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Informal dissemination scenarios and the effectiveness of evacuation warning dissemination of households – A Simulation study

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Abstract

Timely warning of the public during large scale emergencies is essential to ensure safety and save lives. This ongoing study proposes an agent-based simulation model to simulate the warning message dissemination among the public considering both official channels and unofficial channels The proposed model was developed in NetLogo software for a hypothetical area, and requires input parameters such as effectiveness of each official source (%), estimated time to begin informing others, estimated time to inform others and estimated percentage of people (who do not relay the message). This paper demonstrates a means of factoring the behaviour of the public as informants into estimating the effectiveness of warning dissemination during large scale emergencies. The model provides a tool for the practitioner to test the potential impact of the informal channels on the overall warning time and sensitivity of the modelling parameters. The tool would help the practitioners to persuade evacuees to disseminate the warning message informing others similar to the 'Run to thy neighbour campaign conducted by the Red cross.

Keywords: Agent-based model; Mass emergency warning dissemination; Simulation model for warning dissemination; NetLogo; Evacuation warning;

1. Introduction

Effective warning during the large-scale emergency situation is essential for saving lives, by ensuring that the maximum proportion of population are well-informed about the threat. Even though there were more severe hurricanes in the Caribbean regions than in Haiti Island in 2004, the death toll was lower in the Caribbean regions, partly due to the community based warning system apart from official warnings [1]. This present study would discuss various warning channels used during emergency and also demonstrate a means of obtaining an estimate of the effectiveness.

Warning message dissemination is achieved through both ‘formal systems’ (from official warning through TV, radio, telephone, sirens and door-to-door knocking) and ‘informal systems’ (personal notification from neighbours,

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friends). The National Steering Committee on Public Warning and Information, UK [2] has classified the official warning systems into *audible systems* (e.g. sirens, tannoys, route alert), *telecommunication systems* (automated caller systems, emergency phone diallers, bulk messaging service), *mass communication systems* (broadcasting through television, radio and ham-radios) and *verbal information* (door-to-door knocking by officials). In literature various names are used to refer the warning message dissemination with the public as '*informants*', like "unofficial system" [3], "informal system" [4], "people-to-people" [1], "folk and personal system" [5].

During the warning dissemination planning stage the policy makers adopt scenario based approach to set operational targets. For example the 'Shearon Harris Nuclear plant' board decided a policy to notify 100% of the population within 5 miles surrounding the plan area within 15 minutes [6]. The policy maker responsible for warning and informing the public has to choose the best available option during the event.

Moreover, community involvement in the dissemination of warning message or evacuation notifications, along with other official sources, would increase the credibility of information [3], leading to favourable response from the public. Using the public as 'informants' would depend on their behavioural traits [7], which will inform their willingness to disseminate such information. The effectiveness of a warning channel is defined as the proportion of the households that receive the warning message within a specified duration from that channel. As individual warning channels have their own effectiveness and reliability, a warning system with multiple channels (official and unofficial) needs a comprehensive analysis to determine the overall system effectiveness.

This paper will present a tool to evaluate the effectiveness of warning systems when the public is used as an informal source to transmit the warning. The paper begins by reviewing previous studies about the various aspects of warning message dissemination, including principles of emergency communication, behavioural influences on the spread of the message and ways to model this behaviour. Then, the proposed model development is presented and illustrated with different warning dissemination policies. Finally, results are discussed, as is the scope for further research.

2. Review of Literature

A study on the effectiveness of warning message dissemination system would involve various areas of research like principles of emergency communication planning, social communication networks, modelling and simulation tools. This section describes previous studies in each of these areas, particularly related to the effectiveness of large scale emergency warning system, and identifies the gaps for potential study and improvement. The literature related to the role of evacuee behaviour as informants is presented along with the approach of modelling the same using agent-based modelling technique.

2.1. Principles of emergency communication planning

An effective disaster planning should consider both technical and social dimensions of the problem [8]. When planning the warning systems, there is a need for considering human factors in receiving the message [9]. The human or social component is more important than the technological component of a warning system [10]. Designing a warning system requires the choice of message format, timing of informing the public and delivery of the message. The issues pertaining to flood warning system can be classified [11] as 'micro-issues' (design of message format, psychological and demographic factors) and 'macro-issues' (system design, community engagement, risk group identification). In order to maximise the lives saved during disasters, the warning message must be timely, clear [9, 12], intelligible to public [13, 14], in a non-technical language [15], have details relevant to local area [9], designed for a specific disaster [14, 15] and suggest expected actions [11].

