Evacuation plan as a risk mitigation measure:

Scenario - based time estimation of partial evacuation operation

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Abstract: This paper concentrates on evacuation procedure as a risk mitigation measure for managing and coping with emergency due to flood hazard. Emergency Management has been known as an ever-growing area of academic research in the recent decades. Particularly, Emergency Planning ahead of threatening events is crucial for moving toward a resilient society. Effective implementation of Emergency Contingency Plans during the situation of real Risk Scenarios is mainly a matter of situation awareness, cooperation and collaboration of involved organizations, timely decision-making under stressful circumstances, and availability of resources. Having defined a plan for evacuation operations as a protective measure is necessary for reduction of risk consequences to exposed population. This paper presents partial evacuation time estimations related to vehicle movement time by two methods applied to a case study (San Rocco al Porto, Italy) due to flood event: Time is estimated as a result of modeling by Mesoscopic approach. Second, the "timeline of emergency response for flood evacuation" proposed by Steve Opper is used as a quick handy method to estimate vehicle movement time.

Key words: Emergency Planning; Evacuation Time Estimates; Transport Management; Zoning; Flood

Introduction

According to FEMA definition, Emergency management is the managerial function charged with creating the framework within which communities reduce vulnerability to hazards and cope with disasters (FEMA, 2007). The Emergency management process consists of four phases: Mitigation, Preparedness, Response, and Recovery. Figure 1 shows a schematic view of this process.

According to Perry and Lindell (2003), emergency planning, training and exercising are the key aspects of emergency preparedness (Perry & Lindell, 2003). Planning for emergency as a process during the preparedness phase is crucial for coping with disasters. Although developing an effective emergency plan is necessary, there are other crucial aspects: keeping the plan updated, appropriate cooperation and collaboration, and in general real-time implementation.

Emergency evacuation procedures could be included in Emergency plan ahead of occurrence of threatening events. The implementation however will start after the imminent event is realized.

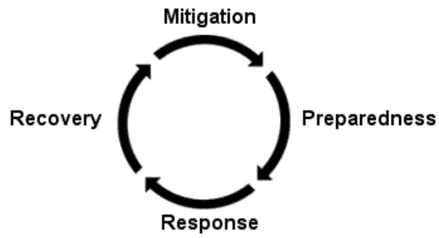

Fig. 1. Emergency Management Process

In order to effectively and comprehensively plan and implement in real time the evacuation procedures, the collaboration of wide spectrum of discipline and expertise is required; beside technical and managerial aspects, the psychological behavior of exposed population should be considered as well. The relevance of some important variables from disaster psychology has been discussed in (Vorst, 2010), in which it is expressed that modeling psychological variables will enhance prediction of human behavior during evacuations. Although this research does not go into such details, some factors in this regard are considered implicitly; for instance, a percentage of people who decide not to evacuate after being warned is assumed, which is influenced by the behavior of people during emergencies.

Evacuation strategies generally vary based on two types of disaster-induced evacuation characterizations: short-notice or no-notice disasters. Short-notice disasters have a desirable lead time between 24 and 72 h (Wolshon, et al., 2001); conversely, a no-notice evacuation takes place when a large-scale and unexpected incident occurs. The evacuation that takes place immediately after the occurrence of such a disaster event is defined as a ‘‘no-notice evacuation’’ (Chiu & Zheng, 2007). Due to the characteristics of hazard in this case study, the second type is our interest since the lead time is in range of few hours.

Irrespective of the diverse contexts of emergency response decisions, no-notice evacuation often entails the following common decision dimensions: To which place (shelters, medical facilities or general safe zones destinations) the evacuees should be evacuated to, which routes they should take and in how much time they should be mobilized in, in order to minimize potential casualties and property losses. In more advanced evacuation plans, which is out of scope of this paper, requirements may arise to permit quick arrival of certain prioritized evacuees (the elderly, hospital patients, or nursing home residents, etc.) at the intended safe zone. This implies allowing them to preempt ordinary evacuees by taking a shorter or less congested route, or overtaking other ordinary evacuees in order to expedite their arrival at intended destinations such as triages, airports, or shelters (Litman, 2006), (Chiu &Zheng, 2006).

Definition of Risk Scenario is a practical way toward having a perspective of what could happen, how, when, and where in the future. “Scenarios are not about predicting the future; rather they are about perceiving futures in the past. The end result is not an accurate picture of tomorrow, but better decisions about the future” (Schwartz, 1996). In this paper we are interested in a flood risk scenario which imposes evacuation of exposed population to predefined shelters.

This paper presents evacuation time estimations by two methods:

First, the evacuation time is estimated by the Mesoscopic Model, which has been simulated by the Cube software. Cube Avenue is the Cube Voyager program for performing dynamic traffic assignment. In our study, the traffic modeling has been performed just from the centroid of each zone (origin) to the shelters (destinations). However, total evacuation time depends on many parameters including the time required for warning, preparation, and so on. The focus of software simulation is on the time required for the movement of vehicles from origins to destinations, which usually consists a considerable portion of the total time.

