF) of 92% in 2001, plant unit capability factor (UCF) of 92.5%, and unplanned automatic grid separations (UAGs) of 1.5 interruptions per 7 000 hour operating period.

- ***Level 3: Financial***

Cost

The cost of technology was initially an issue for head office designers. Once a power station was running, costs of modifications were the responsibility of power station staff. Managers indicated that in certain instances, they had no choice but to accept modifications (such as redesigns to precipitators to reduce flue gas emissions). Tighter financial controls limited desirable but non-essential modifications, so well-motivated proposals were required whereas in the past, it was much easier to implement modifications without assessing the financial implications.

There was pressure to reduce operating and maintenance costs. Some initiatives were embarked upon to ensure that maintenance was effective, and that operations were in accordance with best practice. Managers recognised that with a non-fully technically competent labour force, operating costs were probably higher than would be the case with fully trained staff. However, most firms in South Africa suffered from a skills shortage, and managers believed that their operating costs were reasonable. Even in operational circumstances, managers had limited control over costs of equipment and spares. They were obliged in many cases to continue to use existing technology suppliers. In one instance, some measuring devices were damaged, and locally manufactured replacements were installed. One manager commented this proved an expensive error because these were not as reliable or accurate as the original German thermometers, connection heads, flow and pressure instruments. Ultimately, the German instrumentation was again installed.

Justification of technology on a cost-benefit basis

This was seldom possible, as the effects of a new technological development could take years to measure, and it was not possible to isolate other variables. Thus, for example, extensive modifications to oil burners were required to enable the generator to be synchronised and for minimum load to be maintained without the use of mills. The benefit of this was better steam and metal temperature control without the use of spraywater. Managers saw no way of quantifying the benefit of this on efficiencies, equipment life, and so on, so the modification was accepted only on the basis of a technical recommendation.

The previous example of local versus German instrumentation illustrated that it was not possible to make a rational cost-benefit estimate before placing an order. While both suppliers had guaranteed certain performance standards, there was little that could be done when one (the cheaper South Africa instruments) did not perform as well as expected. In other instances, local manufacturers of LP inner and outer cylinders, condenser shell waterboxes, and feed heater bodies were considerably cheaper than foreign manufacturers, and the local products were totally satisfactory. Managers indicated that South African manufacturers compared well with lower technology items, but high-technology equipment was generally best sourced abroad.

6. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 3 COMPONENTS

The following paragraphs discuss the Level 3 in the Salami and Reavill model.

- *Level 3: Determination of basic human factors for adopting new technology*

Basic human factors relate to technological background and experience, theoretical understanding, and practical knowledge of operations and maintenance. Managers indicated that most of their operational and maintenance problems arose from inadequately trained staff. They identified several levels of human needs in the power station. Eskom had a comprehensive set of training programmes, but training could only transfer knowledge and technology to a certain point. Because of poor educational standards of certain employees, it was necessary to provide basic skills, which, according to one manager, would be taken for granted in first world countries. TT was difficult when operating became a rote process, based largely on a gradual process of on-the-job training. Even operators who had been operating for some time were following a defined pattern of sequences, without fully understanding the process or technology.

The first challenge for the technology acquirer and owner was to provide sufficient understanding of functionality of a system. Suppliers expressed frustration when contracted to do this, as Eskom staff had such a poor grasp of the basic concepts. Simple concepts such as Boyle's Law were unknown, and the trainees even had difficulties in understanding the algebraic relationship between pressure, volume and temperature. An incident was recounted where a qualified electrician was instructed to connect an electric motor. On establishing that that this was a 'star connected' motor, he connected all three phases together to the neutral point. Poorly educated unskilled labourers could only be given narrow tasks and required constant supervision.

Many supervisors were white, but opinions varied as to their competence. One manager felt that their training had taken place when apprenticeships were more thorough, and that they had years of valuable experience. Other managers observed that some supervisors were the product of the apartheid system, which meant that there was relatively little competition for promotion (blacks were effectively excluded), and appointments at supervisory levels did not necessarily result from either technical competency or good managerial skills.

PSZ managers ascribed the success of the project to the keen interest taken by the technology supplier in developing Eskom staff. Managers acknowledged that selection of the better staff (black and white) for the project made it more likely that training would be successful. The ability to work closely with the supplier during commissioning was also extremely useful.

- *Level 3: Evaluation of final costs and benefits of new technology*

Assessing the final costs and benefits of new technology was a head office function for new installations. Power station staff costed subsequent modifications, but managers found it impossible, in most cases, to quantify benefits. If load losses could directly be attributed to the failure of one system, which was then replaced by another, over a period of time the increased availability brought about by the new system could be compared against the old one. However, this was seldom done, and no documentation showed cost-benefit analyses.

No evaluation was carried out at PSZ. The supplier had put forward a powerful case for why the project should be undertaken, and gave examples of costs and benefits achieved in installations elsewhere in the world. Managers admitted that the supplier had been disappointed that a cost-benefit exercise had not been undertaken at PSZ.

- ***Level 3: Determining relevant technology supplier***

Technologies and suppliers for new power stations were chosen by head office. In many instances suppliers determined details of the technology within broad parameters specified by Eskom. For modifications, the choice of a technology supplier was frequently made by power station managers on the basis of functionality ('who can best meet the desired performance specifications?'). Decisions took into account cost, previous experience with suppliers, reliability of their equipment, and in this sense, their technology. A supplier was not usually chosen on the basis of his specific ability to transfer technology, although this was one factor in assessing previous relationships with a supplier.

There are only a certain number of boiler and turbine contractors in the world, so the choice of main technology suppliers was limited. While Eskom supported black empowerment companies, technology came from abroad, and main contractors generally selected their sub-contractors, subject to Eskom approval. This was beyond the control of power station staff.

Previous examples described instances of difficulties with local suppliers. Contractors and suppliers tended to install their own equipment or use known subcontractors. An example was cited where Siemens representatives from Germany refused to install Siemens electric motors manufactured in South Africa; they insisted on using only Siemens motors imported from Germany. European suppliers preferred European equipment whenever they had the choice. Eskom therefore had to be more insistent on using local companies. Managers were experiencing resistance from foreign suppliers in this aspect of Eskom's new purchasing procedures.

Managers at PSZ were convinced of the ability of the chosen supplier to improve the boiler control system. It would have appeared more logical to use the original supplier, but two factors mitigated against this: the original supplier appeared to have lost interest in this power station, and when asked what could be provided, the response was a somewhat vague 'upgrade' of the existing system. Power station management doubted this would result in any improvement. Other suppliers were approached but did not appear particularly keen to integrate their control systems with an existing operation. To that extent the chosen supplier was the only one prepared and eager to provide and integrate the new control system sought by the power station management.

- ***Level 3: Estimation of alternative sources of technology***

This was a head office function for new power stations so power station management had little say in the choice of main contractors. One manager provided an example of different boiler designs: a 'once-through' boiler (without a boiler drum), or a boiler with a drum. Both provide the same output, but constituted different operating contexts. The chosen contractor offered a once-through boiler at one power station, whereas the contractor at the next power station provided a conventional boiler drum, and managers were not aware of detailed comparisons of the performance and merits of the two systems. In reality, the boiler contractors supplied their own technology within the constraints of the contract.

Eskom was strict in its insistence that suppliers should not provide obsolete components or systems. Contract documentation stated that items of plant should not become obsolete within ten years of the commissioning date of the first unit, and that Eskom should not be obliged to discard items due to non-availability of spares.

One manager indicated that alternative sources of technology were evaluated, but technical options were limited by existing technologies. He mentioned the dry cooling systems at Kendal and Matimba power stations as resulting from extremely detailed investigations of water availability, and the implications of dry cooling on technology and performance. The problems of cooling at Matimba during the summer months meant that output had to be reduced. There were suggestions that environmental data provided to suppliers were not totally correct. Nevertheless the alternatives were thoroughly studied. At more detailed plant levels, some managers felt that Eskom left too much to the main contractors in terms of technology selection. An example given was that problems had been experienced with cavitation on a certain kind of extraction pump at older power stations, but that exactly the same design of pump had been supplied in newer power stations.

7. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 4

The following paragraphs discuss the Level 4 items in Appendix V. Level 4 refers to management and supervisory levels at power stations.

- ***Level 4: Technology***

Assimilation of new technology

Managers felt that after years of operation, technology should have been assimilated. Some examples of the many instances provided are described. The thermopile furnace protection on a boiler had operated and tripped out the fires during an otherwise stable situation. This happened several times until the supervisor monitored all activities taking place. Because of a fault in the automatic sootblowing sequence, sootblowing at one level was being undertaken manually. He then discovered that one section of the sootblowers affected the temperature measured by the thermopiles. The first problem was the inability by maintenance to ensure automatic operation of the sootblowers, as manual sootblowing by operators was inconsistent and far from optimal. Secondly, operators failed to understand the process whereby local ash and slag could affect more than one thermopile at one time. The inability to repair the auto-sequence by maintenance staff created numerous problems and resulted in far more tube leaks that would be the case if the system functioned correctly.

Another supervisor recalled the difficulties in operating the boiler feed pump system. Feedwater was supplied to the boiler either by one 100% feed pump driven by a steam turbine (referred to as the steam feed pump), or by two 50% electrically driven feed pumps. The latter were intended for starting-up a unit and as backup to the steam feed pump turbine. While in theory the boiler could operate at 50% load with only one electric feed pump running, conditions were invariably so unstable that the unit would trip. For several years after they had been commissioned, units were usually operated using the electric feed pumps, rather than the steam feed pump, despite the relative inefficiency of this mode of operation on a long-term basis. Difficulties in balancing the steam feed pump were one reason for this (mentioned under Level 3), but steady state control of the steam feed pump could also not be achieved. This was an area where interfacing between boiler and turbine operation was critical. Eskom staff blamed one or both of the suppliers, while one supplier blamed the other and Eskom staff's inability to operate correctly. The supervisor maintained that nothing was achieved through blaming another party, although it was evident that operators and maintenance staff were unable to master the operational and maintenance subtleties of steam driven feed pump technology fully and keep the steam feed pump in service. He saw this as a problem of technology assimilation that could be tolerated because the electric feed pumps were available (although when they were operating, there was no back-up).

The design philosophy adopted in newer power stations is to provide three 50% electrically driven feed pumps, and to dispense with the steam driven feed pump. Some managers claimed this represented a cheaper initial cost, while others suggested that this was only part of the issue as higher overall efficiencies could be achieved using a steam feed pump. However, the availability and reliability of steam driven feed pumps had proved to be low at a number of power stations, so the design philosophy had been changed.

Power station staff made little contribution to original plant specifications. To a large extent, a power station operates within the initial design parameters, but its staff have a direct input with modifications. Several examples were given where equipment or operating redesigns were introduced. These were usually discussed with equipment suppliers. For example, frequent problems had been encountered with severing of spraywater lines. Internal investigations revealed that water was collecting in the high pressure (HP) by-pass pipework. Water had been forced down the pipework to the cold reheat common steam pipe when the HP by-pass valves were opened (typically during shutting down). Water hammer and thermal shock resulted from the carry over, and cracks were discovered on the HP by-pass to cold reheat pipe stub pipe joints. These cracks were in the cold reheat pipework parent metal. It was found that water passing into the by-pass pipework was due to porous welding on the HP by-pass spraywater regulating valve seats. Redesigns were proposed by the supplier, who then carried out the repairs. Finding the cause of this problem was a joint investigation by Eskom maintenance staff and the supplier.

A manager and maintenance supervisor provided this example to illustrate the close contact that had to be maintained with the supplier. While sufficient (core) technology has been transferred from owner to acquirer, as testified by Eskom's ability to operate power stations, there are instances where, even after many years, Eskom's staff do not feel confident to introduce significant changes where these may have an influence on inherent design considerations. This is reminiscent of the comment made in Chapter 3 in the BBC interview on Sizewell B where the interviewee states: "if errors are rectified in complex systems, there is no way of knowing how that might affect the rest of the program. The system is too complex".

The contrast between the opinions of managers and other staff at PSZ regarding the new boiler control system was interesting. Supervisors were generally of the opinion that the new technology was successfully assimilated, but questioned whether it had really been necessary to change the system. Some supervisors maintained that Eskom had been insufficiently rigorous with the initial contract documentation when the power station was constructed, and that the original supplier had not met the contractual obligations. Commissioning procedures by Eskom's on-site construction team had been lax, which aggravated the situation.

Supervisors also mentioned the role that internal politics played. When the head office engineering department showed little interest in the power station's dissatisfaction with the old control system, the power station managers embarked on the project with the intention of demonstrating to head office that the power station was able to specify and commission a new system, with the latest technology. One supervisor indicated that the managers had to say the project was a success and pronounce that technology had been assimilated if only to save face. Supervisors claimed that the reliability of the system was good, but the largely automated system enabled operators to operate the system with despite their limited real understanding of the technology. Maintainers had been called upon mainly to deal with the interface between the new system and the boiler plant. From an operational perspective, the technology was functioning well, but this did not mean that the technology had been transferred. Managers believed the high availability of the boiler was attributable to good technology assimilation.

- ***Level 4: Knowledge***

Understanding new technology

Numerous other instances were cited where technology was not understood. Others referred to head office specification or design misunderstandings. At one power station the hydrogen generating plant supplying hydrogen cooling to the generators was imported. The electrical maintenance department was responsible for maintaining the hydrogen plant, with some input from the mechanical maintenance department. Shortly after commissioning, maintenance schedules were introduced, based partly on the manufacturer's recommendations, and partly on what one supervisor acknowledged was the extremely limited experience of some technical staff. One manager commented that in retrospect, the maintenance schedules had been totally incorrect. The staff entrusted to draw up the schedule had little working knowledge of the plant. Secondly, by implementing the initial maintenance schedules, almost all equipment was to be subjected to a time-based maintenance programme. Invariably after maintenance, the hydrogen plant failed, and hydrogen had to be drawn from a supply of hydrogen cylinders.

One supervisor felt that time-based maintenance was totally inappropriate for the hydrogen plant, which had few moving parts or wearing components. Subsequent investigations revealed that some 90% of failure modes followed a random failure pattern, and time-based maintenance introduced burn-in after the plant was returned to service. The supervisor described the situation that is depicted in Figure VI.1 (this is discussed in Chapter 3), showing three failure patterns where conditional probability of failure is plotted against time. Figure VI.1a indicates the failure pattern for which time-based maintenance is appropriate. Figure VI.1b shows a totally random failure pattern, and Figure VI.1c illustrates burn-in, followed by random failure.

The supervisor commented that no one understood the operation of the plant, and clearly the supplier had transferred no technology at the time of installation and commissioning. The power station had only been able to tolerate this situation because hydrogen was obtainable in cylinders, but clearly, apart from additional hydrogen cylinders, no standby supply was available.

A generator cooling system provided an illustration of poor understanding of technology by head office designers. Eskom required the supplier to provide piping from the point of supply of demineralised water to the point of introduction to the coolant system itself. The arrangement was that prior to the introduction of coolant make-up, it should be possible to run water to waste to ensure that no foreign matter that might have settled in the piping could enter the coolant system. The supervisor pointed out that a drain to waste from the stator water make-up line was not required at the inlet to the system because the make-up entered the system via a headtank and downcomer. The downcomer included a conductivity monitor and there was a drain valve in this line, so there was no need for a drain in the make-up line.

The supervisor also criticised the need for having to bleed off a portion of the liquid coolant in circulation and process this, because conductivity was continuously monitored, obviating the need for sampling. If sampling were required, drains or vent connections could be used. Since the make-up to the system was by a ball float valve, pressure gauges on both sides of the make-up valve served no purpose. Yet, a maintenance schedule existed for inspections of these gauges.