Apart from the message format, the delivery of warning message depends on the warning channel used. Each warning channel has various features, namely effectiveness of dissemination, reliability, credibility and availability [2]. The effectiveness of the channel such as TV or radio is variable depending on the time of the day due to variation in the viewership [4]. Some of the audible systems (e.g. route alert using handheld sirens, official door knocking) require personnel for operating each unit, which might be a limiting resource during emergency.

A satellite-based emergency alert system was proposed [16] for reducing the response rates to less than a few minutes with high dissemination rate of sending message to the public. However, some of the telecommunication systems (TV, telephone network) might get disrupted and not available during emergency. The choices available to the policy maker (who is responsible for warning message dissemination) are limited by various factors such as the availability of technology, personnel for door-to-door knocking and time of the day.

2.2. Public behaviour during emergency and social communication networks

In order to use the public as informants of warning message, it is essential to understand their behaviour during emergencies. There are widespread misconceptions that: public panic on receiving warning message [9, 17], behave as victims, highly dependent on officials resources and are helpless [9, 13]. There are various studies refuting such views, which also caution for developing emergency plans with these assumptions [4, 9, 13, 17, 18].

Parker and Handmer [3] addressed the importance of unofficial communication (including personal network and direct observation) during floods. The personal networks (friends, neighbours and relatives) are used to share and interpret the message, increasing the understanding of the contents, aiding in the informed decision making. A survey conducted by the US ‘Centre for Disease Control’, found that about 40% of the respondents to the survey received emergency message from informal channels – friend or relative, either in person, or through telephone [6]. Another study conducted by Sorensen [4] specified that informal notification among the public plays an important role in warning dissemination in most emergencies. A tsunami warning study in Mauritius showed that about 15.4% public received face-to-face warning [19]. In this study, the significance of face-to-face communication was third behind TV and radio. Another study [20] reported the results of questionnaire survey among the residents of Scottish flood plain region to understand the social impacts of flooding. The study found that, among the surveyed households, 32% received the warning message from neighbours and about 51% of the flooded households actually received the message from official channels. The empirical evidence shows the significance of informal communication channel, and also the possibility of significant proportion (about 49% in this case) of residents not receiving timely information from official sources.

The role of youth and children, as potential informants within emergency communication network is highly underestimated [21] and not directly accounted in the theoretical models of risk communication. This study [21] investigated the community initiatives in El Salvador and New Orleans, and demonstrated the possibility of using youth and children as trusted informants. The children and youth were imparted training in school clubs, and found to posses high understanding of local risk, communicate warning message and even state the actions for reducing risks.

Not all the families or individuals respond in the same way during emergencies [7], which leads to uncertainty in the behaviour of the public as potential informants. Moreover, as each individual takes different time period to assimilate (receive, understand and react) the warning message, there is a possibility of longer time taken for disseminating to public when solely relied on informal communication [10]. The reliability of a warning system is likely to be increased when there are multiple channels of communication, rather than relaying on a single channel. These studies corroborate the observation of rational and active community behaviour, and also that the public could be potential informants for disseminating emergency message. The behaviour of public as informal channel needs to be modelled along with the official channels.

2.3. Agent Based Modelling and Simulation (ABMS)

Agent based simulation is defined as a technique used to model the human social and organisational behaviour to study the social interactions, group behaviour [22]. Agents are defined as a basic unit/component capable of making independent decisions based on the specified behavioural rules [22, 27]. These rules could vary from just simple reactive decision rules to complex adaptive intelligence. Agents have various features like uniquely identifiable, location, goal-directed, autonomous and adaptive learning. In general agents are developed using object oriented programming languages like Java or C++.

The concept of ABMS finds its origin into the theory of segregation proposed by Thomas Schelling [23, 24]. Schelling's work looked at explaining the emergent behaviour of segregation of the ethnic communities due to individual preference on their neighbourhood. This study showed a means of explaining the collective macro behaviour based on individual (or micro) behaviour of the public. Agent-based Modelling is highly suitable for modelling inter-dependencies among various classes of agents with respective behaviour [22]. Agent-based modelling and simulation (ABMS) has applications in wide areas [24] like epidemiological modelling (e.g. the spreading of diseases), economics, military applications (e.g. war-game simulation), supply chain management, ecological networks, biological systems, (e.g. Bird flocking system), social and behaviour systems.