Second, the “timeline of emergency response for flood evacuation” proposed by Steve Opper is used to estimate evacuation time. In addition to NSW SES (State Emergency Service), some parts of the proposed timeline are also formulated by Lindell. Although the timeline is a basic analysis model and does not contain sophisticated traffic network analysis or real time feedback mechanisms, it is a simple powerful tool; especially, considering the importance of making decisions under pressure about evacuation and the lives of perhaps thousands of people, the timeline is, at worst, much better than nothing at all. In a flood planning context the timeline has filled a void in which no easily accessible analytical tool were available and it provides a reasonable estimate of evacuation requirements (Opper, 2004).

To justify the effort of this paper, it should be mentioned that the two methods only differ from each other in the phase of vehicle movement time, which, depending on the case study, is expected to be one of the most time-consuming phases of the evacuation procedure. It is obvious that for performing a reasonably accurate traffic assignment analysis, there is a need for updated, precise, and comprehensive database. On the other hand, the second method is simpler and more available, which make it quite suitable and practical in the emergency decision making, although the accuracy is less than that of the first method.

Case Study

The case study is about evacuation of the population of the city of San Rocco al Porto exposed to flooding of Po River. The city of San Rocco al Porto belongs to the province of Lodi of Lombardy region in northwest Italy. It is located on the northern side of Po River, which is surrounded by the vast Po valley. The city has 3582 inhabitants, an area of 30 km², which stretches for about ten kilometers and occupies fully a wide bend of the river Po, which defines the area from the west, south and east. (San Rocco al Porto commune webpage, 2012), (Raggi, 2009), (ISTAT Webpage, 2012). The Po is the longest river in Italy and subject to heavy flooding. Consequently over half its length is controlled with dikes .The slope of the valley decreases from 0.35% in the west to 0.14% in the east, a low gradient. (Zwingle, 2009), (Burghout, 2005).

It is assumed in our scenario that, according to Figure 2, the “San Rocco Al Porto” Town is endangered by Flooding because it is located between embankment of Po River and Border of morphological terrace. Since this is a highly populated area, in case of flooding, it would suffer substantial damage. To reduce the exposure as an important element of risk, an evacuation plan has been developed by Local Civil Protection. The effort of this paper is concentrated on methods for time estimation of vehicle movement phase in order to further improve evacuation planning, management, and operations.

The aim of evacuation emergency operation is to move inhabitants from exposed area to safe shelters, which could be existing buildings like schools, hospitals, and offices. In our case safe shelters are located in the north border of the city since other sides (east, west, and south) are expected to be fully flooded since they are adjacent to the Po River.

There are 48 defined zones all over the city; for implementing evacuation, the origin centroids are considered in the zones 5 to 48. In zones (5-17 and 18-48), households are distributed like residential buildings: zones 5 through 17 are considered in the town, while other zones (from 18 to 48) are regarded as settlements and scattered. On the other hand, zones 1 to 4 indicate the destinations where the safe shelters are located.

Fig. 2. Primary evacuation routes for Sanrocco al Porto.

First Method – Mesoscopic model

Traffic assignment models can be divided into Static and Dynamic network loading models; in Static modeling, variables such as origin-destination flows (travel demand) and choice of the paths, link flows (vehicle volumes), link costs (congested times), and path costs (cost of origin to destination) are constant and do not change during the model period. Dynamic modeling has Time-varying inputs (origin-destination travel demand, average link costs by time segment, and capacities) and outputs (dynamic path/link flows and path/link costs, and trajectories).

Another classification divides traffic assignment models into categories based on the level by which the model is aggregate or disaggregate:

- Macroscopic models, in which vehicles are analyzed globally by studying fundamental variables (flow, speed, density).
- Microscopic models, in which vehicles are analyzed individually, studying vehicles behavior and vehicles interactions (decisions of accelerating or change lane, behavior at intersection, reaction time ...).
- Mesoscopic models try to find a middle solution between macro and micro models, which can study traffic flows over time (Dynamic). In this model vehicles are analyzed as "packets" of vehicles by studying fundamental variables (flow, speed, density)

Mesoscopic model fill the gap between the aggregate level approach of macroscopic models and the individual interactions of the microscopic ones. These models normally describe the traffic entities at a high level of detail, but their behavior and interactions are described at a lower level of detail (Dell'Orco, 2006).

These models consider the traffic as a sequence of "packets" of vehicles. Two approaches can be followed:
Continuous packets, where vehicles are distributed inside each packet, defined by the head and the tail points;
Discrete packets, where all users belonging to a packet are grouped and represented by a single point, for instance the head (Citilabs webpage, 2012).

The packet of vehicles acts as one entity and its speed on each road (link) is derived from a speed density function defined for that link, and the density on the link at the moment of entry. The density on a link is defined as the number of vehicles per kilometer per lane. A speed-density function relates the speed of vehicles on the link to the density. If there is a lot of traffic on the link (the density is high), the speed-density function will give a low speed to the vehicles, whereas a low density will result in high speeds.

In this paper, a Mesoscopic model based on discrete packets has been developed. Simulation of emergency evacuation plans is an important application of Mesoscopic models. For example for small city like San Rocco al Porto, Mesoscopic modeling of vehicle movement for evacuation operation, taking into consideration the available required data, gives the desired level of accuracy. In this research Cube-avenue software has been used to simulate the above mentioned model.

