INTELLIGENT TRANSPORT SYSTEMS ON EMERGENCY EVACUATION MODELLING

Beatriz Roldão, VTM Consultores, beatriz.roldao@vtm.pt

ABSTRACT

The combined effects of major changes concerning the physical development of urban areas and the increasing demand for travel lead to greater complexity in the control of transport systems. Transport Systems evolution and the rise of its utilization brought a new meaning to an essential matter: the safety and security of these systems. Cities as a whole must be seen to provide safe and secure environment. This is an issue of great importance nowadays and it is highlighted by the rise of mobility and traffic increase which implies a large amount of people and stakeholders involved. So the transportation systems are associated with a high risk of large scale accidents from natural causes or terrorist attacks, whose risk of occurring is more frequent nowadays. The development and implementation of new technologies demands a higher care for its safety utilization taking some extra precautions and keeping the control of the system.

Intelligent Transport Systems (ITS) consists on the application of advanced information and communication technologies in transportation as a way to improve transport systems performance, improving safety and security, time, money, energy consumption and the environment.

It is possible to improve the response capability of transportation systems in critical situations by combining network modelling and ITS application design. An emergency situation may involve static analysis (pre-planning or post-planning) or a real time operation enabling a rapid response and an effective evacuation. Towards pre-emptive planning it is possible to develop and test different scenarios and find the best solution, knowing the exact location of the incident. In contrast, facing the challenge of a more dynamic structure, a real time evacuation program supported by a traffic simulation software package allows an automatic definition of evacuation routes given the conditions and location of the incident. By controlling some ITS instruments, such as traffic evacuation signals placed strategically to flow off the traffic, and manage it with the modelling software, all the process of finding a rapid and effective response is carried trough.

This paper focuses on the feasibility of combining modelling and ITS solutions both on static and dynamic analysis.

Keywords: Intelligent Transport Systems; Emergency Evacuation Modelling; Evacuation Planning; Traffic Simulation Software; STEMS – Smart Traffic Evacuation Management System;

INTRODUCTION

Nowadays major changes are occurring which are fundamental to the ways in which we will live, work and travel in the future. These changes involve an understanding of social evolution, wealth creation and distribution as well as technological developments leading to new approaches about people and goods movements where the rapid development and deployment of technological solutions is the key to progress. Aspects of social change include the aging population, increasing importance of health, environment quality and personal security. All these aspects related to quality of life will become more important as life expectancy rises.

Intelligent Transport Systems (ITS) consists in the application of advanced information and communication technologies in transportation as a way to improve transport systems performance, saving lives, time, money, energy and the environment. Once the transportation systems are associated with a high risk of large scale accidents from Natural causes or Man-made the development and implementation of new technologies becomes a more important issue.

The combination of ITS technologies and network modelling may improve the efficiency of a response to an emergency case especially on an evacuation scenario by controlling some ITS instruments, such as traffic evacuation signals placed strategically to flow off the traffic. The purpose of this paper is to analyze the all process of evacuation modelling and available software's in order to understand where can these innovate technologies solutions be implemented and the feasibility of this combination.

CONCEPTS APPROACH

The basic Intelligent Transport Systems (ITS) elements are: Information Collection, Information Interpretation and Action. The first step is the collection of several types of data through the application of devices such as inductive loop detectors, closed circuit television cameras (CCTV) and GPS (Global Positioning System). Computer hardware and software allow the interpretation of the information collected in real time, making it possible to decide which changes will benefit the system. These decisions are applied in the action phase leading to new changes in the system. In some cases the results from the changes that were introduced in the system are analysed unchaining all the whole process described once again.

There are six ITS major categories (Figueiredo et al., 2001) that cover some of the needs, objectives and problems that these systems are made for. These categories are not defined by common technologies but by the way they can deal with security, mobility, comfort and other user's needs. These areas are grouped in: Advanced Traffic Management Systems (ATMS), Advanced Travellers Information Systems (ATIS), Commercial Vehicles Operation (CVO), Advanced Public Transportation Systems (APTS), Advanced Vehicles Control Systems (AVCS) and Advanced Rural Transport Systems (ARTS).

With the continuous development of cities, new difficulties arise, such as congestion, which are leading to economic and environmental problems. The latter are caused by the increase of pollution and noise which instigate a decrease of air quality and the rise of global warming.