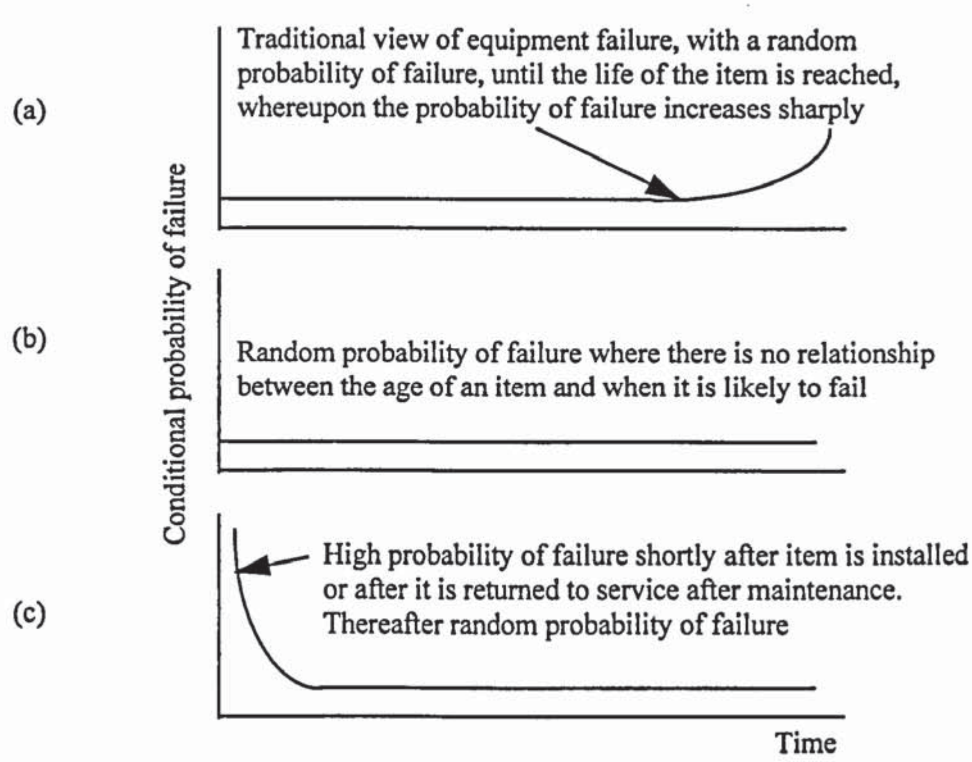


Figure VI.1 Selection of failure patterns (Nowlan and Heap, 1978)

A manager described an instance where various supervisors, operators and craftsmen did not understand the importance of establishing the performance standards for sootblowers. The electrical staff saw the function of a sootblower as the travel of the lance into the boiler for a certain length of time, and then retract. The supply of stream to the sootblower was 'a mechanical problem'. Control of the steam valve was 'an instrumentation problem'. A fitter saw the function of blowing steam into the boiler, but he was unaware of the temperature and pressure limits for this process: 'the steam must arrive at the right pressure and temperature'. The operator was unaware of how the sootblower worked: he was concerned only with the sootblowing function, without recognising that a lack of sootblowing resulted in clinkers forming which caused tube leaks on lower boiler tubes. One supervisor commented 'we do not lose load now if sootblowers don't work; this becomes tomorrow's problem, or another shift's problem'.

Training by the technology supplier at PSZ and working with supplier staff had assisted operators in gaining broader understanding of the technology than had been the case with the old boiler control system. Supervisors commented that at the time of commissioning of a new power station, and when subsequent staff were trained, operators had to master all aspects of the boiler. With the new control system, they had to learn just one small part, so it was reasonable to expect that their understanding would be better.

Understanding of hardware and software
The extent to which Eskom was still dependent on the boiler control system supplier at some power stations illustrated that Eskom staff had a poor understanding of much of the boiler control software. Modifications generally required the supplier's input, and after a major overhaul of a

boiler, the supplier was present during the first firing of the boiler. An operations supervisor contended that the maintenance departments did not really understand the control system, and that their 'maintenance' was essentially changing cards until the problem cleared. Similar accusations were levelled at the electrical department that did not fully understand the battery chargers. The operations supervisor said that at most times there were earth faults indicated on the battery charger panel. These did not directly lead to a loss of output, so electrical staff ignored them, claiming to have more pressing issues. The supervisor was convinced that the real issue was that the electrical staff did not know how to solve the problem.

Panels of the old control system at PSZ were replaced, connected to the original mechanical plant, none of which was replaced. Supervisors indicated that there was sufficient understanding of the new system for operators to be able to operate it, and for maintainers to ensure its functionality, but this did not imply in-depth understanding of all hardware and software.

Codification and documentation of knowledge

The sootblower example demonstrated inadequate technology assimilation and a lack of understanding of an essential feature of boiler operation, as well as an inability to master the software programmes that drive the sootblowing activity. The process had been documented and drawings were available, and staff had been trained in this specific activity, but operations and maintenance staff had not assimilated this knowledge. Although operating and maintenance staff received training on the boiler and turbine control systems, criticisms were made of the operating and maintenance instruction manuals. Explanations were inadequate, and the latest revisions of drawings were not always available.

The boiler control technology supplier at PSZ provided good documentation for the control system. Although much work was done on updating drawings, the supplier had not documented changes to drawings and general operating procedures. A supervisor commented that this was not the supplier's job. The original drawings were not on the Eskom CAD system, so manual updating was required, and the power station did not have the resources to ensure this was done. Managers admitted that this had been a problem that was not adequately addressed.

Failure data from supplier

Rather than supplying failure data, suppliers recommended maintenance intervention, but some maintenance staff questioned the basis both of the tasks and the intervals. Efforts had been made to determine spares requirements based on one supplier's failure data, but the conclusion was that without taking the specific operating context into consideration, failure data was meaningless, particularly as the failure data appeared to apply to European operating conditions. The question of failure data is discussed again later.

Supervisors at PSZ felt that the technology supplier had been a 'good salesperson', and management had accepted what was promised without sufficient ratification. Failure data was not provided, although one supervisor acknowledged that with largely electronic equipment, whose failure pattern was random and could not be predicted, the concept of failure data was largely irrelevant. MTBF figures were meaningless as they could not form the basis of preventive maintenance intervention. MTBF data could however be useful for determining the frequency with which protective systems should be checked for functionality. However, it was impractical to check individual items at different intervals, so protection was generally verified annually when safety values and other specified equipment had to be tested by law.

- ***Level 4: Supply chain***

Supplier networks and local infrastructure

Supplier networks in a supply chain context had not been established. Contacts with suppliers were important for technical advice and spares. A supervisor commented that suppliers had a vested interest in establishing a relationship of trust with Eskom. Some suppliers relied on their long relationship with Eskom, created in the apartheid era, when international suppliers were limited to certain European companies. Eskom now had the ability to seek suppliers from a much wider choice. The supply chain was changing with Eskom's policy of favouring black empowerment companies, as this introduced an additional link in the chain, although respondents felt that this link only served to aggravate TT.

Trust between user and supplier

Trust related to the level of service received from a supplier. When new installations were completed, they were inspected and taken over by Eskom's engineering department site representative, who then handed them over to the operations staff. This meant that in some instances the operators and maintainers did not have direct contact with the supplier. Most respondents believed that levels of trust between Eskom and its suppliers were high. Some staff felt that suppliers did not transfer as much expertise and knowledge as would be expected. The latest updates of drawings were not always delivered. Certain suppliers modified systems without documenting changes, making it difficult for Eskom staff to maintain these.

A supervisor commented that the shortage of technical expertise also affected suppliers, when represented in South Africa by local staff. He indicated that he trusted the European supplier, but that the local representative frequently had no more knowledge than Eskom staff.

Levels of trust between Eskom and the supplier at PSZ were good, although some supervisors wondered whether the supplier would remain as close to the project as he had done if he had known that the next round of control contracts were to be awarded to other suppliers.

Long-term dependence on supplier

A number of respondents felt that some suppliers deliberately sought to prolong Eskom's dependence on them as a lucrative source of income. Yet, it appeared that Eskom would in any event remain dependent on suppliers. Relationships were generally sound, and suppliers understood that when problems occurred, speedy solutions were essential. Suppliers believed that Eskom staff often had too high an opinion of their own abilities, and frequently serious problems could have been averted if Eskom had heeded the warnings or utilised the expertise of suppliers. Supervisors in some departments conceded that it was a matter of pride for them to dispense with the services of suppliers. Others claimed that this arrogance was detrimental as Eskom did not benefit from the expertise of suppliers.

Solutions to engineering problems could often not be solved immediately. A supervisor described a persistent problem of surges in ash lines that caused couplings to part. Eskom staff were unable to find a solution so suppliers were approached to assist. Experiments suggested by a supplier with vents and low line charging showed promising results, but further tests were necessary. This kind of collaboration illustrated the long-term dependence on many suppliers. PSZ managers and supervisors confirmed their dependence on the supplier for resolving short-term failures, and longer term modifications should these be deemed necessary at a later stage.

Procedures for problem solving
Greater emphasis was being placed on training and improved procedures were implemented so that Eskom staff would be able to reduce their dependency on suppliers. Despite claims to the contrary, most supervisors felt that Eskom personnel still depended to a significant degree on suppliers to assist in problem solving. Lightning strikes had damaged instrumentation on pipelines on a number of occasions. Electrical staff had attempted to solve the problem through additional earthing, but this had no effect. The control and instrumentation department approached a cabling contractor and instrumentation supplier, who jointly solved the problem.

Interviews with suppliers revealed that Eskom staff did not always show the necessary commitment to the training programmes that were offered, and Eskom maintenance staff were often not present when technology suppliers were investigating maintenance problems.

The most pressing need in problem solving was to return an item to service as soon as possible. Root causes of problems were often not investigated immediately. Once an item was repaired or replaced, evidence was frequently lost, so seeking the true cause became more difficult. One manager suggested that deeper investigations were only embarked upon with persistent problems.

Problem solving procedures at PSZ had been loose and based on personal contacts. Eskom project managers had established a good rapport with the supplier and, in the opinion of the project manager, Eskom had received 'more than its money's worth' from these contacts.

- ***Level 4: Operational***

Lack of labour commitment and productivity/ability to take responsibility
This was an extremely contentious area, and opinions divided on racial lines to the extent that many operational issues had an underlying political and racial dimension. The earlier comment by suppliers regarding Eskom staff's lack of commitment to learn was just one symptom of a much deeper difficulty. The interviews revealed intense frustrations by both blacks and whites, some of which were ascribed to cultural issues.

One black respondent pointed out the differences between African and European cultures at a social anthropological level, but claimed that such differences played no role in the business world: "We downplay the importance of culture. It's not fashionable in business to talk about culture. It's not 'western' or 'modern'. The previous government's justification for apartheid was the cultural difference between black and black, and between black and white". From a technology acquisition and utilisation viewpoint, respondents claimed the South African business climate was based on market-driven western values, so cultural barriers were not an issue.

Whites accused blacks of a lack of commitment. Comments such as 'they are never there when there is work to be done' were frequently heard. Whites felt that blacks were either unable or unwilling to accept the responsibility that went with their job. Blacks referred to whites' attitudes whereby they (the blacks) were required to do hard physical and dangerous work[2], while the

[2] For added emphasis, the respondent pointedly used the word *bereka* for *work*. This is derived from the Afrikaans word *werk*, rather than the Sotho word *sebeletsa* (which means *to work for someone* in a normal context). The use of *bereka* implies working for a white person (as a black would have done in the apartheid era - hence the choice of a pejorative word of Afrikaans origin), and shows contempt for the situation in which one works. This vividly illustrated that blacks felt that the working environment had not changed much.

whites stood by and watched. Whites were accused of refusing to relinquish the positions of seniority that they gained only through apartheid's discriminatory practices.

Most supervisors were white and Afrikaans-speaking. While it is a generalisation to say they were all somewhat conservative, it was evident that Eskom's personnel policies did not receive their total support. Several supervisors explained the difficulty of having to implement management instructions which pleased neither black nor whites. Black subordinates complained that their training was inadequate, that whites were given the more interesting or less physically demanding tasks, and that racism was still rife. White craftsmen and operators felt that they carried a heavier work load as some blacks were incapable of doing more complex tasks, yet promotion prospects for whites were extremely limited. When asked what personnel and essentially political issues had to do with technology, supervisors explained that much of their time was spent in addressing issues of commitment, responsibility and work allocation.

Supervisors described situations where inadequately qualified craftsmen were appointed in their sections. This either necessitated assigning very simple tasks to the person or required him to work with an experienced craftsman. Scheduling work then became difficult, and aggravated the situation in under-resourced departments. It was accepted that in some cases, it was no fault of the individual, as it was unfair to appoint such people without providing appropriate specific power station training. One supervisor commented that his was not a training department, and that he was not qualified as a trainer, yet this was becoming one of the major components of his job. The perspectives of craftsmen and operators are considered under level 5.

The political divide on racial lines at PSZ arose with a white supervisor claiming that some operators had not been fully committed to the project. The accusation was that they had not attended all training sessions, and when commissioning was underway, certain operators were not always present. This presented difficulties when the system was being handed over, as these operators proved unable to operate as well as they should have done. No black supervisors or operators were interviewed so it was not possible to gauge their view of events. The manager was satisfied that all staff had received adequate training.

During one of the last interviews a manager produced the following article by the former editor of the South African *Sunday Times*, Mathatha Tsedu, entitled *Why can't Africans measure up to the job of leadership?* He claimed that this correctly summed up the situation regarding labour commitment and productivity and the ability to take responsibility.

> "African communities are in crisis and the leadership of many institutions run by Africans is in turmoil ... I had lunch with someone who runs a 3 500-strong company, the most Africanised section of which had been fired en masse for fraud and dereliction of duty. A white replacement has been pointed and work is going on. A member of Cabinet told me about the frustrations of getting into government and hiring African people because that is the right thing to do, only for them not to deliver in the majority of cases. 'When you come from where we come from and you then have to realise that if you want something done quickly you have to rely on whites, it is really debilitating. You bleed internally, but our very own comrades do not work. There is generally no work ethic. Documents will not come on time or they will be sloppy. That is the painful truth.' The question is if African leaders are today forced by the legacy of colonialism to operate outside their cultural heritages and what effect this has on the underlying principles of their leadership styles".

Empowerment

Empowerment in the South African context had more to do with giving blacks a chance to better themselves than empowerment in the sense of participation in decision making. It was closely related to the issues discussed in the previous paragraph and, according to some supervisors, evoked emotions that were easily exposed. Whites claimed that blacks had been promoted through Eskom's affirmative action policies to positions above their levels of competence and experience. So, for example, a white craftsman reported to a black supervisor who knew little about the plant. The white must investigate a problem and obtain the relevant permits to work (commonly the job of the supervisor), do the job, and clear the permits, because the black supervisor was ill-equipped to do these tasks. Whites directed this type of accusation towards blacks throughout the power station hierarchy.

Blacks acknowledged that in some cases they did not have the experience: they had been denied opportunities and promotion prospects to responsible positions during the apartheid era when Eskom rigorously applied apartheid job reservation policies. Blacks also claimed that whites were not as competent as they made out, and much maintenance work done by whites was shoddy, or that unskilled blacks were forced by languid whites to do their 'skilled' work. Whites were accused of being reluctant to assist blacks or train them. Further criticism was directed at whites in that they were trying to maintain the apartheid tradition of keeping select jobs for themselves, to retain their previously privileged positions, and for not accepting transformation in South Africa. Eskom's commitment to training to facilitate the process of empowerment was criticised strongly by some whites who claimed that blacks 'were always on a training course, even if it had nothing to do with their work'.

A manager at PSZ had sought to involve all individuals chosen for the project, although the selection of staff did appear to have a racial bias in that most operators were white. All instrumentation technicians were white.

Cost of training and developing the local workforce

This did not appear to be an issue as Eskom appeared willing to spend large sums in uplifting and developing the local workforce through training and development programmes. Respondents did not see the cost of training as a significant factor since only by training its staff could Eskom meaningfully say that it was seeking to improve the skills of the workforce.

Several supervisors considered training budgets to be too generous, and that too much training was available. This had resource implications when individuals were away for extended periods. A further issue was the quality of the trainers. Eskom's general trainers could offer induction and training in the 'softer' issues, such as motivation, leadership and communication. Of greater concern were the technical courses, as it was felt that in many cases, these were too general, or non-specific. One supervisor commented that boiler operator training covered boiler operation in general and simplistic terms, but did not study the specific boilers at that power station. The training was criticised as being too theoretical, and individuals still had to be shown where every value and pump were to be found.

Transfer of physical equipment, systems, managerial philosophy and values

Transfer of physical equipment and systems was a relatively non-contentious issue between suppliers and Eskom. Previous comments showed that transfer of equipment and systems from supplier to acquirer was not always successful. Managerial philosophy and values again demonstrated the racial differences in South African society. Whites were quick to accuse black managers of attending excessively to their (the blacks') private affairs in work time, and that they were frequently absent when difficult decisions were to be made. The retort by blacks was that white managers in the past directed Eskom staff and resources to do 'private jobs' for them at the managers' homes, to the detriment of pressing power station work.

Supervisors felt the handover of physical equipment and systems followed a contractually agreed process. Contentious issues with contractors would arise, but these were addressed either at site level or at head office. One supplier commented that Eskom's managerial practices and systems were similar to those he had encountered in western countries, although the poorly educated and trained workforce aggravated the task of ensuring correct operation of his equipment.

Transfer of physical equipment and systems occurs in a defined manner with take-over from the supplier by Eskom's engineering department site representatives. Handover to Eskom's operations takes place when Eskom is satisfied that contractual commitments have been adhered to. A unit is required to continue in normal service for a proving period of six months, during which time acceptance tests are carried out. When the supplier has demonstrated through acceptance testing that the unit is in a fully acceptance condition for commercial service, the proving period ends and the 5% of the contract price that has been withheld is paid. A maintenance period of 12 months then begins.

Managers and supervisors agreed that this was the contractual aspect, but the reality was far more complex. Meeting contractual agreements did not mean transfer of technology, nor did it mean Eskom was satisfied with what had been supplied. Further negotiations continued, and suppliers were frequently called upon to assist in matters not directly covered by the contract.

Managerial philosophy and values were not formally addressed. There was tacit acquiescence with the way in which power stations were 'managed', compliance with reporting channels and structures, and acknowledgement of new Eskom policies that reflected changes in the South African political and business environment. One supervisor commented that behaviour change indicated acceptance of these, but that attitudes on both sides of the racial divide had not necessarily changed.

- ***Level 4: Contractual***

Technical documentation and drawings

This issue detracted somewhat from sound relationships between Eskom and suppliers. Although contractually bound to supply these, in practice there was little Eskom could do to enforce this.