The following scheme gives an idea of three aforementioned models:

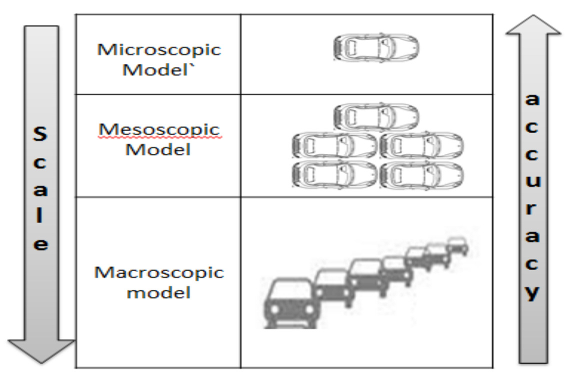

Fig. 3. Three approaches for traffic assignment.

Procedure

As an assumption, in the case of evacuation people and society should handle the situation, so the important thing is to notice whether people have enough number of vehicles to evacuate the risk zone on their own or not. According to the San Rocco al Porto statistics, there are enough vehicles to support the operations.

The model focuses on reaching designated gathering points in each zone, and then to shelters, with least congestion and shortest time. In this regard, four shelters are defined as the destination zones. As mentioned before, the Po River encompasses the city from south, east, and west. As a result the only safe area not expected to be flooded would be the north side of the city, which is appropriate for defining shelters. Moreover, there are 44 regions in the town to be treated as the origin zones. The population of each group of zones will be redirected to the same predefined shelter. These groups of zones will be specified according to two scenarios for zoning. Using Cube AVENUE, the vehicle movement phase of evacuation procedure has been simulated.

Transport offer (supply) is the road network of San Rocco Al Porto. The demand, on the other hand, can be represented by origin-destination matrix, which is defined separately for each scenario. In this case we should build the OD matrix, since the origins and destinations should be determined by the analysis of raw data. Origins are assumed to be defined gathering points (Centroids), and destinations are assumed to be predefined shelters.

In this regard by considering the characteristics of the town itself and also the simplifying hypotheses and Individual data, it would be possible to compute the number of vehicles in each zone to be evacuated. Two scenarios are defined for how people evacuate according to two different zoning schemes. Figure 4, and 5 show these scenarios, which are different in Evacuation Distribution Pattern.

The mentioned data and hypotheses are as following:

- The number of residents is evenly distributed in households (number of residents per household is considered to be constant for all the type of areas)

- Transform household in population considering the average number of inhabitants per household. Population is divided into three categories: Those who have evacuated before the alarm, those who decide not to evacuate, and those who evacuate after the alarm. The latter is our group of concern, which is assume to be 49% of the whole population.

It should be noted that we considered the proximity of the regions as a factor justifying the defined zoning patterns. For example, in both scenarios, the population of the zones characterized by red colour will be redirected to the first shelter.

There are a lot of parameters such as different characteristics of evacuation routes, that are important for deriving the optimum solution for how people evacuate, (i.e. the population of which zones are evacuated to each shelter). However, among different possible solutions just two scenarios are chosen, mainly based on the proximity of zones, and ease of access to main evacuation routes towards the shelters.

To study the sensitivity of evacuation time to zoning scenarios, at least two distribution patterns of zoning should be considered. Of course, the more scenarios are considered, the more accurate the sensitivity analysis would be. As we will see in the results, the choice of zoning affects traffic analysis, and therefore evacuation time.

Scenario_1:

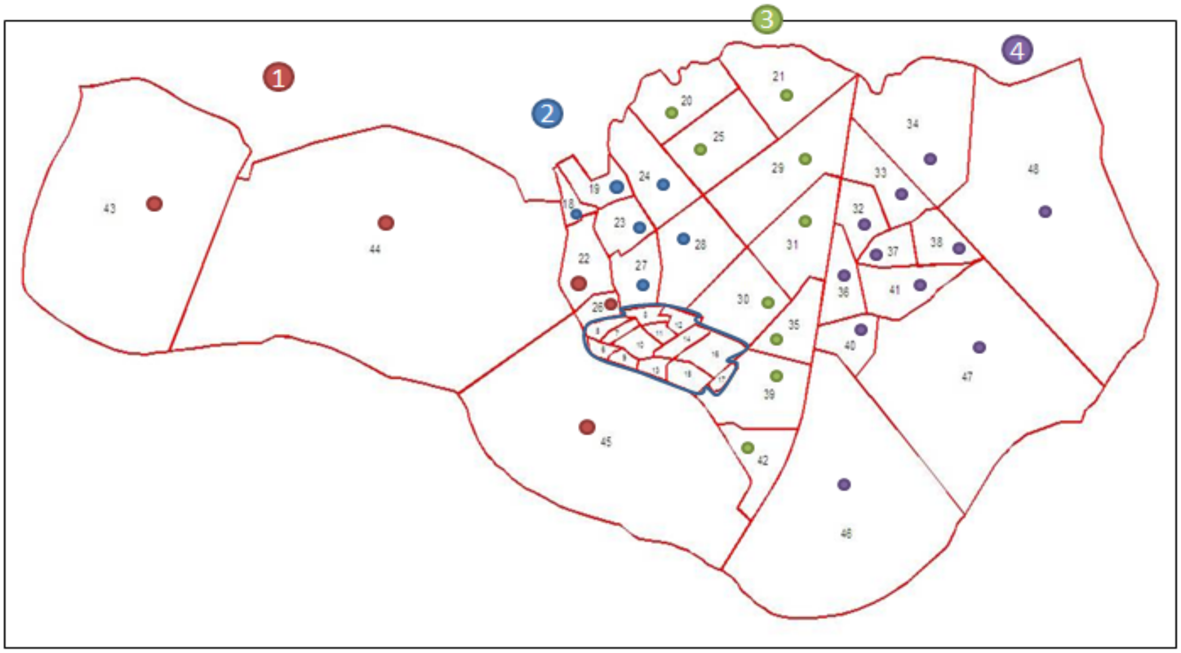

Fig. 4, First scenario of zoning and evacuation

Scenario_2:

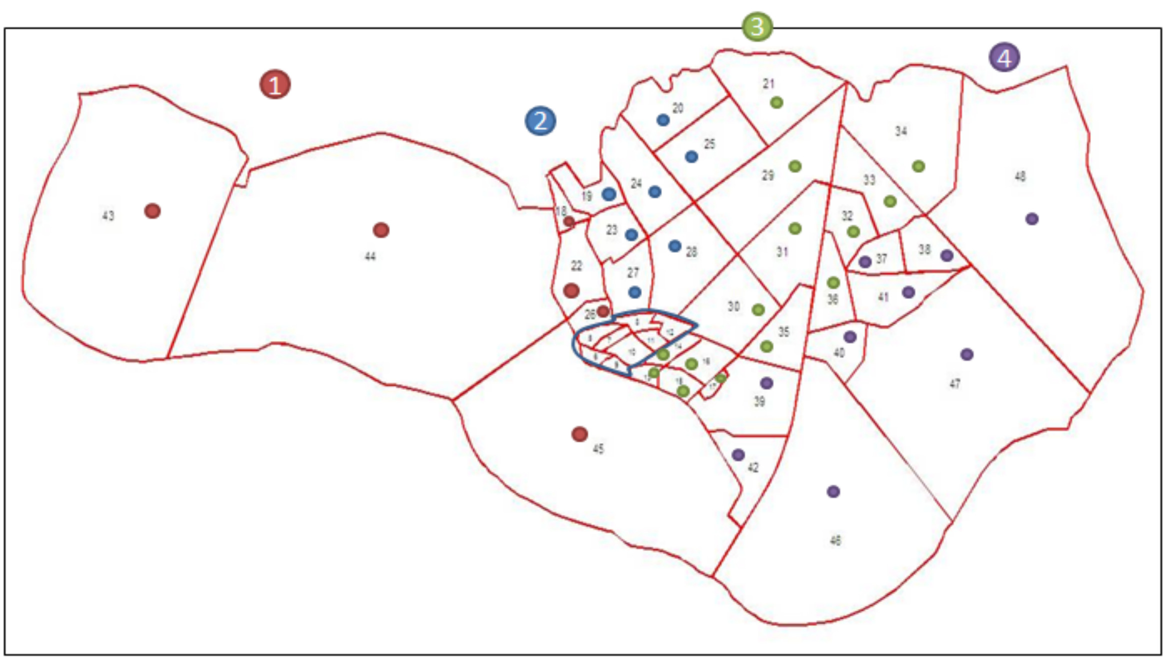

Fig. 5, Second scenario of zoning and evacuation

For each scenario related to the evacuation distribution, it would be interesting to consider two cases in in timing and percentage of people to be evacuated in the considered time intervals. By assuming the evacuation in 15 minutes time intervals during one hour the first portioning would be the case in which 20, 50, 20, and 10 percent of people are evacuated respectively. The second portioning however is that 40, 10, 40, and 10 percent of people will be evacuated respectively in 15 minute intervals during one hour. This one hour duration indicates the time during which all the trips have been generated.

These two types of portioning have been considered for each evacuation distribution scenario, and the results of the dynamic analysis have been derived for each case. It should be mentioned that the packet size is assumed 5, meaning that each 5 vehicles is considered as one packet, for which the analysis is done by the Software.

Before showing the results, it should be noted that for the sake of deriving more accurate results, four intersections located on certain points of the evacuation routes, are considered to be defined in the transportation network of San Rocco Al Porto, which have been simulated by Cube-Avenue.

Cube Avenue Simulation

Cube Avenue is a dynamic equilibrium traffic assignment model. It loads and tracks the movement of vehicle packets throughout the roadway network. Vehicle packets can be of any size, from an individual vehicle up to platoons of 20 or more vehicles. As mentioned before our assumption for vehicle packet size is five.