Through ITS applications it becomes possible to fight some of these inconveniences in an efficient and effective way, increasing safety and decreasing congestion and air pollution.

There are some cognitive and perceptual characteristics of drivers that may influence the success of ITS. These characteristics imply constraints on the information required and how that information can be best displayed. Drivers perceptual and motor characteristics affect their interaction with technology referring to the limits associated with the process of receiving and acting on common activities such as the ability to see or hear signals and execute response to them. Some characteristics are associated with the integration and understanding of information which go beyond whether drivers can accurately perceive and act on signals from environment. They describe the ability of access the suggestion contained in displays and messages and determine how the information is integrated from the environment and ITS components to select alternative routes that avoid congestion and roadway hazards, use in-vehicle databases to fins points of interest, and integrate warning messages to avoid impending dangers. Characteristics concerning knowledge and attitudes influence long-term interaction with ITS components governing whether and how drivers use ITS capabilities they are important because even if drivers perceive correctly and understand information generated by an ITS component, their attitudes and knowledge may inhibit their acting on this information. All these characteristics mentioned before represent a great help while defining the system requirements but they are not the only factors involved in the process. ITS capabilities and design features, environmental factors and driver information requirements are some of the factors concerned with the ITS and represent a vital role in determining information that should be presented to drivers.

The development and implementation of new technologies demands a higher care for an essential matter highlighted by Transport Systems evolution and the rise of its utilization: the safety and security of these systems. This is an issue of great importance nowadays evidenced by mobility and traffic increase which implied a large amount of people involved in the process. So the transportation systems are associated with a high risk of big scale accidents and seen has a favourite target of terrorist attacks, which happen with more frequency these days.

Security Systems are mentioned to prevent all kinds of situations that may represent a threat to human lives and property. These systems are based on some preventive measures that allow to reduce the risk of accidents and to increase preparation in case of emergency through the definition of procedures that aid in the process of decision making and the practice of efficient and effective activities. To have a better comprehension of the most appropriated response to each emergency case it is of vital importance to analyse the most important concepts related with emergency management and multiple organizations and personnel must agree on the use and meaning of emergency management terms and phrases. An emergency situation can be defined as a sudden and unexpected event characterized by the deviation from planned or expected behaviour. It can represent a threat affecting people, property or environment and may require immediate action by capable agencies able to minimize impacts and adopt extraordinary procedures to return to normality. An emergency can be Natural, like hurricanes, tsunamis, floods, earthquakes, volcanoes, landslides, avalanches, tornados, and fires, or Man-made, like hazardous material spills, diseases, malfunctions of nuclear plants or chemical facilities, and terrorist attacks. Sometimes the warning time is long, like on hurricanes, floods and fires for example, but it can be a short warning time notice, like in cases of hazardous materials spills, terrorist attacks, and earthquake.

Dealing with an emergency situation involves more than just simply the response and the procedures taken at that precisely moment. All the conditions verified before and after the incident must be taken into account in order for the complete process to succeed. In other words it is necessary to do some planning where the appropriate resources and methods to reduce the impact of incidents are identified and the essential recovery procedures are identified. Emergency management activities can be grouped into five phases that are related by time and function to all types of emergency and disasters, which are: Preparedness, Mitigation, Response and Recovery. These phases are also related to each other, and each involves different types of skills. Mitigation refers to actions taken to minimize potential risk and hazards, Preparedness to activities developed to consolidate the response and recovery capabilities, Response involve activities following an emergency or disaster and Recovery refers to activities necessary to return all systems to normal or better performance.

To demonstrate compliance with regulations and guide appropriate reaction to emergencies the public transportation organizations are required to devise and maintain an emergency plan leading the response to an emergency situation. The emergency plan is generally a complex document conceived at the Preparedness phase and integrating all the information needed to preserve human lives in emergency situations. The plan serves both as a legal document and as a manual that describes procedures for dealing with emergencies containing information about the kind and location of available safety equipment and detailed procedures to follow in a number of eventualities. Some of these eventualities are specified in the Emergency Plan by the Contingency Plans which are prepared specifically for each emergency type such as bomb threat or fire. These Plans may contain specific Evacuation Plans involving the movement of people to a safer location and that have to be correctly planned and executed in order to be effective. The process of evacuation is described as a risk management strategy which may be used as a means of mitigating the effects of an emergency or disaster on a community and is usually considered to include the return of the affected community.

