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A Review of the Procedures Associated with Devising Emergency Evacuation Plans

By

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ABSTRACT: The incidence of freak weather and geological events, such as earthquakes and volcanic eruptions, has increased over the past thirty years. Coupled with an increase in the populations located in the path of these natural disasters, the imminent danger posed by naturally occurring phenomena has also risen. Given the potential dangers, it is wise for policy administrators to ensure that appropriate emergency plans are in place that aim to minimize the negative consequences associated with these disasters. Effective emergency planning and management should successfully combine the skills and knowledge of law enforcement agencies, transport planners as well as the knowledge and skills of emergency planning professionals.

In Australia, there has not been a thorough investigation of the emergency impacts on the transport infrastructure nor have emergency plans adequately integrated the transportation aspect. Which transport routes should evacuees and emergency vehicles use is a question that needs to be answered urgently to avoid situations:

- Where evacuees are trapped in their vehicles,
- When emergency personnel are unable to gain access to the people in need, and
- When emergency vehicles are not able to get onto the road network due to traffic congestion.

Thus in a case of a suburban bush fire (wild fire), a fire that may have been easily extinguished or controlled is left to engulf more bush land and increase in ferocity.

This paper critically assesses the many emergency evacuation models developed and also describes the important information required to devise the models. It is clear, however, that more research needs to be undertaken that specifically investigates the effects of a mass evacuation on current transport networks.

KEY WORDS: ***Evacuation Behaviour, Travel Demand, Evacuation Modelling***

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1. Introduction

The occurrence of natural disasters is increasing *[1] [2]*, and they are mutating, and to a degree, evolving *[3]*. Despite improvements in technology to be able to predict better the onset of bizarre weather conditions (leading to droughts and bushfires, cyclones and floods), these tools may still not be accurate enough, given that the hazard may arise so quickly that sufficient warning, regarding the intensity or ferocity of the hazard, may not eventuate *[3]*. The threat is compounded by the concentration of populations into "mega-cities", placing more people at risk, hence more people will require evacuation if a natural disaster is predicted to strike an area *[3]*, *[4]*.

Evacuation is defined, generally, as the collective movement of people and the mode of transport used. Evacuations are "round" trip events *[5]*, *[6]*. There are three types of evacuations defined by the type of evacuation order: mandatory, recommended, and voluntary *[7]*. In terms of a bushfire emergency, it was established that people do not like a mandatory evacuation because it prevents them from taking part in any activity associated with property protection *[7]*, *[8]*. They appreciate being given the warning; however, they prefer themselves to make the decision to evacuate *[8]*. Further, the types of evacuation order will impact directly when and how many households decide to evacuate. This will then affect emergency vehicles and equipment access to the emergency area, given the level of traffic flowing out of it. The ability to satisfy evacuation demand depends on the rate at which demand can be exerted and the capacity of the network *[6]*.

A major problem identified with large scale emergency evacuations is that population growth has outstripped the improvements to infrastructure (road capacity); hence, mass evacuations will be more difficult and time consuming *[9]*, *[10]*. This places greater importance on mitigation strategies and more pressure on emergency and associated personnel in an emergency situation. Emergency agencies, responsible for the development of natural disaster plans, are now consulting the transport engineer more regularly *[11]*, hence, the transport engineer's role in emergency management planning is becoming increasingly important.

Travel needs in emergency situations differ from everyday travel needs and have been identified as the following:

1. Increased route capacity;
2. Limited travel demand resulting from evacuation;
3. Good information systems to allow for the accurate delivery of traffic flow and traveler information; and
4. Better coordination between regional and interstate agencies in relation to large scale (interstate) evacuations *[12]*.

Underpinning travel needs in emergency situations is evacuation behavior. Understanding evacuation behavior is crucial to determining the forces behind evacuation travel demand.

This review is divided into three sections. Section one describes the elements of behavioral analysis and the importance of this. Section two is divided into three subsections; the first outlines the components of transport analysis, the second describes macro-simulators, and the third defines a dynamic traffic assignment, describes traffic management strategies employed in emergency situations, and also describes micro-simulators and decision support systems. Section three highlights the increasingly important role of governments in emergency situations and concludes by stressing the importance of emergency evacuation plans that adequately incorporate the transportation aspect.

2. Evacuation Behavior and Analysis

Evacuation behavioral analysis needs to address the following:

- How many people will evacuate (evacuation participation rate);
- When will evacuees leave in relation to an evacuation order;
- What will be the rate of public shelter usage;
- How many evacuees will leave the local area; and
- How many of the available vehicles will be used *[13]*.

Understanding evacuee behavior is essential if an evacuation plan is to be successful *[14]*. What needs to be understood is how people perceive an evacuation, in terms of threat and risk, and how this perception influences the decision to evacuate or not *[5]*.