This software can model traffic signals, roundabouts, stop-controlled intersections, and ramp merges. The modeler can Quantify impacts of upstream traffic congestion, Measure queuing at intersections and merge points in a network, Isolate secondary impacts from one intersection through another, Simulate alternative infrastructure, operational, and policy changes to optimize emergency evacuation plans and strategies, and Test strategies to improve arrival and departure from stadiums and other special-event facilities.

Cube Avenue works with traditional four-step transportation planning models (Citilabs webpage, 2012). It is worth mentioning that the four steps of transportation demand analysis are Generation, Distribution, Modal Split, and Choice of the Route.

Our method simulates the evacuation of the city based on Mesoscopic Model and gives some results regarding to the time needed for the evacuation. Moreover, it considers different scenarios in timing and also in population transfer distributions.

Results

To make a comparison between the four cases, in both scenarios, the second portioning gives a more congested flow at the end of the first interval compared to the first portioning. It is because the percentage of the vehicle being evacuated in the first portion is 20% in the first 15 minute, while this percentage is 40% for the second portioning.

Final evacuation time can be derived by the output of the Cube Software analysis as well. The final evacuation time is the time for which there is no vehicle left on the network anymore, and all the desired trips have been already done. The results of the different four cases are shown in the Table 1.

Vehicle Movement Time (hour)		
	Scenario_1	Scenario_2
Portion_1	2:22	1:31
Portion_2	2:24	1:33

Table. 1. Duration of evacuation by scenarios and portions

It is observed that the portioning (timing and percentage of vehicles to be evacuated), makes relatively negligible difference in the total time of evacuation procedure. On the other hand, the difference of the defined scenarios has an important effect on the final time of evacuation. As observed, the second scenario gives less total time in evacuating people. It can be explained by the characteristics of the 2nd scenario, for which the assigning origin to destination centroids are defined and in a more distributed way; for instance, the most crowded area of the town will be redirected to different shelters in the second scenario, which itself makes the evacuation routes less congested.

Second Method – Timeline Evacuation

The NSW SES (SES Webpage, 2012), has been developing a graphical method for the analysis of flood warning and evacuation scenarios. The method is an adaptation of basic time line management or critical path diagrams. The resulting diagram is a timeline of emergency response for flood evacuation. This method has the advantage of showing how critical the relationship is between flood prediction, evacuation decisions, emergency service response and community actions and the passage of time in a flood.

Figure 6 shows the proposed Schematic Timeline of Emergency Response for Flood Evacuation by NSW SES. A horizontal line represents how much time is expected to be available in a flood with the amount of time available will be influenced by the rate of river rise. Marked off along the line are the points of occurrence of known events e.g. when a flood prediction will be given, when roads will be closed by flooding. Next, in sequential order along the line, the duration of each decision or action is marked off, including safety factors. The resulting time-line can then be used to show participants in a flood planning or response activity what has to be done, when it has to be started, and approximately how long it might take during the flood scenario analyzed (Lindell, 2008).

Procedure

Along the line, the start and end points showing the duration of the common elements in the evacuation process are identified. Some of these elements include: flood prediction; emergency service mobilization; community warning and evacuation traffic movement. Since the evacuation simulation by Mesoscopic model only covers the "Vehicle Movement" phase of evacuation process, in order to compare its results with those of the Evacuation Timeline method, here we are just interested in Vehicle Movement Time. It should be noted however, that the evacuation timeline method covers the entire procedure of evacuation, which is not the case of our research.

The closure by flooding of the last useable evacuation route marks the effective end of the available evacuation time. Its timing with respect to the time required for the evacuation is crucial. If flooding is slow and safety roads are cut after the minimum time required for the evacuation, a safety factors is available and evacuation can succeed even in the case of unexpected events during evacuation (traffic jam, accidents, etc.) If flooding is fast and available time is less than those required by evacuation, other strategies must be planned (Lindell, 2008). The characteristics of the flood event will determine the time available for successful implementation of evacuation. This available time can be considered as a rough estimation of the concentration time of the catchment. However the details about this estimation are out of scope of this paper since our focus in on the time which is needed for vehicles to move on evacuation routes in order to reach from the centroids of zones to the shelters.

To estimate the evacuation time by the aforementioned Timeline, two famous tools can be used. The first tool has been indicated by (opper, et al., 2010), and the second tool has been suggested by Lindell (Lindell & Prater, 2007), (Lindell, et al., 2002). The fundamental assumption in this method is that people evacuate by their own vehicles.

Although the phase of Vehicle Movement Time is our concentration, it's worth to describe all the phases of an evacuation operation in a concise way. According to the Timeline, evacuation is composed of time intervals expressing procedure's phases:

Prediction Time

It is defined as the time required for flood prediction, which can be influenced by factors such as:

- Physical characteristics of the catchment, leading to flood model.
- Data collection, including methods, hardware, and transmission.
- Flood modeling capability, including data, software, and history.
- Human resources, consisting of staff availability, experience, and activation time.
- Weather forecasting capability.

Since the above mentioned parameters are unique for each region of study, an estimation of the prediction time is rather a case specific task.

Decision Making and Mobilization

It is the time required to decide on a course of action and mobilize resources. Decision making in a timely manner is significantly important especially in the case of floods with lower concentration time, when available time from prediction to impact is limited.