Post-installation back-up and support

Irrespective of whether post-installation support was part of the contract, suppliers interacted with power station staff at a personal level. Respondents felt technology could not be transferred by contracts. The personal element played an essential role, particularly when modifications were introduced, and when suppliers shared experiences from elsewhere for plant improvement. Suppliers mentioned occasions when Eskom had delayed acceptance tests or access to plant.

There was no long-term contractual support at PSZ. A supervisor claimed that the supplier had provided good support in an effort to secure another contract with Eskom. He pointed out that no matter how satisfied power station staff were with the new system, head office awarded future contracts, and despite the fact that the supplier had formed a close relationship with the power station, in the face of head office opposition, future contracts could well elude the supplier (this turned out to be the case).

- ***Level 4: Maintenance***

Availability and reliability of equipment

An engineering manager's duties at a power station would typically include: development and implementation of engineering strategies in line with business plan objectives and power station performance targets; compilation, motivation and implementation of technical plan projects; compilation and updating of life of plant plan (LOPP); implementation and management of plant management fundamental policy (PMFP); ensuring compliance with statutory requirements; and management of the maintenance function. Maintenance played a traditional role at power stations in that maintenance departments reacted to defect reports by operations staff, and performed a certain amount of preventive maintenance. Maintenance was not seen in terms of availability and reliability. Rather, respondents saw their tasks as 'keeping the unit going'. Management reports contained figures of plant availability.

In addition, production figures (MWh sent out) and a number of other measures are recorded: efficiencies, and a note of loading restrictions, quantified in terms of MWh lost and the number of incidents. These are broad measures of availability and reliability.

Some respondents felt that such historical reporting, generally only made available to senior members of the management team, was of limited practical use. Clearly, persistent failures were investigated, but insufficient attention was paid to plant performance. This implied that the effectiveness of maintenance, through availability and reliability measures, was not really assessed. The number of preventive maintenance schedules was criticised by maintenance and operating staff, who indicated that preventive maintenance was excessive. Specific illustrations of the relationships between maintenance and technology are discussed in Level 5.

A manager at PSZ was satisfied with the availability and reliability of the new control system. He was unable to quantify the contribution of the new system to overall improvements in boiler performance. An operations supervisor contended that the availability of the system was attributable to its high inherent reliability, rather than any particularly good maintenance.

- ***Level 4: Integration of technology***

Training by suppliers in using new technology

Training was an important issue as affirmative action sought to promote previously disadvantaged employees. Interviews with suppliers revealed that while they were not contractually required to train affirmative action appointees, they were prevailed upon to assist in this aspect of training, particularly for new equipment and systems. Eskom's training departments undertook training in technologies that had been in place for some time.

The training offered by suppliers varied greatly. Some suppliers took Eskom staff abroad to see equipment in operation. Other suppliers installed equipment without training. These organisations were criticised, although it was conceded their contracts had not made provision for formal training. A battery charger supplier was censored as he neither gave training nor attempted to transfer any knowledge of his technology to Eskom staff. Even when called back to site, he rectified the problem without attempting to explain to electricians what he had done.

Shortages of suitably qualified and experienced staff
These were acute, especially since power station operating skills were not available from elsewhere in South Africa, so Eskom was obliged to train staff internally to meet its human resource targets. Since the early 1980s Eskom had been unable to attract skilled staff from abroad. This was exacerbated by emigration of skilled staff and ex-patriots returning home. Private companies paid more than Eskom, and fringe benefits and employment security no longer attracted personnel. This had an impact on the acquisition of knowledge. The shortage of suitably skilled and experienced staff was raised at all levels. Instances were given where plant was operated manually because automated control systems could not be repaired. Certain equipment life was proving to be considerably shorter than supplier predictions. Suppliers attributed this to poor operating and maintenance practices, especially the number of boiler start-ups.

A manager suggested half of all MWh lost could be attributed to poor operating or maintenance. He felt that poorly qualified and trained staff were costing Eskom enormous amounts of money. It was difficult to quantify these, but he listed several examples which could directly be attributed to operator error or maintenance. He contended that all of these were unnecessary failures. Some of the items mentioned are shown in Table VI.1.

Direct cause of load loss	MWh lost	No of incidents
Slagging due to inadequate sootblowing	55 000	2
HP by-pass spray water valve passing (valve had been checked during outage)	32 000	1
ID fan lube oil pump shut down in error	30	1
Boiler tube leak (probably due to sootblowing problems)	9 000	1
Oil changed on one PA fan because this had not been done during outage	50	1
Mill reject door jammed (poor maintenance)	90	1
Mill motor bearing high temperature instrument defective after 'repair' by Instrument Dept	45	1
High LP heater distillate level (not checked by operator)	550	2

Table VI.1 Examples of unnecessary failures (occurring in one month)

A manager at PSZ had experienced difficulties in selecting sufficiently qualified and experienced staff for the project. Additional automation from the new system meant that less qualified staff could operate the boiler, but when extraordinary events took place, or the system failed, it was not clear how effectively the less skilled staff could handle such eventualities.

Installation and commissioning of new systems
This followed the usual contractual process. Suppliers found they spent longer than anticipated in the commissioning phase as they were called upon to train Eskom staff, even though this was not specifically called for. Eskom staff rather considered it their right to be trained by suppliers. Both sides agreed that this area was not adequately addressed in contractual obligations.

A supplier commented that operating staff were not readily available to witness erection, installation and testing. While the final testing process took place in the presence of Eskom's engineering department, frequently operators and craftsmen were present. When operating staff did attend, they were often at engineering assistant level, so were neither those who would operate nor maintain the equipment.

At PSZ the supplier in conjunction with Eskom staff undertook these tasks. This was necessary because maintenance staff, and in particular electrical maintenance, had to assist in tracing, identifying and numbering cables that were not always in accordance with available drawings.

- ***Level 4: Maintenance planning***

Cost effectiveness of proactive maintenance

Maintenance planning took place according to a set of schedules generated by the maintenance information system. The tasks were time based with maintenance intervals set years ago. There was little evidence that these were revisited to determine their applicability and effectiveness.

The cost effectiveness of maintenance intervention was not formally established, and responses to the question of cost effectiveness were met with 'it must be cost effective because of the cost of downtime, and the severity of the consequences'. There was no indication that more appropriate measures of determining maintenance tasks and intervals were used. Interviewees revealed an interesting array of responses when asked about the cost of downtime. One supervisor said that a global figure is 'bandied about', but there was little indication of what this figure meant: lost 'revenue' to the power station, opportunity cost to Eskom, lost 'profit', and so on. This is a difficult concept, but respondents showed little understanding of its significance.

Staff were questioned on the data required to determine whether proactive maintenance was cost effective. Essentially, the question was whether, over a period of time, the cost of doing a proactive task would be less than the cost of the operational consequences which the intervention was intended to prevent. This requires a comparison between the cost of failure and the cost of prevention: how often the failure would occur in a certain time period if no attempt were made to prevent it (the mean time between failures) and the cost of the failure each time it occurs, compared to the cost of the proactive intervention and how often it must be done. None of this information was readily available.

MTBF figures required to calculate the cost effectiveness of maintenance were not available. A supervisor suggested that the maintenance information system contained such data, although others disputed its reliability. The cost of maintenance intervention was not calculated per task. While maintenance staff allocated their time to an activity which was recorded, it was accepted that the insistence that all hours of the day be accounted for, meant that these costs had little true meaning. For example, unaccounted-for time in the electrical maintenance department was invariably allocated to 'station lighting', which was shown in management reports to be one of the highest maintenance cost areas. Mechanical maintenance unallocated times were attributed to checking conveyors. It was widely accepted that figures for this activity was totally spurious.

Although some electronic and IT systems were subject to preventive maintenance, instrumentation technicians realised that proactive tasks were not applicable, so there was no need to schedule maintenance tasks and determine their cost effectiveness.

Problems of 'burn-in' with new equipment and systems
Operations staff complained of the problems encountered when plant was returned to service after maintenance: the common burn-in phenomena, illustrated in Figure VI.1c. One unit had tripped because of a problem with electrical protection. The fault was attended to, but the unit immediately tripped when synchronised as the phases of a voltage transformer had been incorrectly connected, with potentially damaging consequences. After this had been looked into, another attempt was made to synchronise, and the unit tripped again. Inspection revealed that the phase connections were again incorrect. Many such examples were cited. Managers were not sure whether to attribute this to poor supervision, genuine ignorance or carelessness.

Other examples were of delays in returning a unit to service after an outage. After weekend work, it was common to run up the unit on Sunday night so that it would be available for the Monday morning peak. In many instances, maintenance was either incomplete or careless errors had been made. Motors had not been direction tested, limit switches had not been correctly set, or while permits had been cleared, fuses had not been replaced. More serious problems arose, but operations staff felt many costly delays were caused by poor maintenance and inadequate supervision. Respondents reported that it had taken time to master new technology after commissioning, but current problems with 'burn-in' lay with work attitudes rather than insurmountable technology.

Respondents accepted the problems associated with the bedding-in process for new technology and systems. One manager felt that good suppliers could be identified by the extent to which infant mortality was reduced. Of particular concern to operations staff were the problems that arose after outages, where the unit would have to be run up several times because of poor maintenance by both contractors and Eskom during the outage. They contended that this could be ascribed to inadequate planning of the outage, and shoddy workmanship. Suppliers criticised Eskom for the number of times units were started, only to be shut down within minutes or hours. This significantly reduced the operating life of certain equipment.

Supervisors at PSZ recalled many 'burn-in' problems with the new system, but the supplier had generally been able to address these. In terms of Figure VI.1c, the project manager was satisfied that the steep part of the graph was short in duration, and that the supplier had remained on site until system stability had been achieved.

- ***Level 4: Financial***

Quantification of hidden costs of technology
One difficulty with new technology and modifications was the hidden cost, as one supervisor expressed it, which resulted from, "playing around with a system that was otherwise stable". The 'burn-in' problem of Figure VI.1c was ever-present. A previous example related to the adjustment of oil burners to enable the generator to be synchronised without the use of mills. This resulted in far more fuel oil usage in start-ups, which in turn had an impact on oil storage facilities. Supervisors felt that the full impact of modifications had not been taken into account. In their opinion, this was largely due to head office engineers issuing instructions about one section of the plant, without realising the impact elsewhere. This issue was raised several times: the unwillingness of engineers to work in the power stations themselves, as they preferred more comfortable head office jobs.

Supervisors questioned the complexity of some technology, and the degree of protection in some instances. The return of a unit to service had been delayed because of the inability to start a cooling water pump. All electrical and mechanical interlocks were checked, and eventually the problem was narrowed down to an electrical relay, which was on the drawing, but no one knew where this was physically located. The supplier was not able to explain the precise function of this relay, but said it was installed on all cooling water pumps.

Levels of protection were considered excessive in other instances. Turbines were fitted with emergency governors to operate within a range of 9 to 11% above normal turbine nominal speed. These were driven independently of the main governor. Either or both of the emergency governors must be capable of sending a signal to close all emergency and regulating steam valves. A manual device was also installed to actuate the emergency governor mechanism, both from the control room and at the turbine. It was a requirement that the emergency governors could be tested independently and on load without affecting the position of the steam admission valve. However, this had not been tested as no one was quite sure that the unit would not trip. Further, supervisors were not sure how the manual device could be tested.

Issues relating to the number of failure incidents in the Table VI.1 were used to illustrate hidden costs of operating. In some months the amount of oil used in start-ups was twice the budgeted figure. While some of this was attributable to problems with the technology itself, several respondents returned to the issue of poor operating and maintenance practice. In one instance a unit repeatedly tripped over a period of a few days because the automatic voltage regulator chopped over to manual for no apparent reason. On each occasion 1 000 MWh were lost. The response of the supplier was to 'change a whole lot of cards', which appeared to stabilise the system, but the supervisor was not satisfied that the true cause had been found. He attributed this to the complexity of technology that not even the supplier had fully understood.

Supervisors at PSZ noted that the number of trips during commissioning of the new system was significant, and that there was a direct cost (oil for the oil burners), as well as an overall cost to Eskom in that less efficient power stations were called upon to provide power during the frequent stoppages. These costs were not quantified, but supervisors felt that more simulated testing should have been undertaken, and less 'live' operating undertaken by Eskom when operators and maintainers were still learning the system.

- ***Level 4: Resistance to change***

Resistance to change

From a technology perspective, this presented difficulties only when operators and maintenance staff were confronted with issues they did not understand. The example given previously about manual sootblowing arose because operators were given conflicting instructions by different supervisors. Their reaction was to continue using what they considered to be old and tried methods. Generally there was little resistance to what staff deemed to be sensible modifications. Respondents suggested that at a personal level there was overt and covert resistance by whites to the changes in the political dispensation and Eskom's human resource policies.

8. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 4 ELEMENTS

The following paragraphs discuss Level 4 elements of the Salami and Reavill model.

- ***Level 4: Important aspects for suppliers involved in management and implementation of TT***

Suppliers accepted they would be drawn into some of Eskom's political machinations. They were required to deliver in accordance with their contracts, but a different expectation persisted regarding TT. Eskom's technological demands were high, and in many respects technical specifications were higher than those encountered in first world countries. Operating performance standards in terms of efficiencies and losses demanded stringent manufacturing standards. One supplier commented there was nothing 'third world' about Eskom's specifications, but sustaining these in the longer term was difficult as operating and maintenance abilities were seldom adequate. Equipment therefore had to be more robust than that supplied to first world customers. A transformer supplier illustrated robustness in an African context by remarking that Eskom and European specifications could not be used for other African countries because South Africa's electrical transmission and distribution system was stable, with good protection and fault levels, typically found in the developed world. Specifications (such as insulation) for certain African countries must be considerably higher than as electrical 'spikes' and instability made far greater demands on electrical equipment in these countries.

One manager said that several European suppliers found Eskom's purchasing procedures and preferences for black empowerment organisations a tedious process. Alliances with these added a level of complexity to negotiations, but added nothing to the supply chain. Respondents pointed out that participation in Eskom's new purchasing dispensation was fundamental if suppliers wished to do business with Eskom, and alliances with black empowerment companies was an essential component of this. This had little to do with technology as at this stage black empowerment companies were unlikely to add anything from a technological perspective.

Eskom's head office made the purchasing decisions for new technology, unless modifications to existing systems were made at power station level. The extent of the latter was small in comparison to new works projects. There were various opinions of the extent to which head office took into account feedback on technology suppliers received from power stations. A supplier believed that while post-installation service at a power station was important, this had limited influence on subsequent decisions regarding future technology suppliers.

Suppliers recognised that they had to accommodate a client's technical, procedural and human resource requirements. One commented that Eskom was a 'pleasantly demanding customer'. While standards were specified at head office, suppliers felt that many Eskom employees at the power stations did not fully understand the contracts or the technical requirements. Eskom's quality assurance teams varied greatly in their technical abilities, knowledge and commitment.

The relatively low technical education of many of Eskom's operating staff has placed a burden on suppliers in terms of training. This arose during the six month proving period, when Eskom operated a new unit, but the supplier was obliged to ensure compliance with contractual obligations. Suppliers contended that some Eskom staff did not operate the unit as it should be operated. In some instances Eskom staff performed maintenance tasks during the 12-month maintenance period, and that this maintenance work was also sub-standard. These issues required detailed documentation in case later disputes arose in terms of non-compliance.

- ***Level 4: Importance for personnel training and other HR issues***

While contracts were generally vague regarding training by suppliers (or they made no mention at all), suppliers recognised that if they were to retain any credibility in Eskom in terms of long term performance of their equipment, they must at least offer familiarisation training. Suppliers felt training was an essential aspect of TT. Where TT was not effective, this could be ascribed to a lack of relevant experience, or non-committal to the training on the part of Eskom employees. Main contractors remaining on site for several years as each unit was commissioned found this easier as training could take place on a longer term on-the-job training basis.

Other suppliers, such as those involved with water treatment, for example, commissioned their system, and were generally not on site thereafter. They trained staff during commissioning, but were not present when staff changed. Subsequent training was nominally Eskom's responsibility, but poor performance was often attributed to the equipment supplier. Again, this was aggravated by having to accommodate staff appointed without the necessary technical background.

There was criticism of Eskom's education and training programmes. While theoretical training was important, instances were cited where individuals were sent to a technical college, and for their practical work they returned to the power station. Once qualified, such people frequently elected to work in head office. General training was of limited use as power station operation required detailed knowledge of equipment, not overall broad familiarisation with the process.

The project manager at PSZ claimed that the success of the project lay in selecting the best available Eskom staff, as well as training by the supplier. He accepted that this selection would not always be possible, so with lesser qualified and experienced teams, the transfer of technology would be considerably more difficult, and would take much longer. He also questioned the amount of technology that could be assimilated by less educated people.

- ***Level 4: Importance for selecting alternatives for TT***

Suppliers did not install technology that would be 'simpler' to operate and maintain. Eskom's specifications did not tolerate inferior standards, so the selection of technologies was the same for Eskom as for any client in the first world. Accommodation for South African conditions catered for environmental extremes, such as high temperatures (requiring larger cooling systems), or the low calorific value and high abrasion of coal, but the technology required for this had nothing to do with a developing world environment.