An essential element of any evacuation plan is a carefully prepared transportation plan in order to accomplish their main objectives which are the identification of the best evacuation routes, providence of evacuation time estimations for different emergency scenarios and the evaluation of traffic operations strategies. The evacuation plan must respond to the questions of what´s the clearance time required to get safely evacuate the public, which roads should be utilized for the evacuation, what are the critical roads in the evacuation process and how can the efficiency of the evacuation process be improved. The information required for a good planning involves travel characteristics, demand volumes, loading rates and origin-destination information.

EMERGENCY EVACUATION MODELLING

The threat of terrorist incidents is higher nowadays than ever before and terrorist attacks leave many concerns to people's safety due to their potential impact. Unlike some natural disasters that can be anticipated, terrorist attacks are sudden and unexpected. Even if sometimes we do have partial information about a possible attack, it is generally not known exactly where, when, or how an attack will occur. This lack of information posses great challenges on those responsible for security, specifically on their ability to respond fast whenever necessary with flexibility and coordination.

Emergency evacuation plays a crucial role in the purpose of saving lives and properties in case of major accidents. Planning evacuation on an emergency situation may involve a static analysis and/or a more dynamic real time operation. A static approach refers to all the pre and post planning conducted throw different scenarios where all the alternative routes are analysed before anything happens, considering different reactions and human behaviours. This involves developing and testing, in advance, different plans for different circumstances and finding among the available plans the most suitable one to be used whenever an incident occurs. These static predefined schemes are effective only in situations where the exactly location of the incident is known. The dynamic approach takes place during the response to an emergency situation and allows the constant introduction of updates to the process of evacuation. It inevitably requires the collection of actualized data - real time information - in order to take the best decisions each time the execution process is actualized.

Most of the research about evacuation has been concentrated on two distinct problems, evacuation of building and evacuation of large areas like entire cities and an analogy between them both can be carried out (Chamlet et al., 1982). The most important of these models is the dynamic model that represents the evacuation of a building as it evolves over time. With these dynamic models general estimates of clearing time are possible to be made for specific building. To enhance the performance of the urban emergency management system for handling major traffic accidents it has been adopted the modelling and planning of these situations based on traffic simulation software packages that can be used for static or dynamic planning. This is an innovative approach that makes all the process more efficient and successful, enabling the simulation of different solicitations that can be introduced on a big transport infrastructure.

An efficient routing plan is valuable because evacuations routinely result in travel demand that exceeds the available network capacity. There are larger volumes of traffic in shorter period. With evacuation modelling routes are constructed based on a dynamic process regarding routes that get too crowded, blocked by the disaster or damaged sufficiently enough to cause slower egress rates. Concerning the nature of an evacuation process, referred above, this modelling process must consider an assignment based on stochastic user equilibrium where congestion and behavioural characteristics are taken into account. Simulation of human behaviour assumes an important role on this kind of research. The Consideration of behavioural characteristics as stochastic variables in a Monte Carlo sampling framework is vital in all the process development in order to create graphical snapshots of evacuation evolving over time.

The main goal in evacuation routing is to minimize total travel distance and time. Another objective is to minimize or eliminate merging/intersection conflicts transforming critical intersections into uninterrupted flow facilities (Cova et al., 2003). Removing conflict points can reduce intersection delays and total evacuation time (reducing potential intersections accident points) but it may also increase the distance that vehicles must travel to reach evacuation zone exit. A third objective in evacuation routing is to minimize lane changing along multi-lane arterial, trying to avoid traffic delays and the increase of evacuation time. Due to time constraints in setting up temporary barriers, the physical restriction of lane changing is something that might be difficult to achieve during an evacuation, but instructions can be given in order to accomplish this goal. The concept of contraflow is often used referring to a situation in which vehicles travelling on a main road in one direction have to use lanes that are normally used by traffic travelling in the opposite direction. Even though contraflow operation on urban arterial roadways and long sections of interstate freeways for evacuations is accompanied by complicated issues of safety, accessibility and cost there are proposed algorithms for simplified situations (Shekhar et al., 2006) that should be considered helpful to planners designing contraflow plans minimizing evacuation time, which is an essential part of planning.