The information transmission through human informants was studied using simulation model based on the principle of rumour propagation [25]. The study focused on developing models for understanding information distortion. Another study proposed an agent based simulation model [26] for the warning message diffusion among community members. This study adopted concept of trust as behavioural factor for diffusion of warning message. They identified the need for studying effect of multiple sources along with informal communication to determine overall effectiveness. When there are multiple sources of warning message communications, simultaneously functioning with varied efficiency, the information reaching each household unit is not deterministic but uncertain. This uncertainty has not been explicitly modelled in previous studies.

Sorensen [4] in the study on modelling warning dissemination has accounted for dissemination time via different channels (Sirens, tone-alert, telephone, media). The study also specified that time spent by people to respond to warning is an S-shaped curve and also depends on the perceived threat. Family size, community involvement and number of channels are important among the 32 factors identified in this study.

When a household receives a consistent message from various sources, the credibility of message is increased, leading to favourable response to the message. At a macro level, for the community or the city, the metrics would involve observing the time series of proportion of area (or house hold units) covered. Drawing parallels to the rumour model [28], the metrics like expected coverage rate, probability of receiving message from a particular source, etc would also be appropriate to measure efficiency of mass communication through multiple sources. Applying ABMS to warning message simulation would involve specifying behaviour of agents (individual households) as informants along with formal communication channels (as hidden agents).

The trust due to relationship between the sender and receiver of the warning message would influence the dissemination of the message through informal channels. Another study [26] developed a model for the dissemination of warning message through informal channel with the concept of trust between two groups. This study has proposed an agent based simulation model for dissemination of warning message by factoring the behaviour of the public using four axioms.

Apart from designing the emergency message format (including the wordings), the policy maker for warning and informing is also bound to select various communication channels for dissemination of the message. The competent authority is also responsible for arriving at reasonable time estimate between the time to initiate the warning message and expecting pre-mediated response from the public [10]. A review of warning system identified that, officials are slow in making decision [4]. The underlying reason could be the inability to integrate and quantify the effects of operational policy decisions on the effectiveness of warning system. This entails a need for developing a tool to aid decision makers.

In summary the emergency managers apart from designing the warning message content to be timely and actionable to the recipient, the delivery of the warning message through official channels would depend on the effectiveness of the official channel. In the literature review it was found that the role of the public as potential informants has been highlighted in the Hurricane Katrina, post evacuation survey conducted in Scottish flood plain [20] and also the recent London suburban fire [31] where 300 people self-evacuated in the midnight by helping each other spontaneously. The objective of this ongoing study is to develop a tool that could help EMAs to estimate overall warning time by incorporating the availability of official warning channels along with the role of unofficial channels at the planning stage. The evacuee behaviour is modelled as 'Agents' in the ABMS and the model development has been elaborated in the following section.

3. Model Development

This paper illustrates the development of an agent based model to estimate the effectiveness of warning message dissemination considering the unofficial warning channel along with the official channel. The proposed model is implemented in 'Agent based simulation' software called NetLogo and illustrated with a hypothetical community of 1000 households. The unit of analysis is individual house which is modelled as agents in the model. Each agent has attributes like identification number, media channels available (for example TV, Radio, etc), defaulter variable (are they willing to communicate the message?) and state variable (informed, uninformed, disbelief). The level of analysis in the proposed model is for the whole city. The proposed model adopts an axiomatic approach to account for the behaviour of the public in disseminating the warning message.

There are four axioms proposed by Hiu [26], namely, information loss axiom, source union axiom, value min-max axiom and threshold utility axiom. '*Information Loss axiom'* states that the information value of the message is non-increasing and is a function of social relationship between sender and receiver. '*Source union axiom'* explains by a procedure to update the information value from the same source. This ensures that, the messages from the same source are accounted only once. '*Value min-max axiom*' gives a method for determining the information value when the message is received from multiple sources. '*Threshold utility axiom'* defines a procedure for ascertaining the state of a particular household based on the combined information value and threshold value. These axioms enable a means of factoring the behavioural aspects of the public as informants of the warning message.

Each household unit (agent) has an attribute called state variable indicating the status of warning message. This state variable has different possible values namely uninformed, informed, disbelieved and defaulter. Figure – 1 elaborated form of the figure in [30] is a flow chart showing various states of the public from receiving warning message to response. When the public receive the warning message they move from 'uninformed' to 'informed'. The public would require some time between receiving the warning message and responding, for the assimilation of the message content and understanding the same. This time henceforth called as assimilation time. After the lapse of assimilation time, the public could move into either the 'disbelief' state leading to no-action or 'believed'. The warning message would request for the public to relay the message to neighbours and friends [1]. Some proportion of the public may not be informants in disseminating the message to the neighbours. This behaviour could be due to perceived urgency for self, leading to immediate evacuation and hence not warning the neighbours. These households are categorised as ‘defaulters’.