Decisions made at the individual level are:

- Whether to evacuate;
- When to evacuate;
- What to take;
- How to travel;
- Route of travel;
- Where to go; and
- When to return *[5]*.

Individual behavior can result in evacuation shadow or excessive evacuation, panic, convergence (people head towards area that should be evacuated placing more people at risk), spontaneous evacuation, failure to use allocated transport routes, evacuation stress, and failure to respond to an evacuation warning *[5]*. The decision of people to evacuate is influenced by their belief in the evacuation warning, (warnings issued by emergency personnel are effective in getting people to evacuate), the level of the perceived risk, a plan to evacuate (the success of this plan relates to evacuation experience), and the family context in which the warning was received *[5], [7], [15]*. For example, after a cyclone warning was issued for parts of Tropical Queensland, Australia, people inadequately prepared their homes because of a lack of experience, lack of good information about what should be removed and a general feeling of complacency *[16]*. People with less warning time were more likely to be in denial and did not take the warning seriously *[16]*. However, people are likely to respond to an evacuation order if it is addressed to them, and the mode of message delivery is personal *[17]*.

Participation in evacuation procedures depends on the confidence of the public in the authorized evacuation process. Respondents require more information on evacuation routes, track of the storm or natural hazard, and would like to obtain maps that graphically depict this information. Transport related information was considered extremely important to individuals thus highlighting the importance of transport in an evacuation *[15]*. Also, independent decision making requires information to enable individual risk assessment.

Public perception of risk is different to expert perception and this must be acknowledged *[15]*. It has been identified that three social-network variables affect warning response. These are family interactions (extended family links are important in explaining evacuation response regardless of age; warning messages from family and friends are more effective than media sources in stimulating adaptive behavior), community involvement, and age *[5], [18], [17], [15], [19]*. Members of the same household exhibit the same evacuation behavior thus demonstrating the effects of family interactions on evacuation behavior *[20]*.

It was also found that households with children are more likely to evacuate and long term residents were not likely to evacuate *[15]*. Access to homes after an evacuation, protection of property, job obligations, and the well being of pets can often outweigh advice on safety and thus prevent households from evacuating *[15], [20]*. Evacuation delay was observed for older households and households with pets due to inappropriate transport: owning pets was the most significant reason why childless households did not participate in the evacuation procedure *[20]*. The reasons for households not evacuating can be summarized by the following:

1. Wanted to stay to protect property;
2. Did not see neighbors evacuate; and
3. The inconvenience associated with evacuating *[17]*.

Evacuation rates are much higher for floods and chemical spills than for hurricanes possibly due to the level of uncertainty of landfall: people do not decide to evacuate until they become more certain that they are located in the direct path of the hurricane *[21]*. This may also apply in bushfire situations. A summary of the influential factors towards evacuation behavior are displayed in Figure 1.

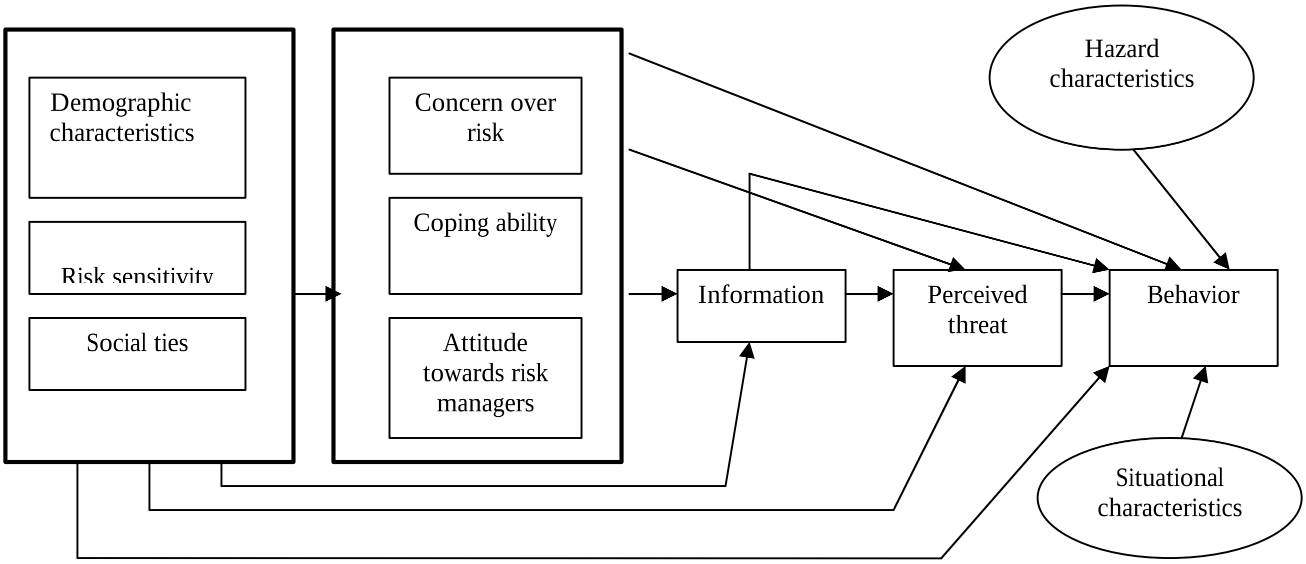

Figure 1: A general model of evacuation behavior.
Source: Sorensen *et al*., 1987.

