The role of demand models in evacuation

G. Chilà
DIMET, Dipartimento di Informatica, Matematica, Elettronica e Trasporti, Università degli Studi Mediterranea di Reggio Calabria, Italy

Abstract

In this paper a review of demand models simulating user behaviour in evacuation conditions is proposed. The role of the human behaviour in demand models is highlighted as component of the decision-making process. A review of surveys to calibrate demand models for evacuation conditions is presented.
Keywords: evacuation conditions, demand model.

1 Introduction

The decision-making process of people under evacuation conditions is a very complex issue influenced by different factors, such as kind and entity of the dangerous event, informer, socio-economic characteristics of users and panic [1]. At the same way, the prediction of user behaviour's is essential to optimize the evacuation planning and minimize the chances for human losses. After 9/11, the Indian Ocean tsunami, Katrina and the recent Irene, the production of papers related to mobility simulation in evacuation conditions has significantly increased. The most literature papers are implemented considering an isolated and non-system approach and the availability of data needed for evacuation simulation modeling, not usually covered in the transportation census database, continues to be an obstacle to model calibration.

When a dangerous event occurs, in emergency conditions, demand models specified and calibrated in ordinary conditions cannot be directly applied for several reasons: multiplicity of decision-makers (mayor and citizen); choice set (which may differ for typology of emergency scenarios and for decision makers); statistical and probabilistic aspects; attributes and parameters [2].

Moreover, in emergency conditions the analyst must consider possible targets set by the public decision-maker. Different demand models have to be specified,

WIT Transactions on Information and Communication Technologies, Vol 44,
www.witpress.com, ISSN 1743-3517 (on-line)
doi:10.2495/RISK120381

in relation to event kind, which can be classified according to its effects in the space and in the time [2, 6].

In respect of the effect in time, in demand analysis we consider a delayed or immediate approach, in relation to the time gap available between the time at which the dangerous event actually occurs and the time when the event starts its effects on the population. In previous works [7, 8], we have defined:

- t_0 the initial instant at which we decide to plan [9–13];
- t_1 the time at which the dangerous event is expected to occur or is forecast;
- t_2 the time at which the threat occurs and becomes a dangerous event;
- t_3 the time at which the event starts its effects;
- t_4 the time at which the dangerous event ceases its direct effects on the population.

If $(t_3-t_1)\neq0$, as in the case of the hurricane, we consider a delayed approach and during this gap there is the possibility of evacuating the population and thus mitigating the effect when the event occurs.

In John Leach's dynamic disaster mode, as reported in Vorst [14], three phases during an emergency condition are indicated: a pre-impact phase, an impact phase and a post-impact phase. In comparison with previous classification [7, 8], we suppose that the pre-impact phase corresponds to time before t_3, the impact phase occurs at t_3, the post-impact phase occurs after t_3. A different user behaviour corresponds to each phase: in the first phase the risk estimation is very low and also the probability to evacuate, because the risk is not perceived; the second phase is influenced by stress and denial of life-threatening; during the last phase, strong and irrational emotions are expressed and emotional disorders are developed. The differences in user behaviour between ordinary and emergency conditions are synthesized in the human factor by Vorst [14]. Naser and Birst [15] highlights that human behavioural analysis is critical to obtain accurate evacuation models and reliable estimates of the time needed for evacuation.

In this work we analyze literature models which deal with demand evacuation from an extensive area and with delayed effect in the time $((t_3-t_1)\neq0)$. Given the availability of data for hurricane evacuation, in the literature in the last years there was an increasing of model related to this kind of dangerous event. These models are based on data obtained during hurricane evacuation and aren't able to simulate user behaviour for different kind of emergency. Therefore, a general review of surveys useful to calibrate demand model in a more general evacuation conditions is presented (sec. 2). In section 3, a classification of the literature demand models is described, according to the simulated user choice. Finally, in section 4 a synthesis of literature approach to simulate the transport demand in evacuation conditions is proposed.