A reference value for Decision making and mobilization time is six hours, recommended by NSW SES. On the other hand Lindell method does not provide any estimation in this respect. In fact when catchment response time is too short (e.g. in flash floods) decision making must be anticipated in order to implement evacuation; therefore uncertainty increases.

Warning Time

It is the time required to warn people. The influencing factors for warning time estimation are as following:

- Warning methods which could be door knocking, radio, TV, web, sirens, telephone, and so on.
- Human resources such as staff availability, experience, and activation time.
- Extension and features of area at risk.

According to SES the time required by a two person team to physically knock on the door of a house and warn is equal to five minutes.

According to Lindell, on the other hand, the following formula could be used:

$$P_t = 1 - e(-at^b)$$

In which, "Pt" is the proportion of the households that have been warned at time t. "a" and "b" factors depend on how rapid the warning is expected to be accomplished. For example a=2.5 and b=0.6 are suggested in a case of very rapid warning.

While warning technology does hold great promise in terms of broadening the arsenal of warning methods, the SES is confident that door knocking provides a high degree of warning reliability. Importantly, the SES has found that a very short warning time may not only be unnecessary, it may be entirely counter-productive and lead to traffic congestion or total grid-lock. (Opper, 2004)

Response Time

It is the time required for people to organize themselves for preparation. SES considers a reference value of three hours for response time, which is derived by summation of Warning Lag Factor (WLF), and Warning Acceptance Factor (WAF).

To be noted is that response time must be added to the start of the concurrent traffic movement element. This is done because traffic flow begins only after the first period WLF has ended i.e. literally after the occupants of the first house warned have begun to depart. WAF takes into account that people usually wait some time before deciding to respond.

Lindell suggests a similar formula to that of warning time however, "Pt" is the proportion of households prepared, and "a", "b" are empirical factors depending on the number of residence per home.

Lindell asked residents to report the length of time they estimated that it would take them to prepare to leave work, travel from work to home, gather household members, pack travel items, install storm shutters, and secure their home before evacuating from a hurricane. A plausible assumption is that tourists would be three times as fast as permanent residents at home. The rationale for this assumption is that transients would only need to pack and check out. For this case "a=0.35 and b=3.00".

Vehicle Movement Time

It is the time required for vehicle to move to safe areas. The two methods for calculating the vehicle movement time are as following:

- SES Method:

The purpose of the model is to produce a best estimate of how much time is expected to be needed for traffic clearance from the area being evacuated. To enable the timeline to be developed some assumption has to be made about the scenario and the number of vehicles.

It may be possible to calculate actual demand on a scenario by scenario basis but the SES has adopted a proxy for maximum vehicle demand. SES model assumes that maximum traffic demand is likely to be based on the total of all private vehicle ownership within the target area (Opper, 2004).

SES considers a traffic safety factor (TSF) to take into account of possible accidents and road interruptions. Moreover, a road reduction capacity factor is considered for taking into account of adverse traffic conditions, heavy rain, and so on.

Vehicle movement time is calculated by the following expression:

$$VMT = N_v / (C_{PER} * f_r) + f_{TSF}$$

In which,

N_v: Number of evacuating vehicles
C_{PER}: Capacity of primary evacuation route.
f_r: Capacity reduction factor
f_{TSF}: Traffic safety factor

To allow for the delays that would be caused by a major traffic incident or a tree/power line falling onto the road, a specific Traffic Safety Factor (TSF) must be added to the calculated traffic movement duration.
To account for and the time needed to attend to a serious traffic incident and get traffic flowing again, it is considered that the minimum TSF is one hour. It was considered that a minimum TSF of 1 hour for traffic flow durations of l-3 hours should be applied. The TSF then increases by 0.5hrs for each additional 3hrs of flow duration i.e. TSF = 1.5 hours for 4-6 hours duration and 2 hours for 7-9 hours duration, etc (Opper, 2004). The following table shows a more detailed of TSF values.

Base Time (Hours)	Safety Factor (hours)	Total Time (Hours)	Base Time (hours)	Safety Factor (Hours)	Total Time (hours)
1	1	2	9	2	11
2	1	3	10	2.5	12.5
3	1	4	11	2.5	13.5
4	1.5	5.5	12	2.5	14.5
5	1.5	6.5	13	3	16
6	1.5	7.5	14	3	17
7	2	9	15	3	18
8	2	10	16	3.5	19.5

Table. 2. Evacuation Traffic Flow Traffic Safety Factors

SES method does not consider an explicit separate parameter for the influence of waiting time in queue, but this effect can be implicitly taken into account in capacity reduction factor. In our case for both scenarios a capacity reduction factor is equal to 0.5.

For the sake of simplicity and necessity of gaining timely and applicable information to support decision making in emergency situation, a simplifying assumption is made: for deriving the number of vehicles to evacuate in each scenario, the zone with longest distance to the safe shelter is chosen, and corresponding number of vehicles is extracted from the available data. It's worth to mention that this parameter is different for the two scenarios because of difference in zoning.