Figure 1 depicts the complexity involved in understanding and quantifying evacuation behavior and demand. However, estimates need to be made for modeling purposes. Evacuation behavior is quantified through the estimation of evacuation time. Evacuation time involves the estimation of the number of people expected to evacuate (evacuation demand), time required to move the evacuation population outside the evacuation area, the available road capacity, and the impacts from surrounding areas that will affect the evacuation results *[12], [10]*.

Evacuation time consists of response time (the time required for respondents to physically travel to safety, also known as clearance time), decision time (time between incidence detection and an official decision to order an evacuation), notification time (evacuation warning) and preparation time *[21], [22]*. An understanding of the components of evacuation time is extremely important when conducting evacuation behavioral analysis.

Response times may be depicted graphically in response curves (Figure 2). In any evacuation plan, evacuation times must be determined, or approximated, to allow planners to develop strategies that enable the safe evacuation of residents of threatened areas *[24]*. This information will be used in modeling techniques: knowledge of evacuation behavior enables the estimation of evacuation travel demand. However, a problem with the definition of evacuation time is that it only considers evacuation based on a mandatory evacuation order. Recommended and voluntary evacuations are not considered. Thus, evacuation models to date only incorporate evacuation behavior based on mandatory evacuations. The most recent bushfire experience in Sydney involved recommended and voluntary evacuations. The exclusion of evacuations resulting from voluntary and recommended evacuation orders leads to an underestimation of evacuation travel demand: a vital input of evacuation models.

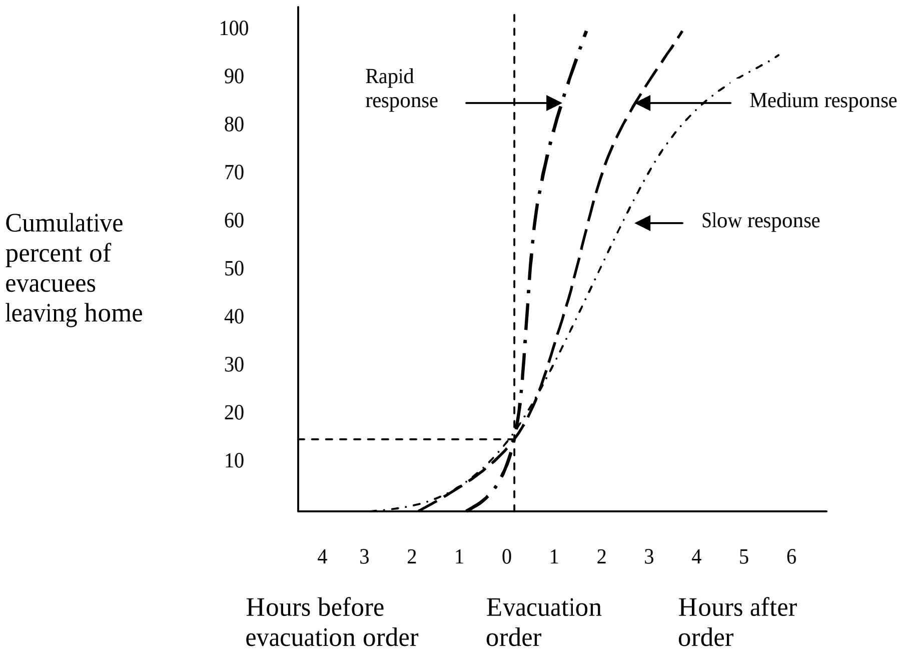

Figure 2: Behavioral response curves.

Source: Lewis, 1985.

3. Evacuation Modeling

Transport analysis is an important component of the overall evacuation plan. This analysis is a combination of road and street network evaluation and inputs from behavioral analyses. Transport analysis involves the following:

1. The specification of disaster scenarios (a separate transport analysis is conducted for each scenario);
2. Definition of evacuation transport zones;
3. The determination of demographic characteristics such as the size of the population at risk and characteristics of the evacuation population for each zone;
4. Updating traffic conditions as they become known;
5. Simulating changes in the links (roads) resulting from extreme weather conditions and fires and floods;
6. Identifying roads and streets expected to be heavily used in an evacuation as well as their characteristics;
7. Estimating the number of trips expected (this depends heavily on the outcome of the behavioral analysis) and trip productions and attractions are calculated for each zone;
8. Distributing trips among the evacuation transport zones. In some instances, gravity models are used to show the effects of distance between pairs of production and attraction zones and the population size of likely attraction zones;
9. Assigning trips to the road network connecting the zones; and
10. Calculating clearance times for each scenario *[13], [10], [25]*.