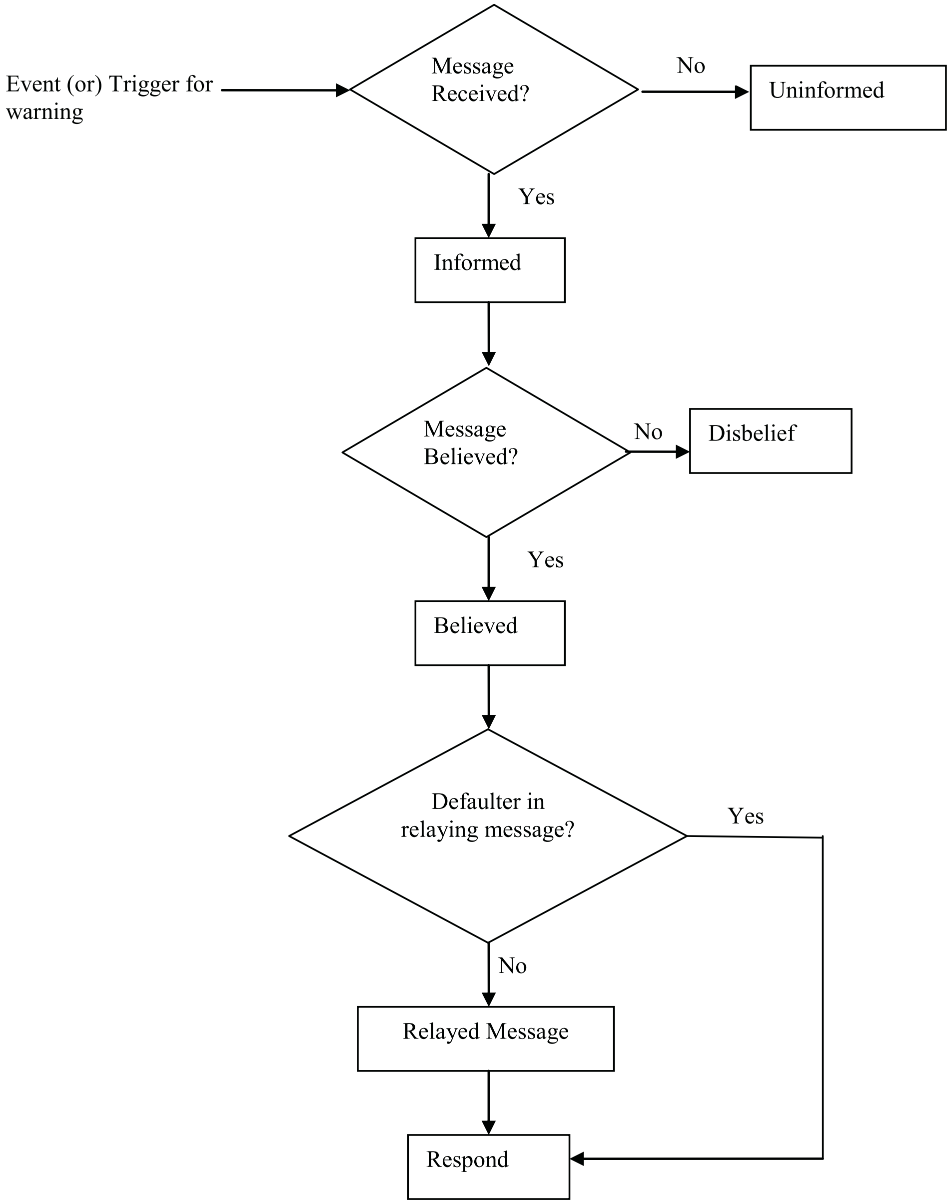

Figure 1. Flow chart showing various states of the public in receiving the warning message to response.

The NetLogo model is provided with effectiveness values of various sources in percentage. The proportion of defaulter houses would be an input into the model. Before the model starts disseminating the message, the defaulter houses are randomly selected to the specified proportion. The defaulter state is indicated as an attribute at the individual household level. The initial warning message is selected randomly based on the effectiveness of each channel. The assimilation time is the time from receiving the message to the state of understanding and confirming the message, is an input to the model based on the estimate from experts. After a time delay equal to the assimilation time, the household would inform the neighbours. The time taken to inform the neighbour is taken as five minutes as adopted by [29]. On informing the neighbour and reaching the believed state, the household is said to be at the state of ready to respond.

