Journal of Risk Analysis and Crisis Response, Vol. 6, No. 3 (October 2016), 135-144

Route Guidance Map for Emergency Evacuation

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Received 17 June 2016

Accepted 18 July 2016

Abstract

An efficient process of emergency evacuation must be guided. In the event of an evacuation instruction, a significant amount of time is spent by evacuees looking for a place of relative safety or an exit. Due to the ensuing stress and confusion evacuees try to follow others, consequently, all the exits are not used effectively. Therefore, it is important to develop a route guidance map for the emergency. The focus of the map is to help both, the evacuees and the authorities to perform evacuation efficiently. This paper presents a route guidance map for pedestrians that aims an efficient evacuation in case of an emergency. An agent-based simulation framework is used for the simulation of various scenarios to prepare the guiding map. A real world case study of Sarojini Nagar, Delhi is presented to test the presented methodology. Eventually, several strategic recommendations are provided for improving safety of existing infrastructure.

Keywords: Disaster preparedness, public safety, simulation, emergency, evacuation plan, strategic planning.

1. Introduction

In recent years, public safety and disaster preparedness have become a prime focus for national authorities, urban planners and civic agencies due to losses of human lives. In year 2014, at least 32 people were killed and 26 injured in a stampede shortly after the celebration of festival Dussehra in Patna, India (Express News Service, 2014). There are many similar examples across the world (see Table 1 for similar examples), where due to lack of efficient evacuation planning, people have suffered. The recurring stampedes occur mainly at places of mass gatherings for example religious places, railway stations, sports/political/social events etc. There are many causers and triggers for the crowd disaster including structural design, fire, rumors, and sudden mass evacuation (NDMA, 2014).

Evacuation is a process in which endangered people are moved from a dangerous place to a safe place in order to reduce the vulnerability during these dangerous circumstances. In order to mitigate impacts of disasters, proper evacuation planning is required. In many of the past events, lack of evacuation planning has resulted in loss of human lives, particularly in India (see Table 1). Improper selection of exit or failure to avoid the obstacles may lead to either serious injury or death. Therefore, a proper route guidance map in terms of an “Evacuation Plan” is required that can help evacuees to find the suitable exits and the route to be followed to evacuate the

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Published by Atlantis Press

Table 1. Past mishappenings due to improper evacuation modeling.

Year	Place	Reason	Casualties
1903	Iroquois Theatre fire, Chicago (U.S)	No exit signs; No emergency lighting; Exit routes were confusing (Disaster, 2015)	602
1913	Italian Hall disaster, Michigan (U.S)	Escape from a falsely shouted of fire at a party (HallDisaster, 2016)	73
1995	Dabwali, Haryana (India)	Synthetic tent caught fire, blocking main entrance (NDMA, 2014)	446
1997	Uphaar Cinema, Delhi (India)	Smoky cinema hall (NDMA, 2014)	59
2000	Night club Lisbon (Portugal)	Head for main exit and ignore alternative exit (Helbing et al., 2002)	7
2006	Jamrat Bridge (Saudi Arabia)	Overcrowding and poor crowd management (Still, 2016)	363
2008	Chamunda devi temple, Jodhpur, Rajasthan (India)	Stampede due to false rumors of bomb (NDMA, 2014)	249
2010	Love Parade (Duisburg)	Trying to escape the overcrowded tunnel (Still, 2016)	21
2011	AMRI hospital, Calcutta (India)	Basement fire, suffocation causing deaths (NDMA, 2014)	89
2014	Patna Stampede (India)	Mass exit from a single gate and rumors also that live electric had fallen on ground. (Express News Service, 2014)	33
2015	Mina Stampede	Blockage of route to Jamrat Bridge (Still, 2016)	2110

endangered area in minimum time and with minimum loss of life. This guiding map can also serve as a reference for security staff to guide the evacuees on the route to take for evacuation. This evacuation plan may also suggest the structural improvements, which can be helpful for further reduction of the evacuation time. Limited research on developing evacuation plan has been done and reported in literature. The ability to evacuate people depends mainly on two factors viz.: structural design and behavior. Inefficient design and panic behavior may lead to overcrowding, which in turn may lead to crushing, suffocation and trampling. Besides planning the infrastructure efficiently, it is also essential to understand the movement and flow behavior, which may help planners and civic agencies to reduce the severity. Evacuation, where there may be a transition from normal behavior to irrational panic behavior, is governed by factor of "nervousness" which leads to slow down the crowd and tendency to follow others (Helbing *et al*., 2002).