In other words, due to changes in the expected travel behavior of individuals in an emergency situation, the evacuation model must be able to determine the number of individuals who need to be evacuated, allow the planner to determine as accurately as possible the origins and destinations in a specific time period, replicate as accurately as possible human behavior in an emergency situation and be flexible to allow for changes in the demand characteristics of the emergency *[10]*.

However, to conduct transport analysis, the following list of information is required:

1. An accurate description of the transport network/infrastructure;
2. Size and makeup of the evacuation population including the location of sub-populations such as hospitals and schools;
3. An accurate description of the spatial distribution of population by time of day and type of activity. Traffic rates are diffused throughout the day and therefore traffic peaks do not just occur during peak commuter hours. This needs to be accounted for as well as large amounts of background traffic which may include through traffic;
4. Shape, size and rate of growth of the evacuation area (identifying the Emergency Planning Zone);
5. An accurate representation of vehicle utilization during an emergency. It is assumed that the number of household vehicles used during a night time evacuation is lower than the number of household vehicles used during a day time evacuation. Thus, it is expected that vehicle occupancy rates during night time evacuations will be higher than day time vehicle occupancy rates. This is an area that requires further investigation;
6. An accurate representation of the timing of people's response to an emergency;
7. An accurate representation of evacuee route and destination selection behavior;
8. An accurate representation of traffic management controls that may be included within the evacuation plan; and
9. An accurate representation of any non-evacuation based protective actions *[10], [21], [26], [24]*.

Also, to model the evacuation process, sub-models of initial response, route choice, accident response, and human behavior are needed *[27]*. Without most of the information listed above, the ability to simulate an evacuation realistically is drastically reduced. This information is used to create:

- A traffic generation model (travel demand);
- A traffic departure time sub-model (traffic loading rate or traffic mobilization);
- A destination selection sub-model;
- A traffic route selection (traffic route assignment) model; and
- A user specified plan set-up, analysis and revision procedure *[21], [28]*.

4. Emergency Evacuation Models

Computer simulation models were developed to analyze and evaluate evacuation plans for urban areas in particular. In this section, macro-simulation models developed in the 1980s are described first. This is followed by descriptions of micro-simulation models and decision support systems developed in the 1990s, and current practices.

1980s

Unreasonable estimates of evacuation times, obtained from a dissipation rate model (that used a simple aggregate formula to estimate evacuation time) and manual capacity analysis (capacity for each road in the area was calculated and evacuation routes for each sector were allocated the population for each sector; clearance time was calculated by the total number of vehicles assumed to evacuate by the capacity of the evacuation routes) led to the development of NETVACI, a traffic simulation model for emergency situations (primarily developed to assess evacuation times in a nuclear plant emergency: *[29]*). Prior to this, NETSIM, a micro traffic simulation package, was widely used *[20]*. A recognized limitation of NETSIM was its limited capacity despite its use of data at a disaggregate level.

NETVACI is a fixed time macro traffic simulation model that gives information about the queue forming process and dynamic route selection. It enables a number of options to be adapted to account for weather changes, intersection controls and lane management strategies *[29]*. It uses a graphical representation of the transport network. However, it does not track individual vehicles; it is an aggregate model. This model uses mathematical relationships between flows (capacity of the roads under investigation), speeds, densities, queue length, and other important traffic variables to simulate the evacuation process. NETVACI deals with both section and approach capacity[1] and assumes that driver's choice is based on prior knowledge of the network in terms of directionality and normal link characteristics, as well as a narrow minded view of traffic conditions ahead *[29]*. NETVACI requires three types of input data. These are network description, spatial, and temporal loading patterns and traffic control parameters *[29]*. There is no explanation as to how vehicle loading rates were calculated and no mention of evacuation behavioral analysis.

Another model developed in the 1980s was MASSVAC. It incorporates three modules:

1. A community and disaster characteristics module that defines the community threatened, the natural disaster looming on the community, and the boundary of the hazard;
2. A population distribution and characteristics module that identifies the geographic and temporal allocation of the permanent and transient population; and
3. A network evacuation module that contains characteristics of the transport network, the traffic assignment method, the re-routing of excess demand to alleviate congestion on particular links within the network, and the estimation of evacuation time *[24], [31]*.

[1] The former is the capacity along the link regardless of downstream intersection restrictions and the latter is the capacity of the link to cope with vehicles going to the downstream intersection.