The proportion of defaulters and the effectiveness of the official warning channel are independent variables for the proposed model represented in percentages. The behaviour of evacuees in informing the neighbours is represented using the scenarios (table – 1) based on number of neighbours informed. The assimilation time and time to inform the neighbour are household level parameters provided at the initial setup stage. These estimates are provided by a panel of international experts who belong to the advisory board of European commission funded project ERGO: Evacuation responsiveness by Government Organisations (http://www.ergo-aston.eu/). The ERGO project identifies how the government use analytical models for mass evacuation preparedness and also how the government prepare the public for the same.

The outputs of the model are time series of warning dissemination, level of warning and the equilibrium time (defined as the time at which there is no further increase in the level of warning for the hypothetical area). Each household in the hypothetical area would move from ‘uninformed’ state to ‘informed’ state as described in figure – 1 depending on the initial setup of the model. This forms the basis for the development of the proposed agent based simulation model by having both formal channels and representing the informal channels using axioms [26]. These output variables are computed by the NetLogo model based on the dependent variables and parameters chosen at the setup stage. Figure – 2 shows the snapshot of the developed NetLogo model.

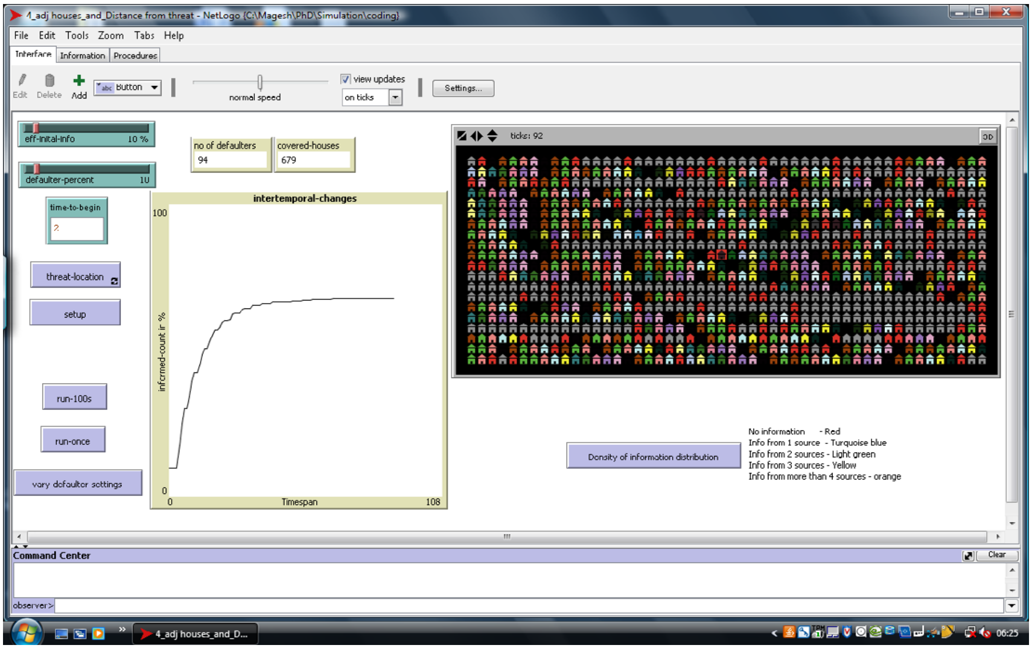

Figure 2. Screenshot of the NetLogo simulation model.

The public's response to the warning message is influence by their perception about their threat. The threat perception is also influenced by the distance or proximity of the threat from the public particularly when the threat has epicentre [4]. This would influence the assimilation time of the public. When the threat has an epicentre, for example a dirty bomb blast or a nuclear release from the plant, the public closer to the incident may perceive a higher threat, hence could take less time to assimilate the warning message and respond quickly. The public farther from the epicentre are perhaps more likely to have lower threat perception leading to longer time for responding to the evacuation warning message. This study assumes that the relationship between distance and threat factor is exponential distribution. The present study has proposed a new axiom, '*threat proximity factor axiom*' to reflect the effect of threat epicentre location on the dissemination and assimilation of warning message by the public. This factor is given by the following relationship

$$TPF = e^{f.d} \tag{1}$$

$$Corrected\ Assimilation\ time = Assimilation\ time * TPF$$

Where,

TPF = threat perception factor (no units)
f = unit distance factor (in miles^{-1})
d = distance from the threat (miles)