The Model outputs are produced according with the needs and purpose of the emergency plan and they may respond to the questions of what is the clearance time required to get safely evacuate the public, which roads should be used for evacuation, what are the critical roads in the evacuation process and how can the evacuation process efficiency be improved. Output information would include such items as: total volume and percent of vehicles by hour at each Emergency Protection Zone (EPZ) exit node/point, average travel time, the longest queue length with the highest traffic volume, total vehicles exiting the network, an evacuation curve which describes the cumulative percentage of evacuees who have exited the EPZ and the average speed for each roadway segment that exits the EPZ.

There is a large range of transport modelling software's available, a variety of commercial, academic and governmental sources offering an expanding series of tools able to support efficient, evacuation planning. For public agencies this is a constant issue and the availability of tools and high performance computing platforms encourage them to keep looking for analytical methods to improve their evacuation planning or operational practices. However, usually these agencies don´t have trained people able to decide which one is the best analytical tool that best address the goals of a planned analytical effort or fit within resource constraints such as staff expertise, data requirements, or computational speed.

A recent report with an inventory of tools focused on evacuation modelling has been done recently (Hardy et al., 2007). The report represents the transportation modelling inventory component of the U.S. DOT Evacuation Management Operations modelling assessment project, documenting surface transportation modelling tools that have been applied or could be applied to evacuation modelling. These tools range in geographic scope and analytical complexity from state-to-state coordination tools such as the Evacuation Traveller Information System (ETIS) to detailed traffic micro simulation models such as the TSIS/CORSIM traffic simulation model. The modelling inventory includes a summary of more than 30 transportation modelling tools that have been used, or can be used, for evacuation modelling.

There are three basic approaches to modelling a traffic network: macro, meso and micro (Hardy et al., 2007). These approaches are distinguished by their ability to model a geographic area and the detail level of analysis. Macro models can represent a large geographic area, able to represent an entire metropolitan region, but cannot represent individual vehicles or people on the network, lacking also time sensitivity. Micro models on the other end of the spectrum can generally represent only a certain segment of road. These models are not usually used to represent large geographic areas because it would require a large amount of input data and computing capability. Micro models are useful in modelling specific aspects of a network such as a corridor or interchange. They provide very precise results since individual vehicles are tracked on the network for a small time segment. Meso models are placed between these two modelling approaches. They represent larger geographic areas than micro models and allow for more precise results than macro models. Meso models generally represent individual roadway links and vehicles on a network but not individual lanes on each roadway segment. The following table (Table 1) lists the available software's for evacuation modelling ordered by the basic approaches referred before.

Evacuation Modeling Tool Inventory

	NAME	DOMAN	SUPPORT
MACRO	DYNEV	Planning Model	Legacy
	Emme/2	Planning Model	Commercial
	ETIS	Hurricanes	Government
	EVACNET4	Building Evacuation	Academic
	HEADSUP	Hurricanes	Government
	HURREVAC	Hurricanes	Government
	MASSVAC	Evacuation Management	Legacy
	NETVAC	Evacuation Management	Legacy
	OREMS	Traffic Simulation	Government
	PCDYNEV	Evacuation Management	Commercial
	REMS	Evacuation Management	Legacy
	TEDSS	Evacuation Management	Legacy
	TransCAD	Planning Model	Commercial
MESO	Cube Avenue	Traffic Simulation	Commercial
	DYNASMART	Traffic Simulation	Academic
	Simulex	Evacuation Management	Commercial
	TRANSIMS	Planning/Simulation	Commercial
	TransModeler	Planning/Simulation	Commercial
MICRO	AIMSUN II	Traffic Simulation	Commercial
	CLEAR	Evacuation Management	Government
	CORSIM/TSIS	Traffic Simulation	Commercial
	DRACULA	Traffic Simulation	Academic
	DynaMIT	Evacuation Management	Academic
	DYNASIM	Traffic Simulation	Commercial
	EXODUS	Enclosure Evacuation	Academic
	INTEGRATION 2.0	Traffic Simulation	Academic
	MITSIMLab	Traffic Simulation	Academic
	Paramics	Traffic Simulation	Commercial
	SimTraffic	Traffic Simulation	Commercial
	VISSIM	Traffic Simulation	Commercial

Table 1 – Evacuation Modelling Tools (Source: Hardy et al., 2007. Pp.25).