The model is able to perform analysis at both the micro and macro level, but it is not a micro-simulation model. The macro level looks at the evacuation process on the network by focusing on major road arteries: these are considered as a complete and integrated system. Under this level of investigation, the model estimates the maximum time to evacuate the network given various disaster intensity levels and identifies potential areas where heavy congestion is likely to occur. Solutions to prevent or minimize these areas of congestion can be entered into the model and clearance times can be recalculated *[24], [31]*. The problem with this approach of the MASSVAC model is that the time taken to reach the nearest major arterial is ignored. It may take a significant amount of time to reach the arterial. For example, if the natural disaster or threat is located within a suburban area which is connected to a major arterial road by a few small two lane roads[2] and a mass evacuation is taking place, then this approach of the MASSVAC model leads to a gross under estimation of evacuation time. It does not account for traffic congestion on segments of the road network other than the arterial roads. The micro level investigates the highway network in more detail in terms of allowing for different traffic controls and operations across certain intersections and varying traffic operational strategies, to improve the evacuation process *[24], [31]*. However, this approach also leads to an under estimation of evacuation time for the same reasons as explained above.

MASSVAC requires the network to be coded, the calculation of loading rates[3], appropriate selection of evacuation scenarios, and traffic operation strategies, such as increased road capacity (reverse lanes so that all are operating out of the evacuation zone). It scenarios described in the simulation *[24], [31]*. Again, there is no mention of evacuation behavioral analysis or how vehicle loading rates were calculated.

According to Stern and Sinuany-Stern *[32]*, behavioral based models (micro-simulation models) display a different evacuation process to that observed in the non-behavioral based models. The behavioral model accounts for the diffusion time (information diffusion) and decision making time. Therefore, vehicles gradually accumulate at urban exits before reaching a peak. After a specific time, in this case nine minutes, the number of vehicles passing through the urban exits decreases. This enables higher driving speeds in the first few minutes of evacuation. The incorporation of behavioral aspects leads to longer evacuation times, but is more realistic and leads to a more accurate estimation of peoples' travel behavior in an emergency situation. In other words, micro-simulation m s output includes street status[4] and the total evacuation time for time intervals under the odels that look at individual vehicle behavior are more useful when it comes to emergency evacuation modeling.

According to Southworth *[31]*, destination selection procedures, a component of an evacuation model, can be modeled in four ways:

1. Evacuees are assumed to exit the threatened area by moving towards the nearest exit;

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[2] These provide access into and out of the suburb in question.
[3] Number of vehicles entering the road network at a given time interval.
[4] Information about each street on the network in terms of volume, travel time and speed, congestion and duration of the congestion, at each time interval.

2. Evacuees will disperse and not choose similar exit points; this will depend on location of friends and relatives and the travel speed of the approaching hazard;
3. Evacuees will move towards pre-specified destinations, depending on the evacuation plan in operation; and
4. Evacuees will depart the area given the underlying traffic conditions of the network at the time of evacuation (allows for myopic evacuee behavior).

Which destination selection procedure is used depends on the evacuation model employed. A summary of the early modeling techniques is provided in Table 1.

5. Developments in the 1990s and current practice

Before recent modeling developments are presented, the concept of dynamic traffic assignment is explained. This is followed by a description of traffic management strategies currently used during emergency evacuations.

5.1 Dynamic Traffic Assignment

Many vehicles may take longer to get through the network than described in traditional and widely used static assignment models. In static assignment models, the level of service[5] of the network is assumed to remain constant over the simulation period, i.e., a snapshot of the network is taken at 8 a.m. and modeling is for the period between 8 and 9 a.m. The traffic conditions are assumed to be constant over the simulation period. However, in emergency situations, large travel distances are usually involved hence, it would not be accurate to assume that conditions remain constant over the simulation period. Dynamic traffic assignment allows for the incorporation of different traffic conditions as the vehicles travel through the network. For instance, by the time a vehicle evacuating reaches a certain point in the network, it is more likely that the level of service and other traffic conditions have changed. Hence, traffic conditions experienced by this vehicle are different to those that previous vehicles encountered. This will also impact dynamic route assignment and it would be better to have an evacuation model that incorporated a dynamic route assignment as well as a dynamic traffic assignment.

[5] Level of congestion and capacity of the network

Table 1: Characteristics of Selected Evacuation Models

Model	Type of Traffic Stream Simulation:			Type of Traffic Route Assignment:		
	Micro	**Meso**	**Macro**	**Simple**	**Static**	**Dynamic**
CLEAR	X			X		
DYNEV		X			X	
DYMOD			X			X
EVACD			X			X
MASSVAC			X			X
NETVAC			X			X
NETSIM*	X			X		
SNEM	X			X		
TWEEDIE ET AL.	X			X		
UTPS-BASED**			X		X	

* NETSIM is a micro-traffic simulation not a full evacuation model
** UTPS is the Urban Transportation Planning System package (now incorporated in various proprietary software packages)
Micro-simulators track individual entities
Macro-simulators track the masses as a whole.
Meso-simulators track movement of groups of vehicles.