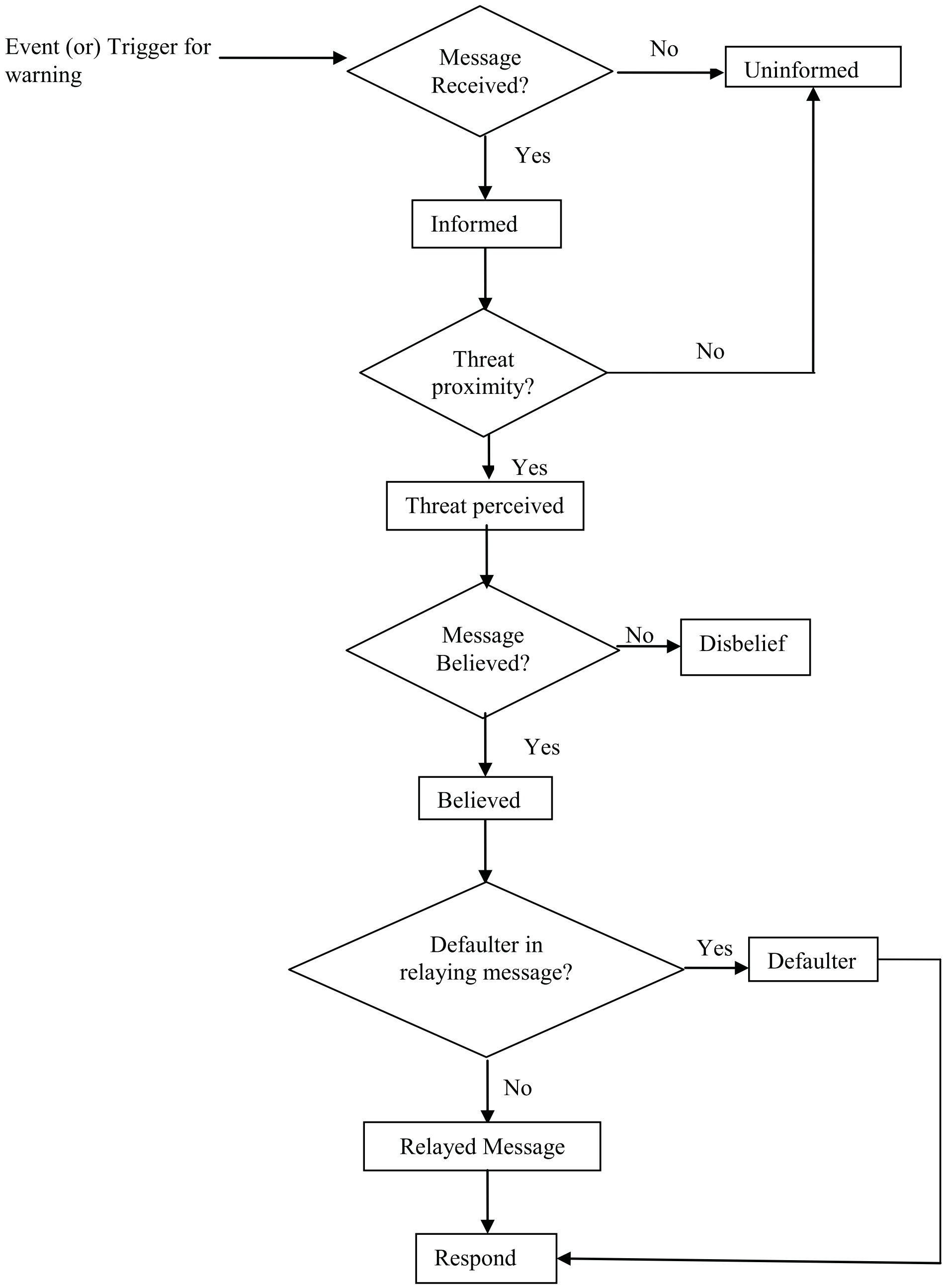

Figure 3. Flow chart showing various states of the public from receiving the warning message to their response considering the proximity of threat.

The model is developed to facilitate the user to input the values of various parameters like effectiveness of each source, defaulter percentage, assimilation time and time required to inform the neighbours. The user can select on the screen the site where the threat has occurred. Thus the developed model can be customized to account for prevailing conditions in reality including the non-availability of warning channels. The following scenarios were studied using the NetLogo model.