There is an important characteristic to analyse among models: functionality. Microscopic simulation is more functional than macroscopic models mainly because they were developed as general transportation modelling tool applied to different scenarios. For instance from the list presented above must of the macroscopic tools are used for general travel demand forecasting and regional modelling except three of them - PCDYNEV, ETIS and HEADSUP - designed and built specifically for evacuation purposes representing less level of functionality.

Another important characteristic is the desired results. The model may be used to provide precise calculation related to vehicles interactions, requiring a large amount of precise data. It´s a trade off that lies between select a model that provides very precise results but also requires a large amount of input data – microscopic models – versus a model that provides less precise result but also requires less input data as well – macroscopic models.

At last the third characteristic is geographic scope. Macroscopic models allow the analysis of a large range of area enabling the outlook of region wide impact but conducting to a fragile single corridor analysis with limited results. On the other hand there is microscopic tool very useful in corridor-level analysis but also very challenging in what refers to calibration of conditions.

Baring in mind the available software´s for emergency evacuation modelling and the process of an Intelligent Transport System it may be possible to combine them together in effort to improve evacuation effectiveness. ITS are mainly focused on managing day to day normal traffic by providing real time information to reduce congestion and expand travel choices. They may also play an important role in transportation systems safety and security by allowing a real time emergency evacuation traffic management process, distinct from a well studied evacuation planning and aiming to guide evacuation traffic flow dynamically in order to minimize losses and fatalities. The process starts with the collection of real time information obtained from sensors (traffic surveillance cameras) and other surveillance technologies and is followed by information treatment with the help of an evacuation process, ending up with the afterwards executing process corresponding to the action phase. The main challenge is the integration of these systems.

There is a Smart Traffic Evacuation Management System (STEMS) (Hamza-Lup et al., 2005) that has been developed to respond rapidly and effectively to human-caused threats and disaster by dynamically control a set of traffic evacuation signals placed at intersection to reroute traffic effectively. These evacuation signals are controlled by a set of algorithms that generate dynamic evacuation plans based on real time information obtained from sensors and other surveillance technologies. STEMS assure a dynamically production of optimal evacuation plans given an incident and guide evacuees on the proper routes according to the generated evacuation plan. STEMS is the first system that automatically generates evacuation plans, given the location and scope of an incident and the current traffic network conditions, and dynamically adjusts the plans based on real-time information received from sensors and other surveillance technologies. In STEMS the streets network is modelled as a graph with nodes representing intersections and links corresponding to the streets segments between two intersections.

After design the street network model on STEMS the next step is to define the evacuation problem. The incident location is identified and the Incident Node (IN) is defined as the closest node to the incident location. The Evacuation Zone (EZ) is the circular area centered at IN with a radius R and the Evacuation Exit Points (EEP) are defined as nodes outside the EZ but connected to nodes inside it. The intention is to direct the traffic from links inside the EZ away from the incident to a safer place outside the EZ throw the EEPs. Figure 1 illustrates these concepts representing evacuation routes radiating from the IN. The EZ is represented by the smaller circle, and the area between this circle and the surrounded one involves the chosen EEPs, from where all traffic will be prohibit entering EZ.

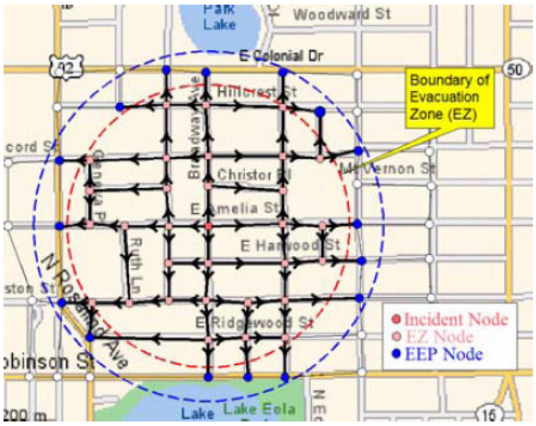

Figure 1 – All-Links Evacuation (Source: Hamza-Lup et al., 2004. Pp.251)

Figure 2 – Fastest-Link Evacuation (Source: Hamza-Lup et al., 2004. Pp.251)