Source: Southworth *[31]*.

5.2 Traffic Management

In emergency situations, it has been identified that transport routes out of the affected area are either limited in number or will not cope with the expected increase in demand resulting from a mass evacuation. These circumstances warrant a change in traffic management practices to accommodate the needs of the emergency evacuation plan. This is also exacerbated by the fact that, in most emergency evacuations, the traffic mix is different to the everyday traffic mix *[11]*. An inexpensive and relatively quick and simple way to increase route capacity, thus improving the level of service, is to engage in contra-flow or lane reversing *[11], [9], [12]*.

Four variations exist for the use of contra-flow. These are:

1. All lanes reversed, the most commonly used because it results in the greatest increase in capacity;
2. One lane reversed and one lane normal inbound for emergency vehicle entry;
3. One lane reversed and one lane normal inbound traffic; and
4. One lane reversed with the use of the shoulder segment of the outbound lane *[12]*.

Contra-flow has been used in the United States primarily in hurricane prone areas in the South East of the continent, but may be applied in any disaster situation *[11], [12]*. Importantly, before lane reversing takes place, information needs to be dispersed throughout the affected area to enable people to know about route closures and the change in traffic conditions *[9]*. However, with changing traffic conditions, come increases in risk. A major concern associated with contra-flow is the re-routing of traffic at the end of the reversed segment of road as well as limited access to highways, that may be the main evacuation route, from specific points on the road network *[11], [9]*. The level of risk associated with lane reversing has not yet been investigated and more research still needs to be conducted in the areas of travel/evacuation demand and behavior, increased capacity, traffic speed and other data requirements *[11], [12]*.

5.3 Micro-Simulation Models

MITSIM is a Microscopic Traffic Simulator that simulates integrated traffic networks supported by advanced traffic control and surveillance systems. Transport networks are represented by nodes, links, segments and lanes and a probabilistic route choice model is used to estimate driver's route choice decisions in real time traffic information, obtained from Intelligent Transport Systems *[33]*. The simulator only considers travel time in choosing a route: a dynamic shortest path algorithm is used and this accounts for link travel times perceived by particular driver groups[6], delays and regulations of turning movements at intersections and lane use privileges *[33]*. The simulator's outputs include: vehicle specific information (i.e., total travel time, kilometers traveled, average speed), readings from traffic sensors (i.e., traffic counts, occupancy, speed, point to point travel times and incident information), segment specific traffic data (i.e., density – number of vehicles per kilometer, average speed, and travel speeds), warnings and error messages of the simulation run, and a graphical display of the vehicle movements and segment-specific traffic data, i.e., average density and speed *[33]*. It is undergoing further development to account better for travel behavior.

A review of micro-simulation models, partly funded by the European Commission for Transport Research, was undertaken in 1997. This investigated the micro-simulation models outlined in Table 2. This review incorporated data obtained from a survey sent to the developers of the models and also to the primary users of these models. The majority of the respondents stated that the objective of a micro-simulation model is to quantify the benefits of Intelligent Transport Systems, particularly Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) *[34]*. Forty-eight percent of the models analyzed incorporated a dynamic route assignment. However, none of the models incorporated a dynamic traffic assignment. Some of the respondents claimed that current micro-simulation models are not suitable for large travel time and large distance networks *[34]*. In emergency situations resulting from natural disasters, evacuees sometimes need to travel long distances to avoid natural disasters such as a hurricane, thus corresponding travel times are also large. In other words, the models mentioned in Table 2 are not useful for emergency evacuation modeling. Also, two of the models mentioned, SITRAS and TRANSIMS, in their most current versions, do not incorporate a dynamic traffic assignment *[35]*, *[36[7]]*. Modeling human behavior is very complex and difficult. In order to develop micro-simulation models that incorporate dynamic traffic assignment, more accurate relationships expressing human travel behavior need to be developed.

A more recent development, DynaMIT, is a simulation based system that incorporates a dynamic traffic assignment. This model is able to:

1. Perform dynamic traffic assignment;
2. Account for the effects of updated traffic information;
3. Amalgamate real-time sensor data and historical information;
4. Estimate and predict origin and destination flows in real time;
5. Produce descriptive as well as prescriptive information; and

[6] Driver groups were not defined.
[7] In this review, the model TRANSIMS, a dynamic route assignment, was termed a dynamic traffic assignment. This model does not incorporate a dynamic traffic assignment.