A great share of literature focus is on simulating a single room evacuation pattern (Casadesús *et al*., 2009; Takahashi *et al*., 1989; Taylor, 1996) where in true sense little evacuation planning take place. On the other hand, to evacuate a larger area, egress route have to be defined first, which requires optimization techniques. In a similar research direction, this study aims to investigate sudden mass evacuation from a crowded place. This paper presents a real-world case study for evacuation preparedness due to disastrous events in large-scale pedestrian areas. A majority of crowd disasters have occurred at shopping malls, music concerts, and stadium in developed countries (NDMA, 2014). With increasing population, developing countries are also susceptible to crowd disaster at such venues (NDMA, 2014). Therefore, main focus of this study is to evacuate persons from congested areas such as market places or mass gathering venues. The objective is to make recommendations to improve the evacuation time of all people in the identified area. The key outcome is an "evacuation plan" for designated sites. The event of potential bombing is used as an example of the disaster where evacuation is required. The methodology presented in this study is applied to a market place, Sarojini Nagar, New Delhi, however, it can be applied to any scenario wherever evacuation is required. Also, in order to check the applicability and robustness of the approach, the same methodology is applied to two other areas namely Lajpat Nagar and Laxmi Nagar, New Delhi.

Table 2 shows several models that have been used in the past to reduce the response time for an evacuation. In a study by Flötteröd & Lämmel (2010), the authors suggested to adopt dynamic traffic assignment model to develop an evacuation plan for open spaces. In general,

Table 2. Method used in literature to reduce time.

Past study	Model	Description
Taylor (1996)	Macroscopic	Find minimum time to evacuate building and optimal plan in terms of exit usage.
Casadesús Pursals & Garriga Garzón (2009)	Macroscopic	Find the distribution of exit usage for minimum evacuation time.
Takahashi, Tanaka, & Satoshi (1989)	Macroscopic	Optimal exit from a room is chosen for evacuating.
Han, Yuan, Chin, & Hwang (2006)	Macroscopic	Routing for reducing total evacuation time.
Klüpfel (2003)	Macroscopic	Shows connection between choice of exit and individual egress time.
Stepanov & Smith (2008)	Microscopic	Potential egress route described by K^{th} shortest path using distance, travel time and level of congestion as objective function.
Abdelghany, Abdelghany, & Mahmassani (2014)	Microscopic	Show that evacuation time reduces significantly by optimizing the temporal distribution of evacuation and exit gate selection.
Kneidl, Thiemann, Hartmann, & Borrmann (2011)	Microscopic	Find the probability of choosing a route to reduce the evacuation time.

dynamic traffic assignment relies on microscopic models. Zheng *et al*. (2009) compares several modeling approaches at different scopes, for e.g. a) cellular automata models based on lattice gas or social force models b) agent-based models based on cellular automata or social force models etc. Most of these models are detailed models which are resource hungry and need higher computational time. However, the aim of the present study is to develop and test a route guidance map using an approach that is computationally efficient for large-scale scenarios. Therefore, the present study uses an evacuation planning approach in a multi-agent simulation based framework (Lämmel *et al*., 2010). The multi-agent systems are preferred for crowd simulation modeling (Almeida *et al*., 2013).This approach has also been applied to a real-world evacuation scenario of Patna city, India (Agarwal and Lämmel, 2016) under mixed traffic conditions. This simulation framework is suitable for large scale scenarios due to its queuing model (see Agarwal *et al*. (2015); Balmer *et al*., (2009) and also section 2.1). Every person in the area under consideration may not be familiar with the prevailing traffic conditions and alternative exit routes during evacuation situation, therefore, this study proposes an evacuation plan and subsequently, investigates the response time when this evacuation plan is used under different situations.

The rest of the paper is organized as follows. First, the detail of simulation framework for the present study is explained in Section 2. Section 3 exhibits the methodology and the case study of Sarojini Nagar market is illustrated in Section 4. Section 5 shows the impact of "Evacuation Plan" and its usefulness. Finally, the last section concludes the overall work and provides some outlook for future work.