This paper adopts a similar approach of [6, 26] for the planning of warning message dissemination for various scenarios. Table – 1 contains the list of scenarios studied using the proposed ABMS. Scenario-A considers the behaviour of public informing the adjacent houses on left and right side. Scenario-B considers the behaviour of public informing the warning message to the adjacent and opposite houses. Scenario-C incorporates the proximity of threat from the public on the warning message dissemination.

Table 1. Different scenarios used in the simulation model

Scenario	Informal dissemination scenario	Warning channels	Threat or Hazard
Scenario – A	Public disseminate the message to adjacent houses only.	Multiple official sources and Informal notification	Not for specific hazard
Scenario – B	Public disseminate the message to adjacent and opposite house	Multiple official sources and Informal notification	Not for specific hazard
Scenario – C	Threat perception as a function of distance from the epicentre of the hazard along with informing 'adjacent only' policy	Multiple official sources and Informal notification	Threat with epicentre – for example dirty bomb blast.

4. Results and Discussion

The proposed dynamic simulation model generates the time series of the proportion of public receiving the warning message through official and unofficial channels. Earlier study [29] has adopted the approach of taking the worst-case scenario (for example, late night scenario) for planning the warning message dissemination. For illustration of the model, the effectiveness of the official channel is taken as 10%. The model was run multiple times (100 runs) to avoid bias on the results due to the initial selection of defaulter houses. By repeated experiments it was found that running the model 100 times was large enough to address the randomness in the initial selection on the output of the model. Figure 4 shows the comparison of average results for scenario A and scenario B.

The proportion of the public receiving the message in scenario B was found to be higher than scenario A. This is due to the dissemination happening across the streets leading to the diminishing effect of defaulters. The proposed simulation model enabled to study the dissemination of warning message among the public factoring the perception due to proximity of the threat. The results are also analysed for residual population, defined as the proportion of the public that remain in uninformed or disbelief state at a given point of time. Apart from the estimation of the number of evacuees and proportion of residual population, the result from this model is useful in the planning of subsequent services. For example, the time series of public arriving at the evacuation gathering point is a function of time series of the warning message received. The output of this model could be used in the planning of transport service from evacuation gathering point to shelter locations.

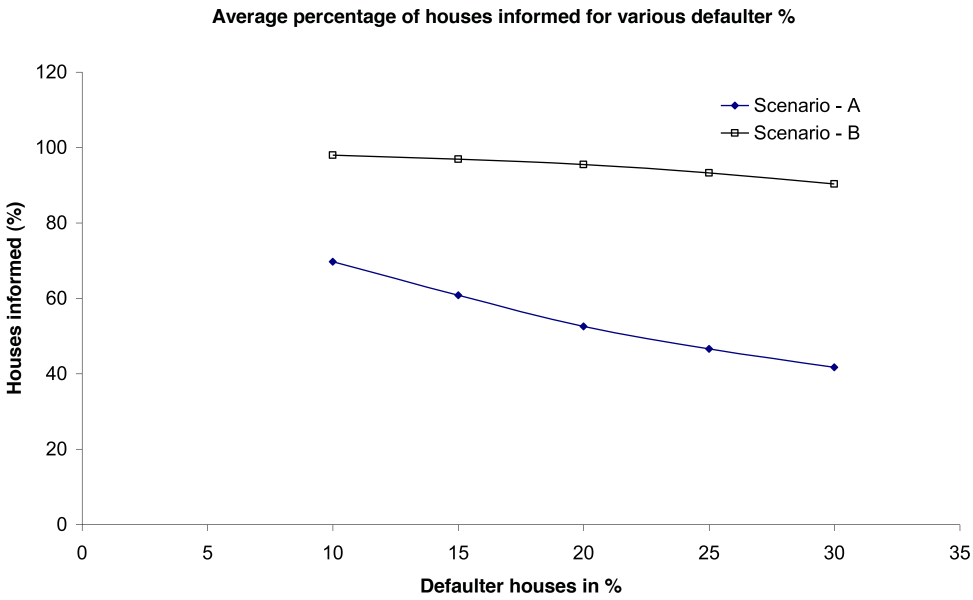

Figure 4. Comparison of residual population between various scenarios

Table 2. Proportion of residual houses for various % defaulter values for scenario A