In some cases suppliers were granted a choice in design approaches (such as motorised or hydraulic control mechanisms). In others, a technology or approach was specified, or expressly excluded. Thus, HP piping was required to be solid drawn steel, although Eskom would permit electrically fusion-welded piping in exceptional circumstances. Within the conditions of the contract, suppliers determined details for the most appropriate technology.

At PSZ power station managers had selected what appeared to be an off-the-shelf boiler control system. The supplier had assured managers that this standard system was appropriate and little adaptation appropriate, so no further consideration of alternatives was undertaken.

- ***Level 4: Identification of criteria for better adaptation of new technology***

Suppliers did not believe that their technology required adaptation for South African conditions. Eskom's requirements could only be met with the latest technology. The example was given of the choice between 'roller' and 'ball' mill technology. Some engineers favoured one over the other, so the vertical spindle type of mill at PSW, was in the opinion of some, an inherently better design.

However, this was not an issue of saying that one was better suited to the South African operating context: it was better for the type of coal and demands of the boiler.

Respondents did not consider adaptation of technology an issue at Eskom, except where the original specifications were incorrect, or when operating circumstances changed, such as persistent problems with varying grades of coal resulting in inconsistent mill performance.

Suppliers provided tried and tested systems and equipment, and unless specifically instructed not to do so, would use these as they represented the best on offer, within financial and logistical constraints. Cost was the only factor that would favour one technology over another. The most appropriate materials were used, and control systems were of the same standard as those used in the developed world. Eskom was more stringent in terms of its specification of stand-by equipment than some European operators, and suppliers suspected that this was because stand-by plant was called upon more often than in other installations. This was a reference to lower maintenance standards and abilities in South Africa.

The expertise of staff at PSZ required a balance between a greater the level of automation and less skilled operating staff, as opposed to greater complexity of systems, and more intricate maintenance. Some features of the boiler control technology were not used (sometimes because they were not functional), particularly those relating to automatic start-up and shutdown. A supervisor suggested the start-ups were 'rougher' when done manually, particularly where operators rushed the process without considering specified heating gradients. However, during start-up, some ancillary equipment invariably did not work, so the automation expected too high a level of overall functionality of all equipment.

9. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 5

The following paragraphs discuss the Level 5 items in Appendix V. Level 1 refers to supervisory, operator and maintenance levels.

- ***Level 5: Knowledge***

Understanding failure modes and effects

This item was closely related to other issues discussed under maintenance. A fitter commented that insufficient time was spent on establishing root causes of failures, recalling a failure on part of the water treatment plant where he had been required to replace a set of nozzles on a cation unit that had suffered acid corrosion. Some weeks later he had had to replace the nozzles again. When the same kind of acid corrosion was noted, the supervisor ordered nozzles made of different material that would withstand the corrosion. The fitter's point was that no effort had been made to find why the nozzles were corroding: the true failure mode had not been ascertained. There were no immediate effects as a result of the failure, but the fitter claimed that no account was taken of the price of new nozzles (twice that of the old nozzles). Several examples were recounted, where as long as there was no immediate production loss as a result of a failure, little attention was paid to root causes. A supervisor acknowledged this occurred when maintenance staff did not fully understand the functionality of a system, or how it failed.

A second example related to excessive corrosion on the gear teeth of a mill gearbox. The gears were replaced at great expense and their condition monitored, but no further investigations were undertaken. Within days corrosion was again evident, so the gears were replaced, whereupon it was found that an additive in the oil had caused the corrosion. The gears were then inspected weekly for some 6 months, whereafter the supervisor seemed to lose interest. The fitter's comment was that oil samples should have been taken immediately, and particles in the oil indicating corrosion of gears would in any event have been evident from the samples. It was unnecessary to sample the oil daily, and certainly not necessary to inspect the gears themselves weekly as the corrosion would not have caused a failure of the gearbox after so short a time.

Failure and effect analyses (FMEA) were seldom undertaken formally. Maintenance was seen to be 'fixing things', or 'keeping the unit going'. A fitter described one mechanical maintenance task: check all conveyor idlers monthly (physically turned by hand). This was tedious for hundreds of idlers. He admitted there were many volunteers as all fitters knew they could disappear for a day, and that no one could verify whether the idlers had been checked. He did not describe the situation in terms of an FMEA, but his insight was correct. He questioned the need for checking the idlers. There were two conveyors in all cases, and stocks of coal in the boiler bunkers that would last longer than the time required to change an idler. In any event, the failure of just one idler would not stop coal conveying. He further added, that even if an idler were checked today, there was no guarantee that it would not fail before the next monthly inspection.

His analysis was that those setting maintenance policies had not understood that the failure of an idler bearing was totally random, and that there were no direct operational consequences of such a failure. Further, he claimed that once an idler began to fail, the bearing would seize in a matter of days. He had been told that 'frequent' (monthly) checks were required because the coal conveyors were so critical for the operation of the power station. Provided the operator inspected the overall operation of the conveyor as part of a zonal inspection, a faulty idler could be repaired within 30 minutes. The maintenance schedule was completely inappropriate. He proposed a policy of breakdown maintenance for idlers, but was not supported by his supervisor.

Understanding impact of maintenance/failure on overall process

Errors relating to deficient knowledge were made at two levels. The first resulted in immediate failures; the second did not prevent operating, but affected efficiencies. Lack of knowledge in the second instance was more complex. Various measures of overall power station performance were used. Units generated in GWh or plant load factors such as MWh sent out as a percentage of maximum demand or installed plant capacity were overall measures of effectiveness but did not measure efficiencies. Other measures such as auxiliary units (as a percentage of units sent out), coal burnt (tons per kWh sent out) gave some indication of power consumed or heat conversion in the generation process, but managers indicated that these measures were at too high a level to manage efficiency improvement at machine or system levels. Other measures such as boiler house efficiency, overall efficiency (S.T.E.P factor, station heat rate/kWh sent out), and so on, provided a narrower measure of performance, but changes in these could not be attributed to any specific knowledge deficiency. At a narrower level, for example, measures of precipitator availability pointed to the effectiveness of the electrical maintenance department, but the presence of other factors questioned the validity of such a conclusion.

Lightning strikes in the summer were a common phenomenon, but they were initially considered random events with indeterminate consequences. It was subsequently discovered that each time there was a severe electrical storm the control air compressors tripped. This was not immediately apparent as there was a standby diesel compressor, and further, only when the pressure dropped below 260kPa would an alarm sound. The standby compressor would start automatically before this occurred. The severity of the consequences only became apparent when the diesel compressor did not start due a faulty battery, and the low pressure alarm was ignored. This caused the unit to trip. A second problem from lightning strikes arose when ash water return pump motors tripped, but the alarm was not functioning. There were no immediate consequences, but low water levels eventually became evident causing the boiler to trip. Referring to these problems, an electrician commented that unless consequences were immediately apparent, operators did not react to failures as they did not appreciate the implications. The impact of many other failures was not understood, such as the persistently high ph of demineralised water. The unit operated satisfactorily, but neither laboratory staff nor operators seemed to appreciate the long-term implications.

Lists of causes of loading restrictions are produced under headings such as boilers, milling plant, electrical, instrumentation and control. Managers had access to these, but did not appear to use them for close measurement purposes. The turbine supplier claimed that operators had little detailed knowledge of the theory of thermodynamics (as would be required of an operator in Europe), so operators were unable to appreciate the subtleties of truly efficient turbine operation. This indicated a lack of both explicit and tacit knowledge.

- ***Level 5: Maintenance***

Safety assurance through maintenance

Because maintenance was seen as 'fixing things' at failure mode level, suppliers commented that it was not considered at system level. It was evident that the relationship between maintenance and safety or environmental protection was not generally recognised. When asked about safety valves, a fitter said a safety valve lifted when the pressure reached a certain pressure, and it was the task of maintenance to ensure that it did so. He was unable to say what this pressure was or what the discharge capacity was. He did not construe a safety valve as a protective device designed to prevent over-pressurisation of the boiler.

In the case of precipitators, the task of the electrical maintenance department was seen as one of repairing these, rather than preventing atmospheric pollution. Similarly, the tasks of verifying the functionality of protective systems were seen as 'testing the diesel generators' rather than ensuring an electrical back-up supply for essential equipment. No connection was made between maintenance, and safety and environmental infringements.

One supervisor pointed to inconsistencies in maintenance policies. A particular pressure relief valve had failed in a closed position, resulting in fractured pipes and superheated steam narrowly missing an operator. It was decided to 'look at this valve as often as possible, but at least once a month'. The instruction was to open the valve and test it each time the unit was down. The supervisor recalled when the unit was out of service for several hours, so the valve was inspected and found in order. Two weeks later the unit was down again, but the valve was not to be inspected as this had 'recently' been done. Despite several short stoppages in the weeks thereafter, no testing was done. A month later the unit was down, and the valve was inspected. The unit then had a record run of four months without stoppage, when the valve was not looked at. He commented that the initial instruction that the valve be inspected 'as often as possible' was nonsensical: if time-based maintenance were required, then the appropriate inspection interval should be determined, and the valve tested, particularly as people could be killed if it failed.

Clearly production considerations were deemed more important than safety considering that the unit remained in service for several months on the occasion mentioned. The supervisor concluded that management did not see any relationship between maintenance intervention (inspecting the valve) and safety (the possible death of an employee). It was the supervisor's contention that there was no time basis for the failure of the valve, and that opening it and inspecting it increased the likelihood of a failure. He admitted that neither he nor his fitters were precisely sure what they should be looking for, and that a visual inspection could not guarantee the valve would operate when reassembled (again analogous to the Sizewell B statement above).

Power stations had good safety records, attributed to strict adherence to safety codes of conduct. Less well understood was the relationship between maintenance and safety. One craftsman acknowledged that more maintenance did not necessarily mean a safer plant. He recalled two events several years ago at other power stations. In one instance, an FD fan had been worked on, returned to service, and shortly thereafter, part of the impeller had become detached, seriously injuring an operator. In another case a fitter had been required to climb inside a mill to check the gap between rollers. The mill had been inadvertently started and the fitter killed. In the case of the FD fan, he contended that poor maintenance had been the cause of the accident; in the mill instance, proper procedures had not been followed regarding clearing of permits.

Appropriate maintenance policies (intervals and tasks)
Craftsmen and supervisors questioned whether some maintenance tasks were appropriate. One instance related to outsourcing the maintenance of certain classes of valves. They believed that the service Eskom was receiving was not adequate because contracts were agreed on the basis of time-based maintenance that were, in the opinion of mechanical staff, incorrect. This detracted from cooperation between operations and contractors. The money paid to the contractors was determined by the number of valves in the system and a time estimate for each. It transpired that contractors were paid whether or not they were granted access to a valve, as the contractor considered it unreasonable if they arrived on site to undertake the maintenance, but access was not granted for operational reasons.

A supervisor described the detrimental effects of outsourcing. Firstly, the contractor was not always on hand to attend to breakdowns, so Eskom maintenance staff were called upon, despite their limited experience of valve maintenance, because they did not often work on valves. Secondly, the operating context of the valves was not taken into account. A series of large cooling water (CW) butterfly valves enabled sections of the CW system to be isolated. The CW system was divided into a north and a south plant, interconnected by a valve. However, in order to inspect this interconnecting valve the whole power station would have to be closed down. Clearly the contractor never looked at this valve, yet was paid regularly as the valve appeared on the valve maintenance schedule. Prior to the publication of the schedule, few people knew of its existence. It could be questioned whether this valve was of any use, and whether it should be removed. This issue gained greater prominence when it was discovered that it was passing, rendering work on either the north or south plant extremely difficult, and even dangerous.

In the opinion of some maintenance staff, inconsistencies in maintenance policies suggested that those who determine maintenance tasks and intervals were neither fully aware of the nature of the failure of items, nor the basis on which maintenance intervals should be determined. Maintenance tasks and intervals were generally based on supplier recommendations and adjusted as a result of the experience of maintenance supervisors. When asked how intervals for condition monitoring checks were determined, the answer was invariably that this depended on the severity of consequences. This frequent error has potentially catastrophic implications.

Certain tasks, such as regular replacement of motor and pump bearings had been dispensed with. The reason for this was that the length of outages was to be shortened, rather than a realisation that the failure pattern for many roller bearings was random, and that replacing them did nothing for system reliability. The operating context of mills was not taken into account at one power station, as identical maintenance policies were in force, despite different grades of coal being supplied to different units.

Some craftsmen were critical of maintenance practices. One example was transformer maintenance, where the policy required checking the transformer once a year. This was a general examination of coils, a detailed examination of all nuts, and tightening those for current-carrying terminals and bolts that clamped core and yoke plates together. Windings were to be meggered, and insulators cleaned. Silica-gel in the breather was to be replaced. The electrician said that to the best of his knowledge, none of the work had ever been done as it was deemed too intrusive, and opening a transformer in dusty conditions was ill-advised. His contention was that flashovers occurred when insulators were dirty as a result of grass fires followed by rain, so cleaning the insulators in summer when electricity demand was lower, was more appropriate.

Understanding impact of maintenance/failure on overall process
An example was provided of how electrical staff did not understand the wider effects of their actions. They had been working on a unit transformer. There had been reports that electric motors supplied from that transformer were tripping on low voltage under certain circumstances. Some time later the boiler fires were lost when the mills tripped as a result of the loss of the lube oil pumps. The lube oil pump motors had tripped on over-voltage because the voltage on the auxiliary board was too high. An investigation eventually showed that the tap setting on the unit transformer had been changed during maintenance. In the unit transformer instance, electrical staff had not reported that they had changed the tap setting. It was unclear who had given the instruction, and on what basis. Previous failures of motors on low voltage (the ostensible reason for changing the tap setting) were not recorded, but it was suspected that this occurred during starting of an electric feed pump, where direct-on-line starting results in a 15% transitory drop in voltage. Head office load flow studies showed this voltage drop should not affect other motors.

Verification of protection (failure finding of hidden functions) is to establish whether a protective device is in a functional state. It was clear that operators and maintainers typically did not see the larger picture. The weekly running of the diesel generators became a routine task in itself, but maintenance staff were not aware of precisely what emergency equipment would be driven by the emergency supply. As an exercise, it was decided to test the (emergency) DC barring gear motor, which is fed by the diesel generators to a DC distribution board or from batteries. This was used for turning the main turbine shaft after a shutdown of the turbine (in the event of a failure of the main barring gear motor). The motor did not start because a lug had broken in the supply connection box, so the functionality of this motor had never been tested.

Diesel generators supplied emergency power to essential services in the event of a unit failure, and an auxiliary power failure. The diesel generators were tested once a week. On one occasion when a failure of electrical auxiliary supplies occurred when after the unit had tripped, the diesel generators started as required, but no power reached the essential distribution board. It transpired that the circuit breaker was faulty. It was possible to restore auxiliary power after a few minutes, but the consequences of a lack of emergency power could have serious operational consequences.

Checking the diesel generators is a maintenance function, and a supervisor admitted that they had not thought to check the entire circuit as this would require isolating essential boards from the main unit supply boards. He was not sure if this could be done under normal operation, so it would only be possible to check the entire emergency supply system when the unit was off load. This illustrated that one test was being performed without understanding the entire system.

Failure data generated internally
Supervisors were confronted with the reluctance of craftsmen to complete the 'action taken' aspect of work orders and defect request forms. The excuse by craftsmen was that as soon as they had completed a task, they rushed to the next one, and had no time to complete the required information. If any descriptions of maintenance undertaken were written, the comments would typically be that an item had been checked (with no mention of its condition), or that an item had been replaced (again, with no description of the extent of its deterioration, or why it had failed). Because supervisors found ever fewer defect reports were being completed, the only option was to give craftsmen a list of possible actions, from which they were only required to tick the relevant box. So, for example, a list of possible failure modes for a defective pump could be: impeller worn, impeller broken, casing cracked, bearing seized, coupling failure, and so on. Even with this simplified process, little meaningful failure data was recorded. This meant that the plant history was of limited value.

The planning department commented on the poor quality of information provided on defect reports. Supervisors explained how difficult it was to ensure that the craftsman who had undertaken a certain task provided meaningful information. An example of a lubricating oil pump motor illustrates the point: the work request was recorded as 'lube oil pump failed'. The history showed that a motor had been replaced three times in one year (the serial number was required, but was not given). No reason for the failure of the motor was provided. A maintenance task was then created: 'check lube oil pump motor'. A number of ticks on the planning schedule indicated that the motor had been 'checked'. An electrician admitted that he had no idea what he was supposed to be checking, but if the motor was running then it must be in a satisfactory condition. Failure data could provide information on which maintenance planning could take place, but planners commented that the computerised maintenance management system lacked credibility, although the system itself was good (it was used at all power stations). According to one supervisor, the result was that actual maintenance activities were determined on the basis of intuitive feeling and experience.

10. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 5 ELEMENTS

The following paragraphs discuss Level 5 in the Salami and Reavill model.

- ***Level 5: Criteria for evaluating performance based on suppliers' goals***

Suppliers considered TT successful if Eskom were able to operate and maintain its equipment in accordance with contractually agreed performance standards on a sustained basis. There was considerable debate within Eskom and among suppliers regarding Eskom's effective derating of its plant. Table 7.1 shows that current available megawatt ratings coal fired power stations are between 5 and 7% below their nominal ratings. The nominal output ratings are the capacities at which the older power stations operated when first introduced into service. To justify the effective deratings, the analogy was used that 'even though your motor car can travel at 100 mph, you don't drive at this speed all the time'. This was rejected by some suppliers, who claimed that Eskom was not able to maintain their equipment to the level that would enable operating at 100% of rated capacity.