2. Evacuation Modelling

Three different modelling approaches can be applied to an evacuation process (Schadschneider et al., 2009): a) risk assessment, b) optimization and c) simulation. Simulation of pedestrians is generally used for two purposes: to gain insight on a particular situation and to prove/disprove a hypothesis (Still, 2007). The output of a simulation mainly includes: distribution of evacuation time, evacuation curves (number of people evacuated with respect to time), sequence of evacuation (snapshot at a specific time), and identification of congestion (Schadschneider et al., 2009). In this article, multi-agent simulation framework (MATSim) is used to identify the evacuation time, congested links and sequence of evacuation. In this, all evacuees are modeled as individual agents. A Geographical Information System (GIS) based Risk Assessments Information, Planning System toolkit (GRIPS) is used along with MATSim (Taubenböck et al., 2009).

MATSim has an evolutionary algorithm which consists of mainly three steps as shown in Figure 1

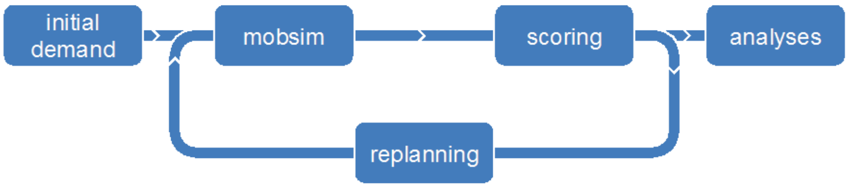

Fig. 1. Iterative appraoch of MATSim (Horni et al. 2015).

(Balmer et al., 2009; Horni, Nagel, & Axhausen, 2015). In this iterative cycle, an agent learns and adapts to the system. The minimal inputs are network and daily plans of the individual agents.

- **Execution (mobsim)** - In this step, all the plans are simultaneously executed using predefined mobility simulation (mobsim) on the network. The network loading algorithm is a queuing model (Cetin, Burri, & Nagel, 2003; Gawron, 1998).[1] The queue model tracks every agent only at entry and exit and never in between which makes it computationally efficient. Hence, a large-scale scenario can be simulated in reasonable computational time (Agarwal, Lämmel, & Nagel, 2016a).
- **Scoring** - Various plans of an individual are compared using a utility function. The utility function consists of utility of performing an activity, (dis)utility of traveling etc. All executed plans are evaluated using the default scoring function (Charypar & Nagel, 2005).
- **Re-planning** - For some of the agents, a new plan is generated by modifying an existing plan depending on the so-called innovative strategies (choice modules). Several choice dimensions are available for e.g. reroute, time mutation, mode choice etc. The new plan is then executed in the next iteration. The innovation is used until a fixed number of iterations (for e.g. for 80% of the iterations). Therefore, rest of the agents until innovation and all the agents after innovation select a plan from their choice set according to a probability distribution which converges to the multi-nomial logit model.

[1] Refer to (Agarwal et al., 2016b, 2015)for details about the queue model and its extensions in the MATSim. For simplicity, the present study uses *first-in-first-out* (FIFO) approach of the queue model.

3. Survey methodology

Typical crowd density at various sections of the road is estimated as illustrated further. A travel count survey data is conducted as follows to identify the initial person density on each link.

1) On every link of the road network, three surveyors are placed to count a) the number of persons present initially at time *t*, b) number of persons entering and c) number of persons leaving the link in 5 min time bin.
2) Thus, number of persons on a road at any time t is given by Equation (1)

$$N(t) = \lambda(t) + I(t) - O(t) \qquad (1)$$

where, $N(t)$ is number of persons on a road at time t;
$I(t)$ is number of persons entering the link in time bin,
$O(t)$ is number of person leaving in that time bin and
$\lambda(t)$ is number of persons initially present on the link at time t.

3) Thus, total number of people to evacuate from a link is given by Equation (2), which includes the persons on the road and also persons inside the shops. Let $S(t)$ be the number of people present inside shops on the link in time bin t (counted by fourth surveyor). Then the total number of persons to evacuate on the concerned road $TP(t)$ is:

$$TP(t) = N(t) + S(t) \qquad (2)$$

4) Thus $TP(t)$ is computed from the survey data. The pre-evacuation coordinates of all agents are assigned randomly on corresponding link.
5) In an evacuation problem, destination and route choice are interrelated. For the simplicity, in the present study, only one destination is used which reduces the whole problem to one dimension only.