6. Is integrated with MITSIMlab (a microscopic traffic simulator, described above; *[37]*, *[38]*.

Table 2: List of Micro-Simulation Models

Model	Country	Model	COUNTRY
AIMSUN 2*	Spain	NEMIS	Italy
ANATOLL	France	PADSIM	UK
AUTOBAHN	Germany	PARAMICS*	UK
CASIMIR	France	PHAROS	USA
CORSIM	USA	PLANSIM-T	Germany
DRACULA	UK	SHIVA	USA
FLEXSYT II*	Netherlands	SIGSIM	UK
FREEVU	Canada	SIMDAC	France
FRESIM*	USA	SIMNET	Germany
HUTSIM*	Finland	SISTM	UK
INTEGRATION*	Canada	SITRA-B+	France
MELROSE	Japan	SITRAS	Australia
MICROSIM	Germany	TRANSIMS	USA
MICSTRAN	Japan	THOREAU*	USA
MITSIM	USA	TRAF-NETSIM*	USA
MIXIC	Netherlands	VISSIM*	Germany

* Commercial products

Source: Algers *et al.* *[34]*

This model may be used to evaluate evacuation scenarios. However, there is no description of how this would be achieved, emergencies for which it may be useful (natural or man-made) or how the model integrates evacuation behavior. Under its limitations, it was highlighted that more data are required to model driver behavior accurately such as route choice and driver's response to information: two crucial components of evacuation behavior. To date, no micro-simulation model is able to incorporate a dynamic traffic assignment while also adapting to the emergency evacuation scenario.

5.4 Decision Support Systems

The evacuation models developed in the 1980s (based primarily on macro-simulation models modified to incorporate and account for characteristics of disasters both natural and man-made) led to the development of Decision Support Systems which include Geographic Information Systems (GIS). The aim of a DSS is to provide a holistic planning package that incorporates both the transport aspect and spatial implications of an emergency evacuation. The first of these was the Traffic Evacuation Decision Support System (TEDSS). TEDSS is based on MASSVAC 4 (MASSVAC 3 modified to deal with transport demands that may arise in evacuation situations) and is composed of four modules: system control module, database module, simulation models module and graphic display module *[39]*, *[40]*. The initial decision to evacuate is obtained from the TEDSS's traffic simulator *[40]*. The simulation module of TEDSS is an event type simulation designed to load evacuees onto the highway network to determine the best evacuation routes, to calculate evacuation time and to identify bottlenecks on the system *[40]*.

TEDSS allows for changes in the transport network to be accounted for and hence is considered to be more dynamic than previous approaches. Due to network data availability in electronic form, damage to the existing road network that results from a disaster may be updated in the system and accounted for in the modeling process by applying a heuristic procedure that determines the shortest possible path for the new circumstances calculated as a time or distance *[41]*. Also, if a volume assigned to a link exceeds capacity, the link is considered congested. If the volume exceeds the capacity by double the amount, the link is declared blocked and will no longer be assigned trips. Trips that cannot be dissipated in the given time interval will be computed and assigned to the link in the next iteration. This demonstrates another dynamic feature of the traffic assignment mode. This information can be conveyed to planners to eradicate excess traffic volumes in the network along particular links *[42]*.

Output includes origin-destination tables, evacuation paths, the assignment of evacuees to shelters, identification of congested links, network clearance times, and the adoption of traffic management strategies. However, as mentioned previously, the macro-simulation model on which this is based, underestimates evacuation travel times and does not include a dynamic traffic assignment.

In the mid 1990s, another DSS for emergency evacuations was developed: Configurable Emergency Management and Planning Simulator (CEMPS) that is actually a Spatial Decision Support System (SDSS) formed through the amalgamation of simulation modeling and Geographic Information Systems *[43], [14]*. The simulation model is used to determine appropriate evacuation plans to enable the movement of the populations at risk to safe areas.

An SDSS has four components:

1. Analytical tools;
2. Decision models (Recognition Primed Decision models (RPD) that are used to understand individual decision making behavior under time constraints; the case in evacuations);
3. Geographic/spatial database; and
4. A user-interface *[14]*.

Simulation and link routines were added to provide dynamic interactive capability. The result was CEMPS which has four main components:

1. A traffic simulation model;
2. GIS;
3. Interactive link module; and
4. A user-interface *[14]*.

Parameters that may be incorporated into simulation to enhance realism of results include information on forces contributing to or easing the situation such as weather conditions, road accidents and closures, route choice behavior of individuals and prompt evacuation by individuals *[14]*. This enhances the dynamic route choice capability of CEMPS. In CEMPS, individual route choice scenarios can be built into the model; however, individual behavior and knowledge prior to evacuation must be accounted for. Behavioral simulation, as discussed earlier, may be conducted at the micro, meso or macro simulation level. The smaller the level, the better and more accurate are the results produced but this makes the modeling procedure more time consuming and more costly because more data are required *[14], [26]*. Spatial decision making is based on qualitative analysis (experience, intuition) and quantitative analysis (data analysis and modeling). Therefore, a lack of experience in dealing with emergencies is an obstacle to obtaining meaningful results from the CEMPS. Future developments in expert systems (decision making through reasoning) and or Global Positioning Systems coupled with GIS will make very effective SDSSs *[14]*. Despite improvements in DSS presented in the CEMPS, the CEMPS still does not adequately account for evacuation travel behavior and its traffic simulation model does not include a dynamic traffic assignment even though it incorporates a dynamic route assignment.