2 Surveys for demand model in evacuation conditions

The international literature related to evacuation conditions proposes many studies which focus on the hurricane emergency case. For this kind of dangerous event, large data collections there exist, allowing the demand model estimation by mean of RP (revealed preferences) surveys. RP surveys include preferences inferred from observations of a decision maker's actual choices, in relation to real contexts. RP data are not available for all dangerous events and then models specified for hurricane evacuation, which are derived by observation of past evacuation behaviour, cannot be directly transferred to the simulation of the other dangerous events. Demand model estimation became a complex problem, particularly when unpredictable events happen and users don't respect targets fixed by the public decision maker [16]. The user behaviour prediction becomes essential. To this purpose, we can carry out SP (stated preferences) surveys, which represent stated behavioural of users, in relation to hypothetical contexts. SP surveys allow simulate several emergency scenarios, which can be different for user's category, for effect in the space and in the time of dangerous event. SP surveys must be designed, defining: emergency scenarios, based on the set of alternative options; attributes for each alternative; variation of level of attributes; mechanism of choice [1, 18, 19]. In relation to this topic, the decision maker faced with a scenario can express different types of preference: choice, which is the most reliable method; ranking; rating. Proposed emergency scenarios must be characterized by the description of: period of reference, targets, effects in the time and in the space produced. A statistical analysis of user behaviour in emergency conditions based on SP data is reported in Russo and Chilà [1, 18].

Between RP and SP surveys, in previous works [2, 16, 17] we have introduced a hybrid class of surveys, named as SP with physical check. In order to obtain data useful to a demand model calibration, given a kind of dangerous event, we have carried out evacuation trials, in relation to the research project SICURO [2]. During evacuation trials, RP data can be obtained, even if they are affected by the laboratory effect, because each user participating in evacuation trials knows that he doesn't run in a real danger. Therefore, RP surveys during evacuation trials are a statement of behavioural in emergency conditions. From these considerations the classification of RP surveys during evacuation trials as SP with physical check is derived.

Naser and Birst [15] confirm the importance of SP data to specify and calibrate demand models for evacuation conditions, recalling a wider class of stated surveys named as stated response (SR). SR surveys, according to a large number of studies [20], can provide predictions of choice behaviour to a satisfactory degree. There are four general classes for SR survey techniques based on the nature of the questions and the expected behavioural outcome: stated preference, stated tolerance, stated adaptation, and stated prospect. According to the literature taxonomy [21]:

- in stated preference (SP) survey respondents are forced to choose or give a trade-off between predetermined options, which are expressed in terms of packages of attributes or as behavioural alternatives in the face of a given set of constraints;
- in stated tolerance (ST) surveys, respondents are asked to identify the nature and the level of constraints comprising the limits of acceptability of behavioural outcomes;

- in stated adaptation (SA) survey respondents are allowed to imagine for themselves how they would behave in the new situation of interest;
- in stated prospect (SPro) survey respondents are asked under what circumstance he/she would be likely to change its/her travel behaviour and how he/she would goes about it..

Recently, Train and Wilson [22] introduce SP-off-RP questions, in which information is asked in a different way than SP surveys. According to this approach, the alternatives and choice of a respondent in a real-world setting are observed, and the respondent is asked whether he/she would choose the same alternative or switch to another alternative if the attributes of the chosen alternative were less desirable in ways specified by the researcher and/or the attributes of non-chosen alternatives were more desirable in specified ways.

3 A review of demand models in evacuation conditions

Demand models are an important tool for solving most problems in transport systems planning and management. In ordinary conditions, people travel in order to participate in some land-based activity and then travel demand is a derived demand. Travel demand forecasting predicts the number, type, origin and destination, and distribution of trips on a transportation system. Several mathematical models to simulate transport demand are proposed in the literature. In most cases, these models belong to discrete choice models, which are defined in respect of the: decision maker, choice set, attributes and parameters, random residuals [23–25]. Discrete choice models are usually derived under the assumption of utility-maximizing behaviour by the decision maker. The most commonly methodology used for simulate transport demand is the fours step process that considers generation, distribution, mode and route choice [19, 26].

In this section we recall literature models specified for evacuation conditions and we propose their classification according to the step and then the user decision simulated: evacuate or not and when (generation and schedule); where to go (destination choice); by which mode and route (mode and route choice). A synthesis of model systems to simulate user decisions according to a systematic approach is proposed.

We highlight that, especially in evacuation conditions, this consolidate four step structure could be modified. For example, in the research project SICURO [2] we have experimented that for the distribution model, in constraint absence, the decision maker chooses together the refuge's area with the transport mode or, alternatively, he chooses before the transport mode and after the destination.

Moreover, it is important to highlight that, in the most cases, despite the unique characteristics of travel under emergency situations, a complete set of integrated tools for assessing all decisions of users is still lacking. A general system of models is proposed in Russo and Chilà in relation to the SICURO research project [2, 16] and includes: a generation model, specified and calibrated according to two different approaches; a modal choice model; a distribution model; a first example of modal choice with distribution model. The consolidated model series, considered in ordinary conditions, is modified in relation to order and structure of simulated choices.