The post-evacuation location coordinate (destination) of each agent is modeled as a virtual point formed far away from the center of the evacuation area. All the exits are connected to this artificial node termed as "super sink" (see Figure 2).

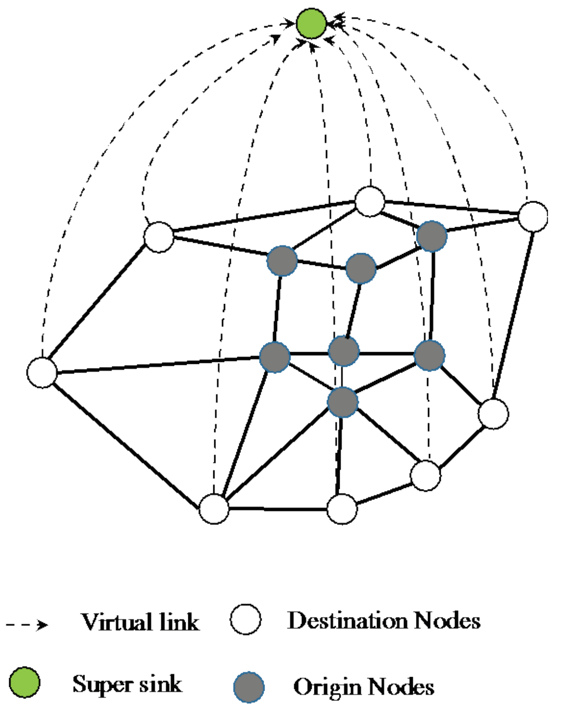

Fig. 1. Exit connected to a super sink (a virtual destination).

4. Scenario set up

Sarojini Nagar is located in the south west district of Delhi. It is one of the most popular market in Delhi. This was one of the site which was bombed in Delhi on 29 October 2005 and resulted in many deaths and major injuries (NCTC, 2006). Thus, because of its past history, it is chosen as a site for potential disaster location.

4.1. *Case study: Sarojini Nagar market*

The surveys were conducted between 4 September and 7 September, 2014 as illustrated in Section 3. Generally, evacuation planning is composed of the following steps (Lahmar, Assavapokee, & Ardekani, 2006):

1) Impact zone: In this step, the evacuation zone is identified. It is generally dependent on the type of emergency. In some cases only small area needs to be evacuated while in some cases complete area needs to be evacuated, in the present study, for the case of potential bombing scenario, complete market is considered as evacuation area. Figure 3 shows the complete market of Sarojini Nagar market.

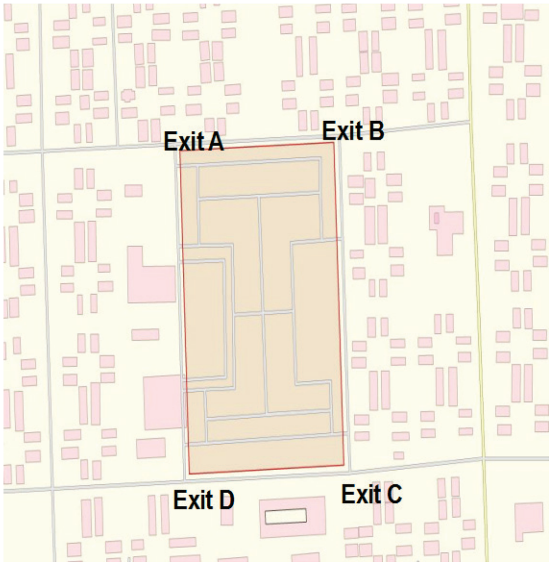

Fig. 3. Market area (in red) under consideration for evacuation.

2) Assignment of evacuees to shelter: After defining area to be evacuated, next is to decide where to evacuate people. In the case study all the exits are assumed as a potential shelter. Once the agent is out of the particular exit, he/she is assumed to be safe.
3) Traffic routing (determining driving direction at each road): In this step, the best route to reach the shelter is determined. Different strategies have been considered in the case study presented in the Section 4.3.
4) Self-evacuation: Agents starts evacuating as soon as warning is announced. They follow the evacuation plan considered in various scenarios.