Three possible reasons were put forward for being unable to attain rated performance output. Firstly, the equipment was underrated in the first instance. Suppliers generally rejected this explanation as they claimed that Eskom would not have taken over equipment that had not met the contractually guaranteed performance standards, and in any event the units had all operated on commercial load at the rated outputs. Secondly, machine deterioration resulted in the inability to achieve what was desired. Suppliers accepted that maintenance related causes would result in temporary loss of function, but effective and applicable maintenance would restore original resistance to failure. The third reason was changes in operating methods caused a system not to be able to deliver as designed. Suppliers claimed Eskom had not attempted to assess the extent to which poor operational and maintenance practices detracted from achieving desired performance.

- ***Level 5: Guidelines for modification of new technology***

Suppliers conceded that in some instances modifications had been required to ensure that performance levels could be achieved. One supplier had just completed the installation of a new resin trap in the condensate polishing plants of each unit. The lower differential pressures achieved with the new designs would solve a problem that had persisted for some time.

No consensus was noted from the interviews for overall guidelines on modifications, other than performing detailed analyses to establish the root causes of failures. Suppliers felt that Eskom sought too many redesigns as the solution to failures when in fact the designs were perfectly adequate. A lack of understanding of a system indicated inadequate TT, so suppliers had to spend an increasing amount of time in familiarising Eskom staff about equipment and processes.

- ***Level 5: Evaluating success and failure of new technology in the future***

Suppliers did not believe simplifying technology was a suitable option for facilitating TT for Eskom staff, even though they required considerable training if they were to operate and maintain sophisticated equipment. It was clearly beyond the powers of a supplier to dictate to Eskom who were suitable candidates for training, but some suppliers now gave detailed feedback on the performance of each trainee. This cleared the trainer or supplier against accusations of inadequate training, as well as giving Eskom honest advice on an individual's capacity to master technology.

Success would continue to be measured in terms of meeting required performance standards. One supplier suspected that financial constraints may force Eskom to lower some of its technical standards, but whatever these were, suppliers would strive to meet them. Another supplier doubted that Eskom would drop some of its stringent specifications, as Eskom had a proud record internationally of technical proficiency, and followed technological developments closely.

- ***Level 5: Introduction of innovative programmes through R&D to develop new technology***

Suppliers encouraged Eskom to make greater use of condition monitoring in order to acquire useful information independent of human intervention. This was a somewhat controversial initiative, as other suppliers questioned whether Eskom had the ability to interpret and manage outputs from condition monitoring techniques. Condition monitoring also reduced the amount of fault detection work undertaken by individuals, and reduced their exposure to the plant.

Developing new technology was not part of the contractual obligations of suppliers. Some suppliers worked with Eskom to refine specifications. For example, one supplier was advising Eskom on revising its procedures in addressing moisture in transformers. Improved performance had already been achieved by simple changes, such as not relying on circulating oil in a transformer to remove water, treating the transformer oil to extend the life of a transformer, and determining whether moisture was captured in the interface between the insulation and the oil. Suppliers believed this kind of advice would be useful if full use were made of new technological developments in maintenance and diagnostics technology.

APPENDIX VII

DESCRIPTIONS OF POSSIBLE MINI CASE STUDIES

The following organisations were considered as possible case studies for the mini cases.

1. Loadout station of a minerals exporting company
Minerals from mines in the South African hinterland are transported by train to this loadout station at a major harbour and loaded into ships for export. The plant for possible analysis contains railway truck tippers, miles of conveyors, and associated equipment, such as samplers and weight measuring devices. Some machines are complex, with intricate pneumatics, hydraulics, and electronic controls for semi-automatic operation. While immediate loading is important when a ship is at the loadout station, plant redundancy and waiting times for ships to berth usually provide adequate time for maintenance. Possible areas for TT investigation included a new sampler for determining the weight of material loaded into ships, and the automatic movement of railway trucks. This company was not selected as it was felt that new projects were undertaken to improve operations by acquiring equipment with limited efforts directed to transfer technology. Changes in the business and political climate did not appear to have affected the organisation significantly. Incremental improvements were undertaken, but there was no indication that strategic issues drove these, or that quality and output were drivers of change.

2. Paper mills
The first paper mill manufactures toilet and tissue paper for the local market. The mill is South African-owned, but most of the equipment is imported, and upgrades rely on technological advances in Europe and the US. The mill comprises paper machines, winders, rewinders, core and log handling, and packaging machines. Various new projects have been undertaken recently, including an upgrade of the logsaw and associated equipment, and a new packaging machine. The second paper mill produces high quality printing paper for the local market and the intention is to increase exports. New technology has been introduced to improve coating and the air removal process during stacking of paper sheets. Although the paper mills offered interesting new technologies, their operations were not greatly influenced by global issues or the new political dispensation in South Africa. The technologies were installed on a turnkey basis, and packaging machines maintained under maintenance contracts with the suppliers. Technology improvements did not appear to have been introduced for strategic reasons, and were not greatly constrained by finances.

3. Water company
This water company is responsible for the distribution of water to municipalities, and purification and reticulation to farmers and isolated consumers in one region of South Africa. The company has other responsibilities relating to deforestation, research into underground water supplies, and the development of new water infrastructure projects. Changes in regulations governing the water industry have encouraged the company to seek additional activities, such as taking over water purification for municipalities. Increasingly demanding water quality standards to international levels have necessitated the introduction of new or upgraded purification works. This organisation was greatly affected by regulatory changes, and was trying to transform itself from a state-owned, inward looking operation to a market oriented firm that had to change dramatically in order to survive, particularly in relation to quality and service. Technology was seen as an important component of its transformation. Levels of technology had been low, so new technology presented

a number of organisational and technical challenges. As a parastatal organisation like Eskom (albeit much smaller), the company could provide some interesting points of comparison with Eskom.

4. Flour mill
This flour mill is one of the larger mills in South Africa, receiving wheat of widely varying grades. The milling process follows a standard pattern with stringent internationally accepted quality standards. Its products are mainly distributed to bakers and supermarkets in South Africa, but expansion of its exports is being considered. While the plant itself is old (some machines are more than 50 years old), new control systems have been introduced to provide an automated process. The large capital expenditure was justified because of customers' tighter delivery schedules and higher quality standards. Changes in the regulatory environment and the abolition of government-controlled boards that governed many aspects of the wheat and flour industries presented this mill with many organisational and business challenges. The mill could only survive with significant cost reduction and quality improvement, and management had concluded that upgrading the mill was essential. These raised interesting TT issues so this organisation was selected.

5. Oil refinery
This refinery is one of the largest in South Africa, and operates under the technical leadership of the company's US parent. Much of the technology dates from the 1970s, so various plant upgrades have been undertaken in recent years to improve separation, conversion and treatment, to enhance safety, and to reduce atmospheric pollution as the refinery is close to a residential area. Two projects considered were a coker heater and its associated charge pumps and flue gas system, and a hydrogen compressor for hydrocracking. Government regulations continue to influence financial returns of oil companies. Technology is not perceived as a component of business strategy, but rather as a purely operational issue. The refinery had a standard approach to new projects, and could afford to second its staff for lengthy periods to refineries throughout the world where similar projects had been undertaken. The apparent abundance of resources for training and development makes this a rather different South African organisation from most others in the selection group, so this case was not selected.

6. Steel plant
This plant makes special grades of steel no longer manufactured by the previously nationalised cooperation, Iscor. Significant new investment has upgraded the plant over the last five years. Low international steel prices, tariffs and dumping have necessitated severe cost cutting exercises, and operational efficiencies have been sought through programmes such as Six Sigma, BPR and TQM. The company is partly owned by a major South African corporation whose performance was adversely influenced by the steel company's losses. A new pickling line was recently installed and presented an interesting case in TT. After significant technology upgrades, quality improvement enhanced the plant's international competitiveness. However, insufficient time had elapsed to judge the nature of TT that had taken place and suppliers were still present on site, so technological problems could be solved with reference to them. For these reasons, and because access may possibly have presented difficulties, the plant was not chosen for analysis.

7. Confectionery manufacturer
This subsidiary of an international confectionery company underwent recent changes in corporate ownership and upgraded technology in various plants. Some sweet manufacturing equipment is more than 50 years old. While operators and maintenance staff have mastered the fine mechanical

components of many machines, the performance of equipment is erratic and quality is inconsistent. A recently upgraded packing machine offered a case study where totally new technology was introduced in a factory that was last upgraded decades ago. The new machines were recently installed. Quality and delivery had been acceptable. Surplus capacity meant increased output was not an important consideration. A manager claimed the new technology had been installed as part of a world programme for technology upgrading. Broad organisational issues had not changed, so the company was not studied further.

8. Brewery

SABMiller (formed from the takeover by South African Breweries of the US brewer Miller) has over 95% of the South African beer market. The breweries in the major centres have identical manufacturing processes and systems. Historically equipment was different, but efforts have been made to standardise, permitting comparison between production standards of all breweries. New processes and equipment are tried out at various breweries, and some of these represent significant technology upgrades. Automatic palletisers and conveying equipment have been installed at one site, and offered an interesting area for TT research. South African Breweries has vast resources and in this respect is not representative of much of South African industry. Standards practices and procedures have given the company a proud productivity record, and technology is seen as a means to maintaining this. Broader aspects of TT do not appear to affect operations, so the brewery was not selected.

9. Food manufacturer

This processor of vegetable oils is a subsidiary of a global organisation. Plant design, layout and equipment specifications are laid down by the European head office. Quality standards had to be raised to be in a position to export its products. Some South African food legislation appears to be less stringent than in developed countries, but ISO 9000 certification is required before European buyers will consider the products. A number of machines and systems have been replaced. The latest upgrade concentrated on control, instrumentation and protection.

Upon deeper investigation, the recently installed technology had a narrow influence on broader operations. While protection is an essential aspect of any factory, this falls into the category of 'hidden functions' and has no effect on operations under normal circumstances. It was felt that studying this company would have produced a limited set of results, applicable to protection in organisations with similar operating conditions.

10. Limestone quarry

This limestone quarry produces various grades of lime used in the manufacture of cement in Southern Africa. The quarrying and crushing processes require large maintenance-intensive imported equipment. Machinery for large operations, such as the kilns is imported, while South African engineering firms supply the plant for less intricate processes, such as the loadout platforms. Operating processes are generally well understood, but maintenance of the large imported machines requires a level of understanding that is generally beyond the expertise of many South African maintenance managers. Efforts have been made to transfer this technology to the plant maintenance teams. This company provided an interesting blend of local and imported technology. Improvements were introduced for reasons of operational efficiency, with almost no impact on the organisation as a whole, which in any event seemed largely unaffected by changes in the broader political and business environment. For these reasons the company was not chosen.

11. Manufacturer of cling film

This company manufactures PVC cling film for food packaging in retail and domestic markets. The industry has been subject to supermarket pressures to reduce prices. The organisation's survival depended on expanding the customer range to include fast-food customers and exports. In order to achieve this, recent plant upgrades were aimed at quality improvements, and more reliable manufacturing processes. The company was selected as many aspects of TT were evident, such as quality, delivery, and organisational and systems requirements. Customers specified international quality standards, which could only be achieved through new technology.

12. Food processing plant

This food-processing factory was driven to expand its market from supermarkets to fast-food outlets. New technology had been introduced in the processing of potatoes for the manufacture of French fries. Although the company does not export a great deal of its production, it must adhere to the international quality standards laid down by American fast-food corporations. The variables that primarily influence the quality of the end product are the quality of the raw material and the manufacturing process. Exposure to global standards forced the company to adopt new technology. While organisational issues were not greatly affected by the new technology, the strategic necessity for new process technology presented some interesting areas for investigation, and the company was selected.

APPENDIX VIII

MINI CASE INTERVIEW SUMMARIES

This appendix summarises the mini case interviews in five sections, corresponding to the levels of the Salami and Reavill framework. The items from the preliminary research pertaining to each level are discussed in the five sections. In order to avoid repetition comments from respondents in each mini case have been combined rather than discussing each mini case separately. Some repetition of comments is evident as respondents at different levels made the same points.

1. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 1

The following paragraphs discuss the items categorised at Level 1 in Appendix V. Level 1 refers to senior management levels where policy decisions are taken.

- ***Level 1: Economic/political***

Crime levels in South Africa

Managers felt that crime affected every aspect of South African society, and impacted on their organisations. Security issues took up a great deal of management time and incurred significant costs. Companies experienced internal and external theft of equipment. Crime affected absenteeism, necessitated special transport for shift workers, and resulted in technically qualified staff leaving the country. A 30-ton truck with wheat belonging to Flourco had been hijacked between the storage silos and the mill. Waterco suffered from tampering with water meters and had to deal with sections of the community who tried to avoid payments. Pumping stations at reservoirs were subject to vandalism and theft of equipment. Plastico managers felt that some international technology supplier staff were reluctant to remain in the country for extended periods of time. Foodco managers suggested that crime led to negative attitudes towards the country both from within and without, although there was no direct link between crime and TT.

Low educational levels of labour

All managers commented on their generally poorly educated labour force. Flourco had provided training for unskilled labourers to perform manual tasks. Operators and maintenance staff at the mill had a good understanding of the old equipment, so their education had not been an issue in the past. The mill now experienced difficulties in recruiting staff to maintain the newly installed control system, particularly as few graduates and technicians had milling qualifications. Waterco and Foodco experienced difficulties in attracting suitably qualified technical staff to live in isolated areas. Local recruits were used wherever possible, but education levels were extremely low. Plastico considered low education to be an acute problem as some workers and many applicants for vacancies were not numerate or literate.

Effect of globalisation

Flourco, Plastico and Foodco were affected by globalisation in different ways. In the apartheid era wheat prices in South Africa were set by a wheat control board, and bread prices were controlled, so mills operated within set cost margins. Since the abolition of these boards, world grain prices governed the input price, and bakers and supermarkets were at liberty to set their own prices for bread. The managers recognised that while their markets were in Southern Africa, their input prices were set in Chicago, so they were in effect operating in a global environment. Plastico saw exports as the most important way of earning reasonable long-term profits. Competition was as intense within South Africa as in world markets, but the low value of the South African Rand gave exporters a good advantage. Globalisation meant that timely deliveries at the specified quality were essential for survival. While most of Foodco's products were sold within South Africa and in neighbouring countries, world markets determined raw material (food) prices. Global corporations laid down quality standards of finished products, and South African supermarkets were adopting international quality standards.

Waterco managers felt that globalisation had had no effect on operations. The firm's spheres of activity had always been prescribed by legislation, which had also precluded other organisations from entering their water market, so take-overs and competition were not a threat. Although Waterco was seeking to expand its activities, this would only be to adjacent regions, and foreign competition was considered highly unlikely.

Overall level of economic development and infrastructure
Flourco was affected by farming and transport conditions. Apart from changes in the pricing structure, relations with farmers had not changed. Strict quality control of wheat at silos meant the mill maintained quality requirements without excessive wastage. Flourco, Plastico and Foodco had dispensed with rail transportation because of its unreliability, and frequent price increases. Road transportation had become expensive since many transportation companies insisted on being paid in dollars (as they were paid for transportation to other African countries).

In Waterco's case political changes in South Africa meant that water provision to poorer communities was expanding. Waterco was therefore involved in developing the infrastructure of the country. Water for household consumption meant that the technology used in purification plants was required to meet international standards.

General conditions in a developing country
Developing country difficulties affected the cases in different ways. For respondents at Plastico and Foodco, the important issue facing South Africa as a developing country was its poor education system. Many workers were not qualified to take on positions of responsibility, so it was difficult to meet government affirmative action and employment equity targets.

Flourco was confronted by a new trend where South African farmers were increasingly seeking faster growing, lice and rust resistant wheat cultivars available from many parts of the world. As their protein and baking properties varied, quality standards were more carefully monitored than in the past. Operating conditions in South Africa were generally satisfactory, but managers feared a 'Zimbabwe situation' at some point. Wheat and flour were politically sensitive products.

Waterco supplied water to some municipalities. Because various black political parties in the apartheid era had dissuaded consumers from paying for services, the company suffered from a consumer culture of 'non-payment'. This affected cashflow and prevented some infrastructural projects from being implemented. However, it was politically unacceptable to disconnect supplies or to take legal action.

Government regulations and bureaucracy
There was general agreement that government regulations and bureaucracy had significantly reduced since the demise of apartheid. This was welcomed, even if business conditions were less predictable. Some managers complained of difficulties in obtaining work permits for

representatives from foreign suppliers. Waterco was subject to government legislation in terms of water quality, statutory duties and areas of operation. This did not directly affect technology issues, provided acceptable water standards were adhered to.

- ***Level 1: Strategy***

Statement of clear objectives to be achieved by new technology

Managers felt that South Africa did not possess technological strengths in any specific areas, so organisations were obliged to seek technologies abroad, and clear objectives were essential when acquiring new technology. Flourco's objectives in acquiring the new control technology for automating the mill were simple: to reduce costs and improve efficiency. Cost reduction pressures since the demise of the control boards and fixed bread prices had forced the company to lower operating costs. Automation was to boost employee performance and product quality. Waterco's managers had set performance standards (particularly in terms of water output and quality). The objectives were thus set in terms of performance requirements. Plastico's management had clearly stated higher quality, reduced downtime, and financial savings that the new technology was to provide. Foodco's management had installed a new production line in order to attain quality levels and meet low cost production requirements.