The developing of algorithms for constructing the evacuation routes represents a big challenge in this process. The authors of STEMS considered two approaches: all-links approach and fastest-links approach. In all-link approach the entire street network is used and traffic flow is allowed on all links. Starting from the IN the network links are traversed only once and the evacuation direction indicates the flow direction that traffic will be forced to follow when reaching an intersection, in order to leave EZ. Figure 2 illustrates the fastest-link approach where evacuation routes are constructed as multicast tree from IN to EEPs. These multicast trees represent the fastest paths by finding the possible evacuation routes that flow traffic has to leave EZ via one of the EEPs. These routes aren´t just simply the possible routes once they are also the desired routes characterized by being the fastest ones. The average speed that characterize each links allows the estimation of the time necessary to traverse all the links of a path which leads to the shortest path, computed with base on the aggregated time. Links that are part of the multicast tree will be one-way only and all the others will have bi-directional traffic during evacuation.
After evacuation routes definition the next step is to assure real time evacuation, directing traffic out of the incident area. The main idea of STEMS project is to use and place signals at each incoming intersection. Each of these signals are represented by an arrow that can take any of the three traditional traffic light colours – red, yellow or green. The green arrows represent the feasible outgoing directions guiding incoming traffic at an intersection throw the evacuation direction and the red arrows on the other hand mark the undesirable directions. The innovative approach of this system resides on the combination of the traffic control signals described before with the evacuation routing modelling.

CONCLUDING REMARKS AND FINAL WORK

Considering the rise of threats from terrorist's incidents nowadays and a higher uncertain security environment, surface transportation systems are gaining a relevant importance in the response to these situations. A quick response with flexibility, coordination and efficiency characteristics is crucial to minimize losses and fatalities. The implementation of Intelligent Transport Systems as a solid process of collection, interpretation and action combined with competitive tools for emergency evacuation modelling may be the key to increase efficiency of emergency planning.

There have been studied a specific system called STEMS that combines evacuation modelling with the possibility of control traffic signals in order to re-route traffic flow away from the critical area. It is certainly an innovative approach however there is still little research work carried out in this field, delaying practical application of these achievable systems.

To achieve an advantageous and successful analysis of the evacuation modelling process it is necessary to bear in mind a lot of concepts involving safety procedures, technologies appliance and human behaviours and interactions facing different scenarios.

Future work includes investigating the capability of available modelling tools to integrate ITS technology within each broad class (macro, meso and micro) and continuous improvement of application of existing software´s.

It is also important to stand out that an effort must be done to assist local officials in selecting and applying appropriate software, once they are the ones with the highest interest on investing in these technologies, acting in profit of people safety. The assistance may be made by the production of reports concerning inventory tools and their capabilities and application fields.

REFERENCES

Chamlet, L. G., Francis and Saunders **(1982)**. *Network Models for Building evacuation. Management Science*.

Church, R.L., Sexton, R. **(2002)**. *Modelling Small Area Evacuation: Can Existing Transportation Infrastructure Impede Public Safety?* California Department of Transportation.

Cova, T.J., Johnson, J.P. **(2003)**. *A Network Flow Model for Lane-Based Evacuation Routing*. Transportation Research Part A.

Figueiredo, L., Jesus, I., Tenreiro Machado, J.A., Ferreira, J.R., Martins de Carvalho, J.L. **(2001)**. *Towards the Development of Intelligent Transportation Systems*.

Hamza-Lup, G.L., Hua, K.A., Peng, R., Ho, Y.H. **(2005)**. *Real-Time Traffic Evacuation Management under Multiple Coordinated Human-Caused Threats*. 12th World Congress on ITS.

Hamza-Lup, G.L., Hua, K.A., Le, M., Peng, R. **(2004)**. *Enhancing ITS to Improve and Support Homeland Security*.7th IEEE Intelligent Transportation Systems Conference.

Hardy, M., Wunderlich, K. **(2007)**. *Evacuation Management Operations (EMO) – Modelling Assessment: Transportation Modelling Inventory*. Research and Innovative Technology Administration.

Shekhar, S., Kim, S. **(2006)**. *Contraflow Transportation Network Reconfiguration for Evacuation Route Planning*. Minnesota Department of Transportation.