4.2. *Simulation inputs*

The Sarojini Nagar market area remains crowded most of the time of the day. Motorized and non-motorized vehicles are rarely used inside this market area and therefore all vehicles are ignored in the present study. Only the walk mode is considered in the simulation framework.

- **Network** - The desired evacuation area of Sarojini Nagar market is taken from Open Street Map (OpenStreetMap, 2015). All exits of this area are connected to a safe virtual destination, which is far away from the centre of selected area. All exits have same exit capacities. It is assumed that travel time from exit points to the safe virtual destination is zero. The network is converted to desired format of the simulation framework. The width of the streets are measured during survey and eventually, due to heavy encroachment, the effective width of link is estimated as 4 *m* which results in a capacity of about 1000 *PCU/h* per direction. The roads in the Sarojini Nagar market are partially tiled and partially concrete and are in good condition. A poor condition of the surface may increase the evacuation time.

- **Plans** - In the evacuation situation, only two types of activities i.e. pre-evacuation and post-evacuation are considered. The activity locations of these activities are the locations of agents before and after the evacuation respectively. All agents use walk mode to travel between these activities. It is assumed that all agents start moving out of the market area as soon as warning is announced. Initial positions and the density of the agents on each link is calculated from the survey (see Section 3). In the simulation, the speed of the agent is assumed as 6 *km/h*. Passenger car unit (PCU) of the agent is taken as 0.08 (Tiwari, Fazio, & Gaurav, 2007). Overall, about 8430 agents are evacuated from the market area.
- **Choice dimension** - In this study, 20% of agents are allowed to change their route until 80% of the iterations. Simulation is run for 100 iterations. Rest of the agents until 80% iterations and all agents after that select a plan from their choice set only which stabilizes the demand.

4.3. *Scenarios*

The first step is to identify the bottleneck links in order to identify the cause and then propose necessary strategic decisions to rectify and improve the overall evacuation time. No single hypothetical scenario is expected to perfectly emulate a real event that will occur in future. Thus, different situations are considered for evacuation of pedestrian in market place. These scenarios help in generating the evacuation plan for an open space environment. The following scenarios are considered.

- **Scenario 1: (No Evacuation Plan)**: In absence of any evacuation plan, all agents are left to themselves. This would replicate the existing situation of the market area.
- **Scenario 2: (Shortest Path):** In this scenario, it is assumed that all agents will evacuate by running to the nearest exit, taking the shortest path between their current location and exit. This is recorded as the “shortest path evacuation time”.
- **Scenario 3: (Benchmark Evacuation with encroachment):** In this scenario, evacuation time is identified based on Nash equilibrium (Lämmel, Rieser, & Nagel, 2008). Evacuation time calculated using this approach is termed as the “benchmark evacuation time”. In reality, it is not possible to achieve benchmark evacuation time (since this is a result of several iterations of MATSim with learning of each outcome) but it is useful to generate a feasible evacuation plan and compare it with benchmark time. Streets of the market area are heavily encroached therefore, in this scenario, the evacuation time is estimated with the existing situation.
- **Scenario 4: (Planned Evacuation):** As discussed before, in this scenario, an evacuation plan is proposed aiming to achieve the evacuation time same as benchmark evacuation time and in turn expecting to be better than shortest path scenario or no evacuation plan scenario. The resulting time is called “planned evacuation time”. This scenario will result in the development of a route guiding map. In case of an emergency, these routes can be followed from the current locations of all agents.
- Further, after analyzing the scenario based on the link flow in peak hours, more recommendations such as widening of bottleneck links by removing encroachments and adding new emergency exits will also help in further reduction in the evacuation time.

5. Results

It is clear that in the absence of any planning and signage (Scenario 1), all agents may produce herding behaviour which results in early degradation of network supply. Thus, evacuation time will be higher than all other scenarios due to sheer chaos.

In scenario 2 (shortest path evacuation plan) everybody moves to their geographically nearest exit point. This kind of plan is most easy to implement, because of its unique solution. It is only required to put sign at crossing of street network. The big disadvantage of such strategy is that, it does not take congestion in consideration. Congestion avoidance is important in case of evacuation. According to Schadschneider et al. (2009), to reduce the congestion, two corrective actions can be taken: change of geometry (wider escape paths) and proper guidance through signage which helps in improving orientation capability. Our methodology intervenes at two levels: it develops signage for the existing geometry and also makes recommendation on specific geometry change for faster evacuation.