Technology implemented because of market demand (demand-pull)

Flourco's new control system was not directly implemented in response to market demand. Increased water requirements at Waterco resulted from market demand, necessitating new technology. Cost played a major role in deciding what technological solutions could be afforded. Plastico's quality monitoring technology had been introduced as a direct result of market demands. A European customer had rejected an order of several tons because the cling film did not meet specified thickness requirements. Foodco's technology was primarily installed to ensure that customer requirements were met. The arrival of global corporations such as the fast-food chains in South Africa after the demise of apartheid required local firms to meet the business standards of these organisations. Foodco managers pointed out how lean principles were introduced with fast-food outlets holding no more than a day's sales; supermarkets dispensed with their central warehouses and required suppliers to deliver products several times a week. Appearance standards were much higher. For example, nubbin, sliver and short piece removal was far stricter; the dimensions of fry cut were precisely defined. Such demands were unknown several years ago.

Technology as a strategic resource for competitive advantage

Technology was not introduced to attain competitive advantage in broad strategic terms. Flourco's technology was acquired to lower costs and ensure reliability of delivery. Flour is an undifferentiated product, with quality standards common to all mills. Being a monopoly Waterco was not subject to competition. Managers at Plastico felt that the technology had given them a cost advantage over other competitors who continued to suffer quality problems and excessive downtime. The new line at Foodco brought the level of technology up to that of competitors, so no additional strategic advantage would be achieved.

Technology to assist in shift from product to process base

The new control system at Flourco was acquired to improve the process which was key to financial success, but the customer was unaware of what milling process was adopted. At Waterco the process was important only in so far as it reduced costs. While the product at Plastico remained the same, operational efficiencies through the new process gave the company a cost advantage in the market. At Foodco the steps in processing the potatoes were standard, but individual activities such as steam peeling and the 'water knife' yielded a better product. The technology therefore assisted in improving the production process.

New business climate (global markets)
For Flourco the new business climate and global wheat prices were both considerations in taking the decision to lower costs through automation. Waterco managers felt that the global business climate did not affect the firm, whereas at Plastico the climate was one of strict delivery, service, lead times and quality standards applicable to international businesses. This had forced the company to change significantly. Adherence to the international quality standards of the fast-food industry was a relatively new development for Foodco. South African supermarkets were also moving to such standards.

Alignment of business goals, systems and technology
Flourco's new technology was not specifically considered as a mechanism for aligning goals and systems. The corporate objectives of Waterco did not refer to technology. Managers stated that technology was the means to meet water requirements. Plastico's business goals made it essential to change the company's approach to quality. In the past poor quality products were reworked, but the costs thereof were never quantified. Since production could not always meet demand, the choice was either to introduce an additional production line, or to improve the efficiency of the existing line. The latter course of action was chosen as the cheaper alternative. The strategy of Foodco was to expand its presence in the fast food and supermarket businesses. In order to do this, it had been necessary to install a new line to meet the quality standards in these sectors.

2. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 1 ELEMENTS

The following paragraphs discuss Level 1 in the Salami and Reavill model.

- ***Level 1: Identification of needs and demands of acquiring country***

Flourco respondents did not identify special technological needs for the South African situation. Its control system was acquired from a German supplier that had made no specific allowances for the South African situation apart from environmental factors relating to humidity and temperature. Waterco managers explained that the provision of water to poor communities at an affordable cost was a government priority, and the ability to do this was the main consideration in selecting technology.

- ***Level 1: Identification of limitations, advantages and disadvantages of needs and demands***

Managers commented that the age of some equipment made automation difficult. Technical specifications of machines acquired by Flourco 50 years ago were often not available. Changes in milling practices meant product flow through the process was not optimal, but it was not cost effective to change. Waterco's limitations emanated from financial constraints, such as difficulties in recruiting technically qualified staff. An automated plant was difficult to maintain without the requisite skills. A further barrier was the expense of appropriate technology. Plastico had found it necessary to change the quality culture of the organisation. Because South African customers were not particularly demanding, quality was secondary to delivery. With American fast-food organisations greater emphasis had been placed on quality. Access to export markets was denied to firms unable to manufacture to international standards. Managers at Foodco acknowledged they were obliged to tighten management control systems. The impact of plant downtime was more important with just-in-time deliveries. While the introduction of such changes had been difficult, managers felt that business was more efficient.

- ***Level 1: Identification of important macro and micro human factors for use of new technology***

A number issues were identified under this heading. Automation of the Flourco mill 'deskilled' operators. Managers felt that operators were satisfied with the new operating environment, particularly as assurances were given that no subsequent downsizing would follow initial redundancies. Recruitment difficulties meant the mill did not have its complement of technicians. Waterco tried to recruit local staff where possible, but this required considerable training and education resources. Water technician courses were of 3 years' duration. Students were required to undertake their practical work at one of the firm's plants. The new technology at Plastico required more sophisticated maintenance. Operators' tasks were less demanding. Managers recognised that while operators were deskilled through the introduction of the new technology, maintenance crews required additional skills. The new line at Foodco dispensed with many manual tasks, such as final peeling and sorting. Additional manual activities were introduced, such as nubbin removal. It was necessary to negotiate changes in operating practices with unions, particularly since new labour legislation had given workers additional bargaining power. More training was offered than before, which was having an overall beneficial effect in the factory.

- ***Level 1: Identification of acquirer's goals and objectives***

Respondents felt their goals and objectives had been clearly identified. Flourco had publicised quantifiable cost reduction targets. A benchmarking exercise with other mills in the group had produced useful comparisons, which were presented to the workforce as the standards against which they should produce to avoid mill closure. The technology supplier's contribution was one of technical compliance with specifications for the new control system. Waterco's goals were the provision of water of the required quality to an increasingly broad spectrum of consumers. While quality standards were externally prescribed, a balance was sought between providing water to farmers and 'richer' municipalities that could afford higher costs, and those where most consumers were unemployed. The goals set by Plastico and Foodco were adherence to international quality standards, and lower production costs.

3. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 2

The following paragraphs discuss the Level 2 items in Appendix V. Level 2 refers to senior and middle management.

- ***Level 2: Technology***

New technology to meet exact needs of customer

The technology supplier was able to meet Flourco's automation requirements, so managers were satisfied that the new technology would assist the mill in achieving customer quality and delivery needs. Respondents at Waterco indicated that customers were not concerned with the means or technology whereby they received their water. Customers wanted high quality, cheap water at all times. Previous quality control checks at Plastico were inadequate (the operator used to feel the thickness of the film with his fingers), so quality-monitoring technology was installed prompting intervention if quality was not within acceptable quality limits. The automated screen changer increased production output by reducing downtime to change the screen manually, and contributed to meeting customer delivery schedules. Foodco had selected the new line so that the needs of a variety of customers could be met. For example, the cut of the fries differed: some fries were to be tapered, while others had a 'wavy' cut; the temperature to which customers wanted the fries to be frozen differed; packaging styles and quantities varied.

Better quality through technology
This was one of the most important reasons for installing new technology in all the cases.

Improved output through new technology
This was another significant reason for updating or implementing new technology.

- ***Level 2: Economic/political***

Pressure from labour unions, affirmative action and employment equity policies
All cases noted pressures for affirmative action and employment equity. The first announcement at Flourco to automate was met with hostility from the unions as this required a number of redundancies. Managers had explained the dire financial situation of the mill meant unions could do little to prevent the introduction of the new technology. The mill published an employment equity plan in accordance with government requirements, stating how many employees of each race and gender were currently in different employment categories, and the plans to increase the number of blacks and females in senior positions. Managers were concerned about promoting individuals with inadequate experience to key positions. Waterco had to contend with one union largely representing white workers, and one predominantly black union. While the black union discussed affirmative action and employment equity issues, all unions raised wages, conditions and job security, education and training. Company policy was to promote previously disadvantaged workers, and unions appeared to be satisfied with developments.

Plastico had undertaken to promote previously disadvantaged employees, with union agreement. The unions had expressed concern that new technologies would result in redundancies, and did not accept managers' assurances to the contrary. Managers had not resolved issues relating to the reduction in work content and skills requirements of some operators' jobs. Correct job evaluation grading would mean a reduction in pay for these operators, but this would raise legal implications in terms of the Labour Relations Act. Unions at Foodco had resisted the new technology because of their fears of job losses. In fact, with the additional manual tasks, the workforce reduced by only 5%, and this was achieved through early retirement of older workers. Plans had been agreed for affirmative action, but managers and unions accepted that this would be a long-term process.

The brain drain - skilled people leaving the country
All firms had experienced difficulties in recruiting technically qualified and experienced staff. Increasing numbers of people leaving the country exacerbated skills shortages in South Africa.

- ***Level 2: Strategy***

Distinctive competency to be derived from technology
No respondents indicated that technology was to enhance distinctive competencies. The technologies would reinforce core competencies in line with competitors (apart from Waterco where competitive pressures were not a motivating force).

Technology permits revisit of vertical integration
Vertical integration was not an issue in the cases, so technology played no role in this.

- ***Level 2: Management policies for technology***

Belief in the need for and commitment to technology, and establishing clear objectives for technology

In all cases managers believed they had demonstrated their commitment to the new technologies, and that clear objectives had been established.

- ***Level 2: High-tech issues***

Novelty of new technology

Supervisory staff at Flourco suggested that the level of automation was excessive. The dusty environment meant dirt in electrical contacts and limit switches frequently stopped production. Maintenance procedures were changed to address such problems. Few operators understood the control process, but this could be temporarily overcome by manual operation. As new operators took over operations, managers feared that lack of understanding of the process through its automation could have serious implications. At Waterco the local labour force was generally poorly educated, and much of the new plant's control system was new to operators. The basic process of purification was the same as in the past, but additional features offered by the technology added a new dimension to their jobs. Both technologies at Plastico were new to the company, and this particularly affected maintenance staff who were not familiar with this level of technology. While the processes were well known to Foodco's workforce (peeling, blanching, drying), the way in which these activities were done and the technology for doing so were new.

4. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 2 COMPONENTS

The following paragraphs discuss Level 2 in the Salami and Reavill model.

- ***Level 2: Identification of appropriate technologies to meet acquirer's goals***

Respondents indicated that little choice was available in the selection of technologies to meet their specific needs. Flourco's goals were detailed in the contract documentation. Managers claimed that the control technology had not in any way been adapted because it was to be installed in South Africa. They had visited mills in Europe, and their tender documentation was based on international standards, with allowance for compatibility with existing older machines. Financial constraints determined the choice of technology installed in Waterco's new purification plant. Technological enhancements were only introduced if the company could afford them. Managers at Plastico believed that the selected technologies were the only ones that would meet their requirements. While the technology was complex, managers did not believe this was beyond the eventual technological capability of their employees. Foodco managers had travelled abroad and selected the equipment which they believed could deliver the desired quality. Some activities, such as nubbin and sliver removal could be assisted using laser technology, but these technologies had not been considered for reasons of cost.

- ***Level 2: Identification and analysis of cost and benefits of new technology***

Two of the case organisations had performed some kind of cost-benefit analysis. At Flourco benefits were based on what managers believed would be achieved by automation. A detailed investigation had been carried out at Plastico to assess the cost effectiveness of the automated screen changer. The downtime for and frequency of screen changes were known, and this could be related to lost production, waste and rework. The precise effect on quality was more difficult to quantify, but even so, managers claimed that the benefits far outweighed the costs.

Waterco had not performed formal cost-benefit analyses. The board of directors had agreed a budget for plant upgrading, whereafter it was assumed that benefits would be forthcoming. A manager at Foodco claimed that a cost-benefit analysis had not been necessary: if the new line had not been installed, the business would have collapsed under the pressure of low cost competition. Equipment and installation costs had been recorded, but these did not include commissioning and training costs, supervision, travel to view other installations, and so on.

- ***Level 2: Evaluation of imported technology on the basis of acquirer's resources***

All respondents suggested that evaluation of technology was essentially subjective and based on visits to suppliers and installations using their technology. A South African representative or agent was considered to be advantageous for support and spares availability. In all cases financial constraints limited the scope of technology options.

- ***Level 2: Analysis of economic and technical factors affecting TT***

Respondents reported that no single technology offered such distinct advantages that technical considerations alone would determine selection of that technology. In all cases cost was a major factor, particularly because of the low value of the local currency.

5. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 3

The following paragraphs discuss Level 3 items in Appendix V. Level 3 refers to middle management and factory engineering departments.

- **Level 3: Technology**

Appropriate technology

Flourco managers were satisfied that the chosen technology was appropriate as a fully automated and integrated system was not possible. Product samples were taken manually and analysed in the laboratory and human intervention (usually by the miller) would determine what action was required, and the control system was adjusted to achieve this. So, if levels of, say, semolina were not as expected, the miller would decide on remedial action, and instruct an operator to change set points on the control system.

Managers in the other cases had not specifically considered appropriateness. Waterco had used consulting engineers to compile tender documentation, without specifying what technologies. Output performance parameters were set, which the technology was required to deliver. Plastico had not considered the question of appropriate technology. They believed that their selections were the only technologies able to address their problems, so it had been essential to acquire these. Foodco managers had never doubted that the technology was appropriate.

Sensitivity of technology

Respondents agreed that the sensitivity of technology to cater for all requirements was difficult to establish before awarding a contract. The sensitivity of the control system at Flourco was able to cater for all eventualities. However, analyses of laboratory results were not sufficiently accurate to make full use of the fine control mechanisms that the technology offered. Further, demands made by the sensitive control system on old equipment had resulted in equipment failure (discussed below). Sensitivity of technology at Waterco had not been considered. Plastico managers felt that the technology could be adjusted to meet their requirements. At Foodco the technology had so far been able to accommodate a wide range of customer requirements and was reliable in the South

African operating context. In some cases, the technology enabled suppliers to change operating parameters to permit different packaging requirements and change the cut of fries according to individual customer requirements.

Transfer of core technology
Managers reported that operational capability of the technologies had been transferred, but how the technology functioned had not been mastered. At Flourco the control system was robust, but mill staff were not fully able to use all its facilities because some features were not understood. At times technicians were unable to programme the PLC to permit certain mixing combinations. Managers attributed this to inexperienced technicians, and admitted that core technology had not been fully transferred. Minor adjustments in the control system were possible, but substantial changes could only be made by the supplier.

Waterco's operating and maintenance staff had experience in water purification. TT required transferring the ability to operate new processes, and maintaining more sophisticated equipment such as variable speed motors, on-line monitoring of water quality, mixers regulated by the control system, and more sophisticated protection. Some of the technology had been transferred, but supervisors felt it was not all understood. Managers at Plastico believed that the necessary expertise to operate and maintain the two systems would eventually be transferred, but further training and experience would be required. Respondents at Foodco suggested that the technology was well understood by operators and maintenance staff, with the exception of the control system, which still presented programming and maintenance difficulties.

Complexity of technology
The miller at Flourco felt that the control system was unduly complex, despite assurances from the supplier that the level of complexity was appropriate for a system requiring the features laid down in the enquiry documentation. The supervisor highlighted certain pneumatic systems and electrical drives that required specialised maintenance. The supervisor was not convinced that the fine calibration of some of the new instrumentation was required, and argued that simpler equipment would have been adequate.

Supervisors at Waterco felt that some of the technology was unduly complex, especially where the retention of manual systems would have had little effect on operational capability. One activity that had caused many problems was the mechanical handling of chemicals. Respondents believed this could easily be done manually, but since the installation of this reasonably complex system, labourers had become reluctant to revert to the manual handling of chemicals when the mechanical system failed.

Respondents at Plastico acknowledged that the technology was complex, and that it had not yet been fully mastered, but were convinced that experienced staff would eventually be able to operate and maintain the equipment so that full functionality would be attained. Foodco staff did not consider the technology to be complex. Nubbing and palletising cartons remained manual tasks as the cost involved in mechanising these could not be justified.

Robustness of technology
The technology at Flourco was considered robust, but respondents felt that interfaces between the control system and the existing plant had not been adequately addressed. Items such as limit switches, valve positioners and electrical contacts frequently resulted in the failure of the entire

system. The problem was not with the new technology, but with the mechanical and electrical interfaces. Variable speed motors had burnt out because the control system activated them more often than their design specification permitted. The mechanical handling of chemicals at Waterco has already been mentioned, and was considered not to be sufficiently robust for the operating context, as dust and exposure of equipment to the elements had not been adequately catered for in the specifications. At Plastico the technologies were considered fully robust in the applications in which they operated. Foodco had found its new line to be reliable in its operating context.

- ***Level 3: Knowledge***

Diffusion of intangible knowledge

Flourco staff were only able to make relatively minor adjustments to the control system. They undertook simple maintenance tasks, such as replacing control cards, when the system's self-diagnosis programme indicated where faults lay. Managers accepted that the system was not understood, and that knowledge of the process was at a low level. Fortunately, changes were not frequent, or manual intervention could override the control system when staff were unable to programme desired changes. This indicated the extensive intangible knowledge of the millers, in that they could revert to 'the old way of doing things', but it demonstrated how little knowledge of the control system had been diffused.