- Lindell Method:

To use this method the following steps are required:

Step1- Compute the Trip Generation Time (TGT); According to Safwat and Youssef's procedure, trip generation time (TGT) - the time required for households to begin evacuating - is assumed to take three hours after local authorities make an evacuation decision. This time lag, which is designed to account for warning dissemination and household preparation to evacuate, implicitly assumes a step function in which no vehicles enter the evacuation route system for three hours, after which time the system immediately reaches capacity (Lindell, et al,. 2002).

Step2- Compute the number of evacuating vehicles.
Considering the population, the number of households and total number of vehicles in the town, a reference value of 1.55 is set for vehicles per household. It is the same assumption made in Cube analysis.

Step3- Compute the vehicle movement time:

$$VMT = tc + tq + th$$

tc: time spent travelling on collectors to the PER (Primary Evacuation Route).
tq: time spent in a queue awaiting access to the PER.
th: time spent travelling on the PER.

The first term (tc) is determined by the speed at which each vehicles travels and the distance from their home to the primary evacuation route. A reasonable value for evacuation travel speed can be considered due to the case study (e.g. 50 km/h). The distance from home to PER varies by household.

The second term (tq) can be computed by using the procedure in which the beginning of warning dissemination is defined as t=0. For each time interval t>1, three equation are solved repeatedly until the time value tq (total queue duration) is reached at which all households that intend to evacuate have entered the PER (the time value at which At=0 and Qt has returned to zero is tq).

$\Delta Dt=\Delta At + Q_{t-1}$
$Pt= Min (\Delta Dt, C)$
$Qt=\Delta Dt - Pt$

In which:
ΔDt: The incremental PER demand at time t
ΔAt: The incremental access flow on collectors and arterials at time t (which is defined by the TGT distributions)
Qt: size of the queue awaiting entry onto the PER at time t (Q0 is assumed to be zero)
Pt: the flow onto the PER at time t
C: the highway capacity (which is assumed to be a constant value of 80% of normal capacity during the evacuation.

The third term (th) is computed by the calculating the time required for the last vehicle to travel from its point of entry onto the PER to the inland boundary of the risk area.

Each of the parameters above can be calculated by the formulas suggested by Lindell method. It would be interesting to perform a sensitivity analysis in order to understand which parameters have the most important role in minimizing the vehicle movement time. This analysis should be case-specific, and it is not performed here.

In general there is uncertainty about the estimates for many of the input variables, so further analyses should be conducted to determine the extent to which any ETEs (Evacuation Time Estimates) will be significantly affected by changes in the values of these parameters. In particular, these analyses should examine the effects of variation in the distributions of warning times and preparation times, the number of evacuating vehicles per household, the rate of warning compliance and spontaneous evacuation, and evacuee route choice as well as the effects of capacity changes such as lane reversals (Lindell, et al,. 2002).

Result

Taking into consideration the characteristics and the parameters of the case study, reasonable assumptions have been made for the variables and factors in order to calculate the vehicle movement time by SES and Lindell methods.

The table 3 shows the results of the two methods for both scenarios described previously. It should be noted that the two scenarios are the same as what were considered for Mesoscopic simulation in order to make the result comparable:

Vehicle Movement Time (hour)		
Method	Scenario_1	Scenario_2
NSW SES	3:07	2:12
Lindell	1:54	1:21

Table 3. Duration of evacuation by scenarios and methods

It should be noted that due to the difference in evacuation routes of different group of zones in the town, the maximum calculated VMT is considered as the vehicle movement time in order to make sure that the entire process of evacuation has been completed; for instance, in the second scenario, 46 vehicles go to the first shelter, 601 vehicles go to the second shelter, 513 vehicles go to the third shelter, and finally, 44 vehicles go to the fourth shelter.