In the scenario 3 (benchmark scenario), the fastest route is computed using iterative algorithm of MATSim. This kind of plan (benchmark) can only be implemented with proper training and repetitive mock drills, which is not feasible in practice. Therefore, a practically feasible evacuation plan is proposed in scenario 4, in which consistent direction signs are placed at all relevant locations. A snapshot of such a plan is shown in Figure 4. Heuristic (colour scheme) and evacuation time of agents help in making the evacuation plan. Routes that are closer to exit but with high congestion are bypassed, agents diverted to a route where there is lesser congestion. The main advantages of this plan over shortest path plan are that it considers the congestion effects into consideration and it is easy to implement. This route guidance map will also serve as a reference for concerned authorities to provide evacuation route related instructions to evacuees.

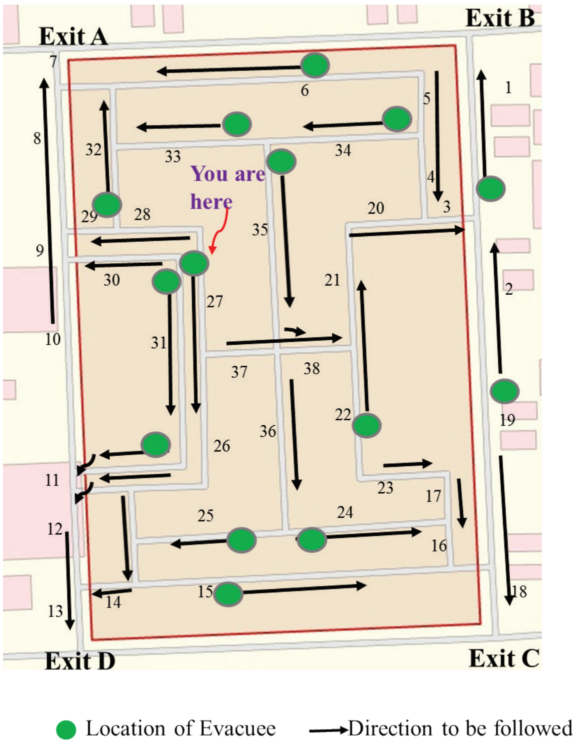

Fig. 4. Guiding map: A feasible solution.

Different scenarios (from Section 4.3) are compared based on total evacuation time and average evacuation time per person. The former is the total time to evacuate all the agents out of the evacuation area. Statistically total evacuation time is not a good measure for finding effectiveness of a given evacuation strategy. Thus, average evacuation time is required, which not only minimizes the response time but at the same time also maximizes the flow at given time (Hamacher & Tjandra, 2001). Table 3 shows the results obtained from these scenarios. Clearly, as expected, benchmark scenario has the least total evacuation time and average evacuation time. This corresponds to a first-best condition in which everyone knows the prevailing congestion conditions and the best route to exit. Further, for the case of planned scenario, the total and average evacuation time is significantly shorter than shortest path scenario and marginally higher than benchmark scenario.

The comparison of evacuation progress is shown in Figure 5. It can be observed that evacuation time is the same for all three scenarios until 50% of the agents are evacuated. Afterwards, evacuation progress for the shortest path scenario becomes slowest and evacuation progress of the benchmark scenario become the fastest. The links towards Exit A (see Figure 4) become bottlenecks in the shortest path scenario (observation from simulation output). Thus to make an effective use of all the exits, some agents are diverted to another exit. The procedure is repeated for all other exits. In this way, planned scenario routing strategy is developed making use of benchmark routing strategy. The evacuation progress of planned scenario is marginally slower than the benchmark scenario.