Defaulter houses in %	Uninformed houses (Residual population) in %	Proportion of houses receiving message from number of sources (N) (%)			
		N = 1	N = 2	N = 3	N >= 4
10	30.2	12.7	50.1	6.8	0
15	39.1	14.9	39.9	5.9	0
20	47.4	16.1	31.2	5.1	0
25	53.4	16.6	25.6	4.3	0
30	58.2	16.9	20.9	3.8	0

Table 3. Proportion of residual houses for various % defaulter values for the scenario – B

Defaulter houses in %	Uninformed houses (Residual population) in %	Proportion of houses receiving message from number of sources (N) (%)			
		N = 1	N = 2	N = 3	N >= 4
10	2.1	3.4	24.5	60.5	9.3
15	3.1	6.0	30.2	52.7	7.8
20	4.5	8.9	34.3	45.6	6.5
25	6.7	12.0	36.4	39.3	5.4
30	9.6	15.1	37.5	33.1	4.4

The sensitivity analysis of the defaulter percentage parameter on the proportion of residual population who did not receive the message is given in Tables 2 and 3 for Scenario A and B respectively.

5. Comparison of Different Scenarios

The proportion of the people who are informed and the equilibrium point (defined as the time beyond which there is no significant increase in the warning dissemination) are the criteria for comparing different operational scenarios. The NetLogo model was run by keeping the assimilation time as 5 minutes, defaulter percentage as 30%, the initial seed as 10%. The efficiency of each channel is taken as 10% for demonstration.

Following table consolidates the mean and standard deviation of the output variable namely percentage of houses informed and also mean equilibrium time for each scenario.

Table 4. Statistical estimates of % houses informed and equilibrium time for various scenarios

Scenario	Mean % houses informed	Standard deviation	Mean equilibrium Point (in minutes)	Standard deviation
A	60.3	0.4	152.4	30.0
B	96.7	0.2	143.7	17.0
C	60.5	0.4	167.6	22.6

The value of uninformed houses has increased by 1.66 times in the scenario A when the defaulter percentage has increased from 10% to 30%. Likewise, in the scenario B, the value of uninformed house has increased by 4.63 times with increase in defaulter percentage from 10% to 30%. The average value of uninformed houses in scenario A is much higher than scenario B, the sensitiveness of defaulter percentage would have higher error in scenario A. Motivating the public to inform the opposite houses would have considerable impact in the overall average people informed and also reduce the likelihood of houses to be uninformed.

On comparing the adjacent only policy with and without threat proximity factor (i.e. comparing scenario A and C), it was found that the value of equilibrium point was 10% higher in the Scenario – C compared to Scenario – A in spite of having similar percentage of houses informed in both the cases. This shows that threat proximity has significant effect on the equilibrium time and hence the effect on the warning dissemination cannot be ignored. The simulation results also estimated the average number of sources per household. This is an important parameter which would indicate the likelihood of a house receiving the warning message. When the warning message is consistent across sources, the higher value of number of sources per household would increase the believability [4] as each source would confirm the message content and hence leading to expected response from the public. Zones within the city with lower value of number of sources would require additional deployment of resources (for example mobile sirens, door-to-door knocking) to reduce the residual population. This section showed the execution of the model and comparison of results for different scenarios.

6. Conclusions and Further Scope of Research

The planning for warning message dissemination requires due consideration for socio-technical issues and also the behaviour of public as informants. This study has proposed an agent based simulation approach to model the dissemination of warning message through official and unofficial sources. This study has proposed an axiom called 'threat proximity factor axiom' to account for the threat perception due to the distance from the threat on the warning dissemination through informal channel. The proposed model was studied under various scenarios on the effectiveness of warning dissemination. The sensitivity of defaulter percentage factor on the uninformed population was also studied.

The effect of factors such as number of channels per household from which the message was received and source credibility, on the time series of proportion of public receiving warning message is to be studied further. The credibility of the source is an important factor affecting the believability of the warning message and hence the response [4, 26]. The proposed model provides a tool for the practitioner to test the potential impact of the informal channels on the overall warning time and sensitivity of the modelling parameters. The tool would help the practitioners to persuade evacuees to disseminate the warning message informing others similar to the 'Run to thy neighbour' campaign conducted by the Red cross. This model could be extended for a real city factoring the geographical features like roads, bridges, etc and then factoring the same in the dissemination of the warning message. Further extension of the model needs to take into account channels such as mobile public announcement (PA) systems. Further research could be done on developing decision support system for the allocation of mobile PA systems. The time series data from the model would serve as an input to the transport planners for making optimal allocation of transport facilities based the demand pattern from the evacuation data.

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