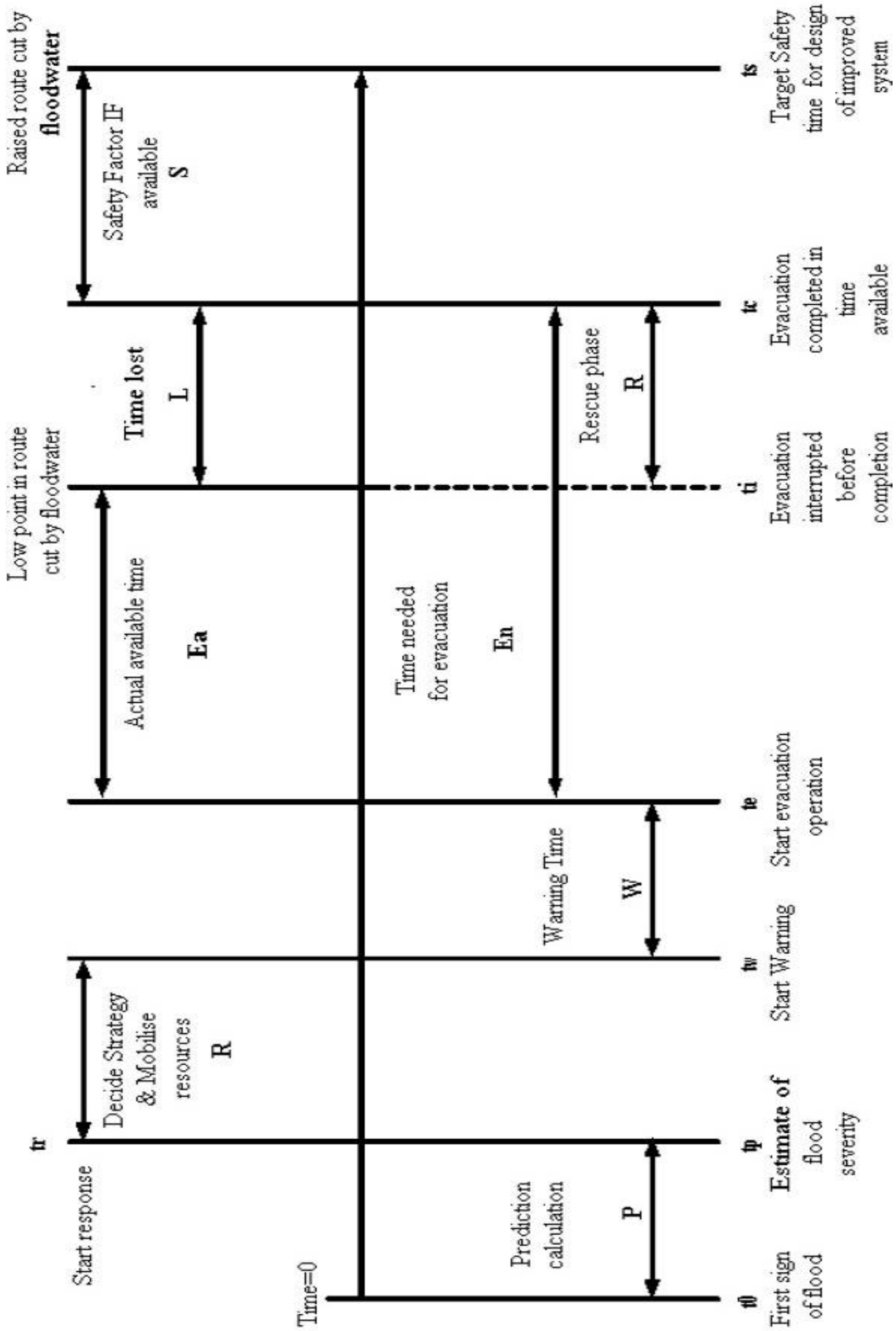

Fig. 6. Timeline of Emergency Response for Flood Evacuation

Conclusions

The two above-mentioned methods only differ from each other in the phase of vehicle movement time, which, depending on the case study, is expected to be one of the most time-consuming phases of the evacuation procedure. It is obvious that for performing a reasonably accurate traffic assignment analysis, there is a need for updated, precise, and comprehensive database. On the other hand, the second method is simpler and more available, which make it quite suitable and practical in the emergency decision making, although the accuracy is less than that of the first method.

The Timeline evacuation method is capable of estimating the time required for entire evacuation operations; although it is not so accurate, it could be beneficial for gaining a perspective of available time for evacuation. In our study, Mesoscopic modeling was used for just the vehicle movement time (VMT) of the evacuation procedure. In order to compare the results of the two models, the focus is concentrated on the vehicle movement phase also in the Evacuation Timeline Method.

According to the table 4, results suggest that the SES method gives a higher VMT with respect to those calculated by Lindell and Mesoscopic methods. On the other hand, Lindell gives lowest values for this part of evacuation process.

Achieved results can be explained by the parameters that each method uses to compute the total time of vehicle movement.

Mesoscopic method which was implemented by Cube software simulation in this study, considers some parameters that enhance the accuracy of the computations; for instance, waiting time before intersections was defined. Also, the simulation is flexible in defining different portions and zones for origins and destinations.

NSW SES Method takes into account a reduction factor for capacity and a TSF factor which can be estimated due to characteristics of roads, probable waiting in queue, possible accidents, road interruptions, heavy rain, and adverse traffic conditions.

Lindell Method considers some parameters in computation of vehicle movement time such as queue time in evacuation routes, and the time needed for vehicles to reach such routes by moving through collectors.

In emergency conditions, using available time in the most efficient way is a crucial factor in coping with unexpected events. Making decisions in such conditions requires timely and actionable information. Having a vision of total evacuation time before its implementation in real time is useful for decision makers to assess whether an evacuation by road travel is totally applicable or not.

One important part of the total evacuation time is the time needed for evacuation vehicles to move on evacuation routes; for deriving the total time of evacuation however, it is necessary to add the time required to response to warnings. While some portions of population have started to move toward the predefined shelters, others are being warned to prepare for evacuation.

An idea for future research is to compare the results of SES and Lindell Methods based on the entire Evacuation Timeline with those of analytical models which are supposed to give more accurate results.

	Mesoscopic		NSW SES	Lindell
	portion1	portion2		
Scenario1	2:22	2:24	3:07	1:54
Scenario2	1:31	1:33	2:12	1:21

Table 4. The summary of results for the Mesoscopic, NSW SES, and Lindell method

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