Table 3. Average evacuation time per person and total evacuation time

Scenario	evacuation time (min)	
	average	total
Shortest path	10.05	23.05
Benchmark	8.94	16.46
Planned	9.45	17.32

Effectiveness of the approach: In order to see the effectiveness of the route guidance map, the same methodology has been applied to two other markets of Delhi (India) namely, Lajpat Nagar and Laxmi Nagar. Evacuation plan for these sites are developed. It can be

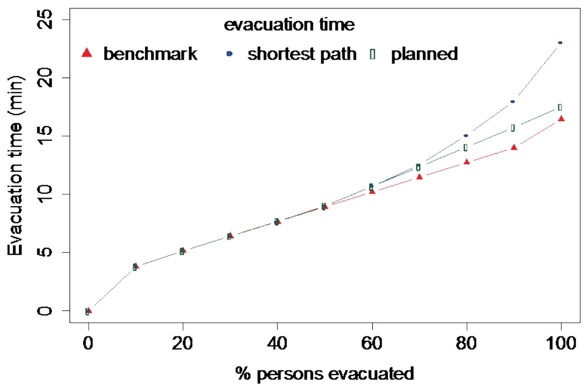

Fig. 5. Plot of evacuation time for different scenario.

observed from Table 4 that planned scenario response time is better than the shortest path evacuation strategy. Thus, clearly, the methodology is transferable to any scenarios where such kind of short-notice evacuation is required.

Table 4. Total evacuation time for Lajpat Nagar and Laxmi Nagar markets.

Scenario	Total evacuation time (min.)	
	Lajpat Nagar market	Laxmi Nagar market
Shortest path	13.25	11.51
Benchmark	10.01	7.34
Planned	10.46	9.53

6. Discussion

The present study shows the necessity of an evacuation plan for improving safety and response efforts. The study provides strategic and tactical recommendations to improve the response time in case of an emergency evacuation. Strategic recommendations include increasing network supply side by making new routes or by widening the existing roads. These strategic recommendations help planners to decide the increase in the capacity of roads, or where an emergency exit should be made to further improve evacuation response. Statistical and tactical recommendations deal with effective utilization of existing capacity. This can be achieved by properly routing the evacuee through a street network in order to minimize danger and ensure safety. The simulation returns the route assignment policy to reduce congestion and improve response time, which eventually will reduce the collateral damage. A policy imperative from this study is that even a static plan would help in reducing the evacuation time.

Further this work and methodology can also be used to determine the maximum allowed safe occupancy for an event in open area, a parameter that can be imposed by decision makers by way of policy. For this, a safe level of evacuation time must be determined through consultation with relevant experts. The evacuation time consists of two time components: reaction time and egress time (Kuligowski, 2013). In the present study only latter is considered and estimated whereas it is assumed that the agents react instantly after the warning.

This lays a future research direction to incorporate the different reaction times for different group of persons depending on the factors such as age and sex similar to the work by (Agarwal, Lämmel, & Nagel, 2016b) in which the authors incorporated a uniform reaction time for all drives in the queue model. Another important observation of the study is that the egress time is highly affected by heavy encroachments. Clearly, removing these encroachments will ease some capacities and would reduce evacuation time significantly.

In the literature, it has been argued that people tend to misjudge the likelihood of a disaster event and range of severity of its impact. This would in turn result in a different outcome; such behaviors are out of the scope of the present study.

7. Conclusion

Evacuation time is a critical factor for developing evacuation strategies. In this work, a methodology to prepare a guidance map was developed using an agent-based simulation framework. Initial inputs were calculated from different surveys. An event of potential bombing was considered as an example of the disaster where immediate evacuation is required due to a disaster on the same location in the past. A real-world case study of Sarojini Nagar market, Delhi was considered. Different scenarios were considered and their total and average evacuation time were compared. It was shown that with the help of proper signages in planned scenario; the total and average evacuation time would be significantly lower than shortest path or no evacuation plan scenarios and marginally higher than benchmark scenario. The planned scenario routing map would help the authorities (the security staff) to guide or push evacuees. The effectiveness of the proposed methodology was shown using the same approach for two more markets of Delhi.

Future work includes an analysis of the robustness of the suggested evacuation plan, particularly with respect to distribution of people in the market. Development of a dynamic evacuation plan, that is, one with message signs that change dynamically with congestion distribution is another possible extension. With this, accounting for behavioral characteristics of agents, after developing appropriate models for the same, can induce even more realism in the recommendations.

Acknowledgments

This project is funded by the Human Settlement Management Institute, Housing and Urban Development Corporation Limited (HUDCO). The authors also would like to thank Dr. Gregor Lämmel for his helpful comments. Lastly the authors would like to acknowledge the contribution of Prem Chand and Rama Shankar for carrying out several supporting tasks throughout the duration of the project.

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