The concept of 'knowledge' was not recognised at Waterco. Respondents referred to 'know-how' in terms of being able to operate and maintain the plant. Experienced staff had process know-how, but it was acknowledged that much remained to be learnt. Training (usually on-the-job training) was the way in which this know-how was passed on to others.

Managers at Plastico were satisfied that their staff would master the technology, and could in any event revert to manual operation when required. In a subsequent interview the supervisor expressed another view: manual operation meant that no significant downtime was experienced when systems failed. However, this was only possible with operators who retained the ability to run the film through their fingers and judge its thickness. This would be lost if they were no longer required to assess quality in this way, and new operators would not develop this expertise. The supervisor questioned whether technical staff could master the new technologies before operators lost their 'intangible knowledge'.

Foodco respondents were not familiar with the term intangible knowledge. They felt that operators had a good understanding of the French fry manufacturing process. The detailed operation of certain machines such as the weighers and carton sealer was not fully understood. Know-how was spread through the organisation through on-the-job training.

- ***Level 3: Supply chain***

Changing approach to supply chain management

The supply chain concept was generally not used. Flourco's managers recognised the importance of retaining close contacts with the German supplier of the control system and the local representative. This was not supply chain management, but respondents pointed out that they had never before relied so much on a supplier. This was not surprising as there had been little or no contact with the manufacturers of the 50 year old original equipment. The firm had 'good contacts' with a number of engineering works and spares suppliers to maintain functionality of the original equipment.

Supply chain management was not understood at Waterco. Relationships with technology and other suppliers were based on formal and informal contacts. Good relationships had been established between Plastico and its technology suppliers. Supply chain strategies had only been established with raw material suppliers, and not with technology suppliers. Foodco was working with customers to negotiate specifications, and to some extent, managers saw the beginning of a supply chain. Technology suppliers were not considered part of a supply chain.

Expertise of international suppliers
Respondents were satisfied with the expertise of their international suppliers.

Moves to local sourcing
No policies specifically required local sourcing, but items were acquired locally when cheaper.

Use of the internet
At Flourco and Plastico some use was made of the internet to obtain prices and determine availability of spares. All respondents felt that their personal contacts gave better service than that obtained from suppliers through the internet.

- ***Level 3: Strategy***

Relationships with stakeholders
Relationships with stakeholders were not seen as a strategic issue.

Technology partnerships
No formal technology partnerships existed, and none were foreseen.

- ***Level 3: Operational***

Promoters and champions for technology transfer
Respondents used project managers to oversee installation and commissioning of equipment. In the case of Flourco and Waterco, project managers were from head office. Local staff had limited input, so promoters and champions had not emerged. At Plastico supervisors were responsible for ensuring that the technologies operated as intended, but no champions had emerged. The project manager at Foodco became the champion for the new line, and ensured the necessary training was undertaken. Respondents suggested that because staff did not fully understand the technology, they were reluctant to assume a leading role in promoting the technology.

Change management
Managers claimed to have managed the changes arising from the implementation of the new technologies in close consultation with the unions and other employees.

Short-term returns from technology
Managers had not specifically measured the effects of the new technology, but cited anecdotal evidence of improved quality, fewer customer complaints, and reduced waste.

- ***Level 3: Contractual***

Contractual arrangements
In all cases the installation of the new plant had been managed on the basis of contractual arrangements, and performance testing was carried out in conformance with contractually agreed

standards. Respondents indicated that contractual agreements for training and subsequent support had not been adequate.

Operational compatibility between owner and acquirer
Respondents felt they had sound relationships with suppliers, but further provision should have been made for additional training, and a longer period of plant handover.

- ***Level 3: Integration of technology***

Integration with existing systems
At Flourco integration of the control system and existing machines was not entirely satisfactory. The miller said that most failures were blamed on the control system, particularly as it demanded response times that were rather quicker than old machines could provide. Previously mentioned examples also apply under this item: actuator motors had burnt out because the control system sensitivity was too fine, and motors were starting more often that their design parameters allowed. Much of the plant upgrade at Waterco involved new equipment, so there was not much integration with existing systems. Plastico managers claimed that integration had been carefully addressed to ensure that the film making process was improved by the new technologies. The quality monitoring system required manual intervention when trends towards control limits were identified by the system, so no further integration was envisaged in terms, say, of automated adjustments to ensure quality compliance. There had been some concern regarding the stability of the bubble during screen changes, but any reservations had been dispelled. The French fry line at Foodco was an independent line, so there was no physical integration with other equipment, apart from services and waste disposal.

Communications and IT systems
The plant upgrade had resulted in some communication and IT changes at Flourco and Waterco.

- ***Level 3: Maintenance planning***

Lead time for spares acquisition
Flourco's supplier had provided a recommended list of spares. Mechanical components were fairly easily obtainable and lead times were reasonable. Control cards and electronic components were imported from Germany. Waterco's respondents complained that the lead time for some spares from Europe was several weeks. An example was the failure of a dosing pump, requiring chemicals to be added manually throughout each cycle, and no matter how carefully operators added the chemicals, water quality standards were not consistent even if they remained within specification. Otherwise the availability of most spares was reasonable.

Maintenance spares at Plastico were kept in terms of suppliers' recommendations, and replaced as required. Managers expressed concern at the level of spares stockholding, but felt this was justified because of the cost of downtime. Few spares for the new line at Foodco were available in South Africa. The relatively large stocks were based on the suppliers' recommended spares. Lead times were at least one week for spares from Europe. As it was not possible to stop the line for this length of time, production continued, by-passing the relevant machine through manual intervention, or temporary repairs were undertaken. These courses of action could have serious longer-term consequences for production.

Unique spares and specialised maintenance
At Flourco special control cards were obtained from abroad. A self-diagnosis facility assisted maintenance staff in faultfinding. Technicians with general PLC knowledge were of limited use because they did not understand the milling process. The upgrade of the plant at Waterco meant that few spares from other plants could be used, and spares stockholding represented a substantial capital investment. In certain cases policies had been agreed whereby the suppliers held spares. Suppliers undertook certain calibrations and specialised tasks as the water company's staff were insufficiently skilled to do so. Spares for the two Plastico systems were only available from the suppliers. Specialised knowledge of the technologies was required to undertake maintenance, but reliability had been good. Spares at Foodco were generally not available in South Africa. On a few occasions spares had been borrowed from other factories in South Africa using similar machines. Respondents did not believe maintenance was particularly specialised.

- ***Level 3: Management policies for technology***

Internal support and communication
Respondents were satisfied with internal support and communication.

General exposure of staff to high technology
At Flourco existing equipment was old and relatively low-tech. This meant that operating staff had had no exposure to high technology equipment, but were able to operate without having to learn a great deal about the new system. Technicians required substantial additional training. Most locally recruited staff at Waterco had not been exposed to technology of the type installed in the upgraded plant. This necessitated extensive training, but the company suffered from not having sufficient suitably qualified staff that were able to train others. Few Plastico staff members were exposed to the intricacies of the technologies. Most operators saw no more than visual indication of quality measurements, and would notice that screens had been changed. They were not concerned with how this happened (and indicated that their jobs had been made easier as a result of the new technologies). The high level of technology was therefore not an issue. Despite the limited education of most of the workforce at Foodco, and their lack of exposure to high technology, respondents did not feel that this was a serious impediment.

Internal infrastructure and facilities
Infrastructure and facilities were generally adequate. While laboratory and maintenance workshop facilities had improved, they were still not fully equipped to deal with all laboratory and maintenance requirements.

- ***Level 3: High-tech issues***

Use of expert systems
Expert systems were not used.

Process optimisation
Process optimisation was not considered to be relevant. Operational efficiency and acceptable quality levels were sought. At Foodco the most challenging aspect had been to determine what processes required mechanisation and which would better be done manually, from an efficiency and cost point of view.

- ***Level 3: Financial***

Cost

At Flourco costs of installation had been closely monitored to avoid cost overruns. Operating costs were lower than before the control system was installed, but the cost of improved quality had not been quantified. Cost was the most important factor in selecting the upgraded plant at Waterco because the budget could not be exceeded. Changes and improvements to other systems were also covered by budgetary constraints. Cost had been an important factor in deciding the extent to which mechanisation and automation would be installed at Foodco. The decision to use manual labour for certain tasks was taken on financial grounds, although one manager did indicate that mechanising certain tasks would have been unnecessarily complex.

Justification of technology on a cost-benefit basis

Managers at Flourco argued that the project had been justified on a cost-benefit basis at the design phase. The costs of the technology at Waterco had been calculated, but respondents felt that a meaningful estimation of benefits of the technology was not possible. Plastico managers believed that returns from the technologies would yield a payback period of 2-3 years. Managers at Foodco had not specifically justified the new line on a cost-benefit basis. The older ways of making fries would not have met current quality standards, so the new line was essential. One manager suggested that a 'back-of-an-envelope' cost-benefit analysis had been undertaken in deciding what should be mechanised.

6. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 3 ELEMENTS

The following paragraphs discuss Level 3 in the Salami and Reavill model.

- ***Level 3: Determination of basic human factors for adopting new technology***

Operators and maintenance staff at Flourco were trained in the use of the new control system. This largely took the form of explaining interfaces between the control system and existing equipment, and how the system affected operations. Little training of how the control system worked was given. Some mill staff worked with suppliers during commissioning, but no other human resource issues were raised. One aim of the new process at Waterco was to reduce manual tasks, such as moving chemicals and adding them to the process. No specific action from a human resource perspective was taken to accommodate the technology, apart from training and familiarisation. Operator training at Plastico in the use of the new technologies was provided. Maintenance staff worked with suppliers during installation but they had received insufficient exposure to the new technology. Human factors had not specifically been considered when deciding to acquire the new technology at Foodco. Previously manual tasks (such as product and materials handling, weighing, some packaging) had not been changed for ergonomic reasons, or to make operators' jobs easier, but automation would increase efficiency.

- ***Level 3: Evaluation of final costs and benefits of new technology***

Final costs at Flourco were calculated and presented in a project report. Benefits were not fully quantified, but management reports showed how by-product waste had reduced and throughput increased. These were ascribed to the new control system, although the supervisor admitted that stricter control of wheat quality at the silos (in terms of falling weight, protein, and moisture) meant that throughput should in any event have improved. The costs of the Waterco plant upgrade were reported to the board, but one manager commented that some costs had been excluded: training and the laboratory upgrade had been included under other cost centres so that the total cost would not exceed the budget. Respondents saw no way of quantifying benefits. From laboratory records water quality had improved, but no financial value could be attached to this. Managers at Plastico were satisfied that final costs would be recouped by the benefits accruing from the technologies. No final cost-benefit analysis had been performed at Foodco because it was not possible to quantify the benefits of better quality and more reliable deliveries.

- ***Level 3: Determining relevant technology supplier***

Managers at Flourco had visited a number of suppliers abroad. They were satisfied that all suppliers were capable of delivering the appropriate technology, so final decisions were based on price and the presence of a local agent, rather than on a preferred technology. Waterco had contracted consulting engineers to manage the upgrade. The issue of a 'relevant' technology supplier was not considered, as the cheapest tender adhering to the contractual requirements was to be accepted. One manager said it was a question of 'buying as much technology as we can with a fixed amount of money'. The various tender submissions showed different design approaches, but the essential purification process was the same in each case. A limited number of suppliers offered the technologies sought by Plastico. Foodco had considered a number of potential suppliers. Their technology was comparable, so the final purchasing decision was taken on the basis of cost, hearsay regarding support, and preferences for certain engineering designs.

- ***Level 3: Estimation of alternative sources of technology***

Alternative technologies were not available.

7. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 4

The following paragraphs discuss the Level 4 items in Appendix V. Level 4 refers to middle management and supervisors.

- ***Level 4: Technology***

Assimilation of new technology

Assimilation of technology was considered at an operational level. Factory staff could operate the processes and the technology was delivering what it was supposed to. All cases reported difficulties in maintenance, largely because maintenance teams did not understand how the technology functioned. In this regard technology in its entirety had not been assimilated.

- ***Level 4: Knowledge***

Understanding new technology

Respondents felt that the technology installed in their organisations was not well understood. Its basic functionality was clear, but maintenance technicians did not comprehend the detailed operation of the systems. Control systems presented problems, which staff were frequently unable to repair despite extensive training courses. A Waterco supervisor commented that training had been moderately successful in that the upgraded plant was operating well within a few weeks after commissioning. His interpretation of 'knowledge' was experience and know-how. Training had addressed the latter; the former would come about through years of operating. A Foodco supervisor gave an example that illustrated a lack of assimilation: the quality of French fries varied somewhat depending on the condition of the raw potatoes (some customers only accepted potatoes with a 21% starch content, to prevent excessive browning and to permit uniform crispiness when fried), how recently they had been dug, how long they had been in storage, and so on. Supervisors were required to change parameters such as temperature set points and washer speed controllers, since operators could only operate the line under a given set of conditions, and were unable to take account of unforeseen events.

Understanding of hardware and software
Generally software was poorly understood, but technicians could change operating parameters. Technicians were better able to deal with hardware failures, although some respondents felt technicians used no more than trial and error in fault diagnosis and repair.

Codification and documentation of knowledge
Respondents were generally satisfied that suppliers had provided reasonable drawings and documentation. On some occasions insufficient detail had been given, but it emerged that most operators had never read the operations manuals. A supervisor at Waterco criticised the consulting engineers for not ensuring more thorough explanations of how the system operated. Waterco staff had made some attempt at writing training manuals, but respondents felt that the level of detail was superficial.

Failure data from supplier
Suppliers had recommended maintenance tasks, but they provided no supporting failure data.

- ***Level 4: Supply chain***

Supplier networks and local infrastructure
Supplier networks had not been established. Respondents felt that relationships with suppliers were good. Local representatives were mainly used for supplying spares and as points of contact with foreign suppliers.

Trust between user and supplier
Respondents were satisfied with their technology suppliers. A respondent at Foodco questioned the price of spares, and felt that suppliers used a captive market situation to charge excessively for spares. As a result, the factory's engineering staff were attempting to manufacture some parts themselves, or were negotiating with local engineering firms to manufacture these. One difficulty was the specialised material used for certain components. The supplier had not been helpful in explaining why titanium was used for certain pump impellers, so the factory was attempting to source cheaper stainless steel impellers, even if their productive life was shorter.

Long-term dependence on supplier
All supervisors envisaged a long-term relationship with suppliers as the lack of know-how within their organisations meant that they would be dependent on suppliers for significant changes in the control systems, and for spares and maintenance. At Plastico discussions were taking place to establish a formal maintenance agreement with suppliers.

Procedures for problem solving
No procedures had formally been established for problem solving. At Flourco the self-diagnosis mechanism within the control system assisted to some extent. In certain circumstances it was possible to override the controls and continue with manual production, although this was discouraged. Technicians frequently had to contact suppliers for assistance in problem solving. Operators at Plastico and Foodco were able to revert to manual systems if necessary, but supervisors claimed that quality problems were invariably encountered.

- ***Level 4: Operational***

Lack of labour commitment and productivity/ability to take responsibility

These were controversial issues. The supervisor at Flourco commented that there had been a tendency since the introduction of the control system for operators and maintainers not to accept responsibility for failures and blame the control system. He attributed this to their poor understanding of the control system.

At Waterco managers and engineers were still white; supervisors and maintenance technicians were black and white; operators were predominantly black. Managers had complained about a lack of labour commitment and low productivity, ascribing this to a poorly educated workforce, lacking in the most basic understanding of operating a process plant, and unconcerned if the process stopped. Black supervisors commented that the company was still run as an 'apartheid company with a civil service mentality', and a top-down management style prevailed with little participative management. Training in how to operate the plant was adequate, but no personal development took place. Some staff had been in their current positions for 20 years, had never attended a training course, and saw few prospects for change.

The supervisor at Plastico felt operators were committed, but he expressed concern that jobs had become more routine and deskilled. Even if this were not verbalised, a lower calibre operator could take over, and would not be in a position to take responsible decisions when required.

Operators at Foodco did not believe that commitment and the ability to accept responsibility had changed since the new line was installed. The supervisor said that worker attitudes were 'neutral': workers were paid to work, they worked as required, but received no reward for anything extra. He claimed this was a hangover from apartheid times, when 'blacks were not expected to think', and their perspective had not changed.

Empowerment

This did not receive much attention at Flourco and Plastico. The supervisor at Flourco complained of a general lack of delegation. The Plastico factory had been expanded in other areas (apart from cling film), so there were promotions and movement to other jobs. Managers had recognised that longer-term affirmative action issues would arise.

At Waterco plans for the development of some staff had been agreed between managers and trade unions. This was in terms of government affirmative action requirements. Managers claimed they could not promote individuals to technically challenging positions merely on the basis of race. Unions had responded that because there was so little development of employees, blacks could not rise in the organisation. They were wary of promises of empowerment as the management culture would invariably mean that white managers would continue to preside over all significant decision-making. Several respondents recalled that the IQ of one manager was lower than that of most of his subordinates. It was not possible to verify this, but the frequency with which this was recounted showed a lack of trust and respect for some managers.