The basis of spatiotemporal models is similar to the traffic simulation model in the CEMPS. Population behavior is captured through the temporal model while land use and network information is captured through the spatial model. These data (temporal, spatial and spatiotemporal) are combined into a dynamic travel demand model that can be used for emergency evacuation planning *[26], [6]*. Hence, spatiotemporal models incorporate activity participation and travel behavior of evacuees and also consider land use patterns at the micro level. The limitations of spatiotemporal models replicate those of the CEMPS described above.

The Incident Management Decision Aid System (IMDAS) is a spatial decision support system, still in the development stage. Its outlined framework is very similar to that of the CEMPS. The main component of IMDAS is a micro-traffic simulator that calculates estimates of evacuation times (also can be calculated for particular segments of the network) as well as allowing for the evaluation of traffic management strategies, identification of evacuation routes and traffic control areas *[25]*. However, there is no mention of the inclusion of a dynamic traffic assignment.

Future developments in DSS should involve the creation of event and emergency risk maps *[6]*. These maps will be very useful to emergency agencies, governments and communities in high risk areas. They will provide a summary of the level of emergency and event risk for locations as small as local communities to entire regions, graphically. A hindrance to the creation of these maps is identifying the Emergency Planning Zones, due to disagreements between different emergency agencies *[6]*.

Overall, the developments in the 1990s and current practice involve a more holistic approach to emergency planning and management; from understanding evacuation behavior and conducting the analysis, applying this information in the transport analysis, and developing strategies and emergency evacuation plans that take into account the information obtained from the transport analysis. However, DSS are based on:

- Evacuation models that do not accurately account for evacuation time and therefore underestimate travel time associated with emergency evacuations;
- Evacuation models that underestimate evacuation travel demand because data obtained from the evacuation behavioral analyses concentrates on mandatory evacuations only; and
- The models do not contain a dynamic traffic assignment.

6. The Role of Government

Local governments need to have emergency mitigation plans, so as not to find themselves without the financial flexibility to account for such occurrences. In Canada, for example, the cost sharing of natural hazard events between insurance companies and local government was equal in 1998 and reflects the rising costs inflicted on governments due to inadequate planning *[2]*. Also, with increasing insurance premiums people are less likely to insure comprehensively. This negatively affects low income households and environmental justice[8] issues arise: governments are increasingly burdened with ensuring that economically disadvantaged groups in society do not suffer more than affluent groups *[2], [46]*.

To plan for disasters, local governments need to be aware of the risks. In Canada, emergency planning has been in terms of response rather than mitigation *[2]*. This needs to change. Mitigation planning needs to become part of the normal planning process and this also means that planners need to work closely with the industry (interagency coordination). In an emergency situation, local government needs to assist local businesses to ensure ongoing employment, and in turn, the maintenance of its tax base *[2]*.

Natural disasters are occurring more regularly, and because governments do not have mitigation plans in place, finite government resources are distributed to areas that were not included in government budget analyses. This puts financial strain on other government services and projects, and reinforces the need for comprehensive emergency evacuation plans.

7. Conclusion

This review has outlined the complicated tasks involved in devising effective emergency evacuation plans that may be applied in all emergency situations (man-made or natural). The importance of conducting behavioral and transport analyses were discussed, descriptions of transport models and emergency evacuation models developed were provided as well as descriptions of decision support systems. The increasingly important role of governments was also mentioned.

Issues raised will become increasingly important as the incidence of freak natural occurrences increases along with the concentration of populations into "mega-cities". This places more pressure on emergency personnel to successfully evacuate populations given no increase in transport network capacity. Currently, evacuation modeling procedures used do not incorporate all aspects of evacuation behavioral analyses and the models used do not contain a dynamic traffic assignment: a critical feature that will more accurately depict evacuee behavior on the transport network. Clearly, more

[8] Environmental justice is commonly referred to as the equitable distribution of both negative and positive impacts across racial, ethnic and income groups, with the environment defined to incorporate ecological, economic, and social effects *(44)*. Environmental justice appears to comprise fundamental elements of Rawls Theory of Justice, which is based on two principles. The first states that all social primary goods such as liberty, opportunity, income, and wealth are to be distributed equally; the second states that if these goods are not distributed equally, they are to be distributed to favour the disadvantaged *(44) (45)*.

research is needed that specifically investigates the effects of a mass evacuation on the current transport network.

A study currently being undertaken by the Institute of Transport Studies, The University of Sydney, Australia, aims to develop a dynamic transport tool for emergency situations, specifically urban bush fires.

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