Cost of training and developing the local workforce

Training at Flourco had been budgeted for when considering the new control system. Newly recruited technicians had to undergo further training with the supplier and this had not been budgeted for. Managers at Waterco claimed that their training budget was limited, and that the cost of sending young staff to technical colleges to study water technology consumed much of the budget. Further, the company was not in a position to provide general education, literary and numeracy skills to workers to compensate for poor state schooling. Plastico's training had been limited to explanations of changes in the operation of the process. As an operator's job had effectively been simplified, the training process had been smooth. Maintenance training was on-going, but not systematic. The company recognised that it had a broader role to develop the workforce, but financial pressures meant that the training budget was limited. Because the business had been expanded, workers were less demanding, but managers realised that earlier commitments to staff development would have to be addressed. At Foodco the cost of on-the-job training was not easy to quantify. There had been complaints that the company did not offer sufficient developmental training, but managers indicated that their training budget was limited due to the tremendous pressures to reduce operating costs to remain competitive.

Transfer of physical equipment, systems, managerial philosophy and values
All cases had used the introduction of new technology to change some managerial systems. This took the form of revised processes of reporting items such as downtime and quality problems, and reasons therefor. Managers had also tried to inculcate a new 'lean' and quality culture to ensure fastidious attention to quality. Attempts were also being made to understand and quantify the broad operational effects of failure at Plastico and Foodco.

- ***Level 4: Contractual***

Technical documentation and drawings
There was overall satisfaction with suppliers' technical documentation and drawings. Because of the age of much of the equipment at Flourco, documentation and drawings of existing equipment were not available. Much time was spent tracing cables, and determining performance standards and settings for machines before contact documents could be drawn up. Documentation from the control system supplier was generally satisfactory, although there were complaints that some documentation was in German. Respondents at Waterco were satisfied that equipment had been installed and commissioned, but found that supporting documentation and drawings were not satisfactory. In particular electrical wiring diagrams did not reflect current installations, and did not show how or where upgraded systems were configured.

Post-installation back-up and support
Respondents were satisfied with this.

- ***Level 4: Maintenance***

Availability and reliability of equipment
At Flourco inadequate knowledge of how the new control system operated resulted in low availability once the technology supplier had left the site. In order to keep production going, maintenance staff learnt how to by-pass steps in the automated process. This temporarily improved availability, but defeated the aim of the new technology. Nearly two years after having introduced the new system, equipment availability and reliability had still not achieved the levels hoped for by management, although overall output and quality had improved. While the supervisor claimed that the random failure of control systems meant that little preventive maintenance could be applied, managers pressed for more maintenance to improve reliability.

Some attempts were made at preventive maintenance at Waterco, but frequently more pressing activities meant that preventive tasks were not carried out, effectively resulting in breakdown maintenance. While details of plant stoppages were noted, data was not analysed, and availability not measured. Because of large water storage facilities, breakdowns did not have immediate operational consequences. One supervisor commented that this resulted in shoddy maintenance, and staff were unaware of the financial implications of water interruptions to customers.

At Plastico the technologies had generally been reliable. When failures occurred, it was possible to revert to manual operation, so production was not immediately affected. This relieved the pressure on maintenance staff to repair failures. Others commented that manual operation was unacceptable for a long period as poor quality inevitably resulted. Technicians usually contacted suppliers for advice, but frequently suppliers' local representatives could not solve the problem.

The supervisor at Foodco commented on the pressure placed on the maintenance function to ensure plant availability. However, plant capacity was considerably greater than demand (he was unable to quantify this), and noted that on many occasions each week the line was idle because all orders had been fulfilled. He therefore questioned the need to undertake some of the preventive maintenance recommended by suppliers.

- ***Level 4: Integration of technology***

Training by suppliers in using new technology

Suppliers to Flourco had provided familiarisation training for operators and maintainers, and more detailed training for technicians, but a high turnover of technicians meant that not all had worked with the supplier. Plastico suppliers had worked with factory staff during installation and commissioning to ensure, as best they could, that factory staff could operate and maintain the technologies once the suppliers had left. Supervisor felt this rather loose approach to training was not satisfactory. Suppliers to Foodco had provided adequate training, but it was not easy to offer maintenance training on new equipment, so maintenance teams learnt as failures occurred.

Shortages of suitably qualified and experienced staff

This was a major problem in all cases, with shortages of instrumentation technicians being particularly acute. At Flourco technical skills by themselves were insufficient as maintainers also required knowledge of the milling process. It had proved impossible to find such individuals, and in any event the technical expertise of many technicians had been poor. Waterco experienced difficulties in attracting qualified staff to the plant's remote location, particularly as salaries were considerably below market rates. Unemployment in the area was high so there was no shortage of unskilled labour, but poor education meant that few locals were suitable for developing further. Plastico suffered from its inability to attract and retain suitably qualified staff. To remedy this, technicians were offered training and attended technical colleges. Despite contractual agreements obliging them to work for the company after completion of their studies, many technicians found higher paying jobs elsewhere.

Installation and commissioning of new systems

At Flourco and Waterco consulting engineering firms were used to write contract documentation, advise on evaluation of supplier quotations, and assist head office project teams with installation and commissioning. Mill staff were involved with commissioning, partly because they were in the best position to assist in interfacing with existing equipment, and to learn the operation of the new system. Waterco had allocated a number of head office staff to the project. A supervisor complained that operating staff were only involved at a late stage, and that they did not benefit as much as they could have from the suppliers' expertise during installation and commissioning.

- ***Level 4: Maintenance planning***

Cost effectiveness of proactive maintenance

The supervisor at Flourco felt that the failure of electronic components in the new control system could not be predicted. It was therefore not possible to schedule proactive maintenance. Cost effectiveness was therefore not considered. Little maintenance planning took place at Waterco and there was no evidence of establishing the cost effectiveness of proactive maintenance. At Plastico proactive maintenance was not considered appropriate on the electrical/electronic side of the new equipment. The intention was to subject mechanical components in the screen changer to preventive maintenance, although some respondents had reservations about the effectiveness of this. Maintenance at Foodco was planned in accordance with supplier recommendations. Respondents were not aware if cost effectiveness calculations were performed.

Problems of 'burn-in' with new equipment and systems

Serious problems were encountered with 'burn-in' of new systems. Flourco experienced significant downtime after the system had been installed. Respondents suggested numerous reasons for this. Performance standards of existing machines had not been correctly ascertained, so response times were inaccurate. Before the new system was installed, running up the mill to a steady-state operation could take up to an hour, but the sensitivity of new controls over-compensated for start-up instability. The supervisor claimed that the burn-in with the new system was more than 'teething problems'. He felt that insufficient preparatory work had been done in ensuring adequate integration with the existing machines.

Waterco encountered difficulties during commissioning, especially as a result of many design deficiencies. A lack of operator know-how also contributed to many failures. As design problems were solved (although some were on-going), and operators and maintenance staff became more familiar with the process, respondents claimed that availability and reliability had increased, even though these were not specifically measured.

Suppliers had been present or readily available for several weeks after installation of the new technologies at Plastico. This reduced the effect of 'burn-in' somewhat, but managers reported that it had taken longer than expected to obtain the desired higher production and quality levels. Frequent failures and system instability severely lowered production output for extended periods.

Failures had occurred shortly after installation of the new line at Foodco. This was partly because of operators' unfamiliarity with the new line, and partly attributable to suppliers' not having balanced the line correctly. Bottlenecks occurred unnecessarily, there was insufficient water for washing and cooling, and electrical supplies were inadequate during start-up.

- ***Level 4: Financial***

Quantification of hidden costs of technology

Respondents had anticipated some unexpected costs, but these were higher than expected, although they had not been quantified. Flourco had budgeted for training and the cost of a supplier representative on site during initial operations. No quantification had been made of the cost of subsequent training of technicians and the costs incurred in requiring the supplier to modify programmes, but this was substantial. Waterco had not initially recognised the hidden costs of technology. Respondents were aware of wastages, say, when incorrect quantities of chemicals had been added, and such solutions had then to be dispensed with. None of these had been quantified.

On several occasions customers had been paid penalties because of interruption of their water supply, but these costs had not been communicated to operating staff.

Plastico had not foreseen the extent of hidden costs. The possibility of maintenance contracts with suppliers had not been budgeted for. The company had not calculated the cost of higher rates of rework as a result of inconsistent quality arising from bubble instability during screen changes. Respondents at Foodco suggested that hidden costs were significant. Many tons of partially manufactured fries had been disposed of when the line was not functioning correctly. Foodco had been obliged to pay penalties for late deliveries.

- ***Level 4: Resistance to change***

Resistance to change

No resistance to change was encountered, apart from some redundancies. The supervisor at Plastico illustrated one instance of defiance when operators refused to use the live SPC display for quality determination. The computer screens showing the SPC display were in the supervisor's office, and some operators were reluctant to enter his office to view the screens because they felt this was a way for the supervisor to check on them. The reason for installing the screens in the supervisor's office was that a clean, cool environment was required. To overcome the operators' concerns an internal window in the partition between the supervisor's office and the factory floor was installed to give operators an adequate view of the screens. The supervisor suggested that this resulted in behavioural change (operators viewing the screens), but attitudes remained somewhat hostile.

8. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 4 ELEMENTS

The following paragraphs discuss Level 4 elements of the model.

- ***Level 4: Important aspects for suppliers involved in management and implementation of TT***

Suppliers were not interviewed, but several respondents in the case organisations suggested that the most important aspect of management and implementation of new technology from a supplier perspective was technical interface management. The perception at Flourco was that the supplier had taken a ready, 'off-the-shelf' system and attempted to install this without adequately taking the existing equipment into account. For example, motorised control valves had replaced valves that had been operated manually. The valve response time during normal operation was programmed into the control system, but the system did not allow for run-up and shutdown times of mills, creating instability and trips during start-up and shutdowns.

Waterco respondents felt that suppliers should ensure greater involvement with operating staff. Communication was invariably between the supplier, the consulting engineer and the head office. While this may have been appropriate for contractual matters, operational issues should be discussed with local plant staff. This would have resulted in early identification of design deficiencies of which head office engineers were not aware.

Respondents at Plastico suggested that suppliers should provide more documentation and training. A supervisor at Foodco regretted that suppliers had not quantified what services were required for the line, and as a result expensive modifications to the provision of services had been necessary. Examples were given that the new line required more water than was available, and direct-on-line starting of electric motors caused significant system voltage drops on electrical distribution boards.

- ***Level 4: Importance for personnel training and other HR issues***

Training was an essential part of implementation. Subsequent difficulties arose because maintenance technicians were not fully competent or familiar with the milling process. Since operators' tasks at Plastico were simplified, operator training had been sufficient. However, the issue of deskilling would have to be addressed in the future as it was not sensible to employ skilled operators for doing less demanding work. Although Foodco managers had communicated with staff regarding the changes at the factory, some respondents felt that redundancy should have been addressed long before the new line was commissioned. This would have avoided much resistance, at the time when the commitment of operators was most required.

- ***Level 4: Importance for selecting alternatives for TT***

Not many technology alternatives were available to the case organisations. In all cases the processes were dictated by product requirements, and improvements were to be achieved by fairly standardised technology.

- ***Level 4: Identification of criteria for better adaptation of new technology***

Respondents had not found it necessary to adapt the new technology at Flourco and Plastico. A Waterco supervisor claimed that greater contact with operating staff would have increased the diffusion of new process know-how and reduced interfacing difficulties. An example was given where the pipes delivering the output of one part of the process were metric whereas the old pipes connected to the reticulation system were imperial. In another instance considerable civil work was required for new plinths and knocking down walls. These could have been avoided if a more detailed investigation of the existing situation had been carried out. Suppliers at Foodco had evidently complained that the line was non-standard in that tasks done mechanically in other countries were done manually in South Africa. Respondents did not believe that this had required adaptation of the technology in any way.

9. SUMMARIES OF INTERVIEWS IN RELATION TO TECHNOLOGY TRANSFER ITEMS AT LEVEL 5

The following paragraphs discuss the Level 5 items in Appendix V. Level 5 refers to middle management, supervisors, and operating and maintenance staff.

- ***Level 5: Knowledge***

Understanding failure modes and effects

Most Flourco operators and maintenance staff with many years' experience claimed to understand the failure modes and effects on the old equipment. The new challenge was to understand the failure modes of the new control system. As these were invariably 'computer' or 'electronic' failures, few staff understood them.

Staff at Waterco lacked theoretical knowledge of the purification process, so did not understand all functions and failures of the upgraded plant. Where suppliers had provided maintenance recommendations, these were invariably at component or machine (failure mode) level, but effects were not explained, and respondents did not specifically take these into consideration when determining maintenance.

Because Plastico's technicians did not fully understand the functionality of the systems, they were unable to suggest possible failure modes. The effects of failures were usually the same: the screen failed to change automatically, or quality criteria were not displayed. Respondents claimed that the new technologies were complex and there were hundreds of failure modes, many of which were embedded in electronics. Mechanical failure modes were easier to identify. To counter for a lack of understanding of failures and effects at Foodco, maintenance programmes followed suppliers' recommended maintenance.

Understanding impact of maintenance/failure on overall process
Failures now tended to have considerably greater long-term effects than in the past. The largely manual operation of machines at Flourco prior to the installation of the new system meant that failures could be isolated to relatively small parts of the plant. The integrated nature of the new control system had a major impact on production, and frequently stopped the entire process. The control system was by-passed when technicians were unable to repair failures.

Suppliers' recommendations did not take the broader operating context into account at Waterco and had not considered the effect of failures on the overall process. One fitter commented that maintenance on equipment was specified irrespective of whether stand-by plant was available, or whether the failure had a direct effect on operational capability.

The failure of Plastico's quality monitoring system had no direct effect on operations, since production could continue. Operators would have to check film thicknesses manually as they had done in the past. The failure of the screen changer did affect production as the process had to stop for an hour for manual screen changing. Quality problems and bubble instability were common effects often leading to loss of production.

A Foodco operator suggested the overall impact of failure was not as serious as some managers made out because of surplus productive capacity. He recognised that failures during periods of peak production were problematic, but these did not occur as often as managers suggested.

- ***Level 5: Maintenance***

Safety assurance through maintenance
There was little change in the relationship between safety and maintenance after installation of the new technologies.

Appropriate maintenance policies (intervals and tasks)
Most mechanical maintenance at Flourco was not affected by the new system. New motorised control valves required a different approach to maintenance, but at this stage their maintenance was according to the valve suppliers' recommendations. Maintenance staff felt the recommended maintenance was excessive, but were obliged to follow this for warranty reasons. Maintenance at Waterco was planned to take place at specified intervals. Respondents did not know how these intervals were arrived at. Some felt that too much maintenance was scheduled, and were vindicated by the fact that much of it was not carried out. Most electrical/electronic failures at Plastico were random failures that were not preceded by any warnings or potential failures so it was not possible to determine how often any such maintenance should be carried out.

Maintenance at Foodco was done in accordance with suppliers' recommendations. Some respondents felt this was excessive, and that items were unnecessarily replaced. Already some intervals had been lengthened, although this had not been reported to management. One craftsman commented that as they gained experience, they would amend maintenance tasks, because many appeared unnecessary. Foodco's preventive maintenance programme was directed at mechanical moving parts, or those items in constant contact with the product, such as knives. The supplier's recommendations were generally followed. Because the cut of the knives was so important, they were inspected several times each day, but this was an intrusive process that stopped the line. A supervisor, recognising that a clean cut indicated a satisfactory knife, also noted that after the first indication of a slightly rough but still acceptable cut, the knife was suitable for use for several days. Following the logic of Figure 3.8, several daily inspections were unnecessary, and could satisfactorily have been replaced by a daily inspection, or better still, by closer inspection of product cuts.

Failure data generated internally
Provision existed in all cases for recording maintenance performed in accordance with jobcard procedures, but there was little evidence that maintenance was subsequently based on the data gathered from jobcards.

10. SUMMARIES OF INTERVIEWS IN RELATION TO LEVEL 5 ELEMENTS

The following paragraphs discuss Level 5 in the Salami and Reavill model.

- ***Level 5: Criteria for evaluating performance based on suppliers' goals***

Suppliers' goals could not be established because they were not interviewed. They had provided performance guarantees, and staff were generally satisfied that these had been delivered. Less tangible issues, such as availability and cost of spares were also important in evaluating suppliers' performance from a customer perspective.

- ***Level 5: Guidelines for modification of new technology***

No significant modifications were envisaged.

- ***Level 5: Evaluating success and failure of new technology in the future***

The technology at Flourco was generally deemed to be successful. Operators viewed the level of automation as excessive, but managers felt that it was appropriate. The new process at Waterco would be considered successful if it met contractually stipulated standards, but respondents felt that a longer-term perspective was necessary. At Plastico success of the technologies was measured in terms of production output and quality criteria. Managers were generally satisfied, but recognised that further refinements would be required to meet changes in product demand and quality standards. Respondents at Foodco were generally satisfied that the new line was performing in terms of quality and output expectations, and they did not envisage any new requirements from the technology in the foreseeable future.

- ***Level 5: Introduction of innovative programmes through R&D to develop new technology***

Respondents indicated that innovation would be not sought through internal R&D. At Foodco factory staff were informally experimenting with ways of improving performance particularly in response to raw material quality fluctuations. This would not result in the development of new technology, but should permit better use of the flexibility offered by the technology.