Another example of general framework of models simulating demand in emergency conditions is proposed by Abdelgawad and Abdulhai [27]. The authors introduce a complete set of integrated tools for modelling and managing transportation systems under emergency evacuation scenarios. The main contributions of the proposed system are:

- it comprehensively models evacuation trip generation, mode split, evacuation schedule, trip distribution and trip assignment in a systematic and integrated fashion;
- it generates an optimized multimodal evacuation plan by combining transit-evacuation and car-evacuation.

In the following paper these general systems of models are analyzed in relation to the simulated single step of the user's decision process.

Finally, we highlight that the most part of literature models related to evacuation conditions doesn’t consider the human behavior in emergency conditions, even if in some studies it is considered as a major factor in identifying the demand for travel and the demand loading rates on the transportation system during an emergency evacuation scenario [15].

3.1 Evacuation generation and scheduling

In this section the recent literature simulating generation demand in evacuation conditions is synthetically described. Evacuation demand is estimated in two steps: 1) the estimation of total evacuation demand, i.e. the total number of people that need to be evacuated, and 2) the estimation of the temporal profile of evacuation, i.e. departure times of batches of evacuees.

A first classification of generation and scheduling model is proposed in Sbayti and Mahamassani [28], which classify simultaneous and staged evacuation: in simultaneous evacuation evacuees are advised to evacuate immediately to their destinations; in staged evacuation, evacuees are advised when to evacuate so as to minimize the network time. For the staged evacuation, Chen and Zhan [29] highlight that the staging evacuation is essential in communities where the street networks have a Manhattan structure and the population density is high.

The two steps are generally carried out using simplified methods [20]. For example, the most common method of estimating evacuation demand is to use participation rates in evacuation zones. Some researchers report the use of response curve, sensitive to the characteristics of the hurricane, time of day, type and timing of evacuation order, to simulate evacuation demand [8]. Baker [31] proposes an analysis of hurricane evacuation behavior considering five variables: area risk level, action by public authorities, housing, prior perception of personal risk, and storm-specific threat factors. Dow and Cutter [32] examine aspects of household evacuation decision making that potentially affect transportation planning for future evacuations. Wilmot and Mei [33] compare the relative accuracy of alternative forms of trip generation of evacuation traffic.

Solis *et al.* [34] examine a set of econometric models to analyze the determinants of household hurricane evacuation choice for a sample of 1355 households in Florida. Hasan and Hukkussuri [35] propose a threshold model to analyze the social influence in evacuation decision making process. Russo and Chilà [2, 16] propose statistical and behavioural generation models in evacuation conditions, distinguishing different users' categories: residents in the study area, workers, students, weak users and non-residents who occasionally reach the studying area to shopping or business. In the recent literature, advanced dynamic models are proposed to simulate user behaviour in evacuation conditions. Wilmot and Mei [33] propose the use of a model named, by the authors, sequential logit model, simulating the decision whether and when to evacuate simultaneously. They postulate that this joint decision is an issue that is considered repeatedly prior to it being taken. In Russo and Chilà [7, 37] dynamic approaches are proposed to simulate user decisions in evacuation conditions. Among dynamic models, sequential dynamic discrete choice models [37, 38] represent a special class and are proposed with sequential tests to ascertain whether current decisions are directly influenced by the most recent previous decisions, also in emergency conditions.

3.2 Destination choice

In relation to the destination choice, it is necessary to highlight that, in comparison with ordinary conditions, when the destination is a homogenous area including several elementary destinations, in emergency conditions alternatives are discrete points fixed by a decision-maker [16] and the traditional Newtonian method is not very effective to represent user behaviour. In the most papers, evacuees are assigned to pre-determined destinations based primarily on the geographical context and activities' distribution. As in [16], the distribution model could be applied to simulate the user distribution among:

- different point destinations, fixed by a public decision maker;
- fixed point destinations and the other areas no-fixed by a public decision maker, but considered sure by the users.

One literature approach is related to relaxation of constraint of assigning evacuees to pre-fixed destinations. In other words, instead of assigning the demand to pre-fixed destinations, evacuees are directed to the nearest safe destination outside of the impacted area. Chiu *et al.* [39] and Han *et al.* [40] propose the One-Destination evacuation model in which the traditional road network with m origins to n destinations has been modified to a network with m origin to one destination. Chiu *et al.* [39] applied a system optimal dynamic traffic Cell Transmission Model to a simple evacuation event to solve the evacuation destination-route-flow-staging problem. A disaggregate choice model for hurricane evacuation was developed with post-Hurricane Floyd survey data collected in South Carolina in 1999, by Cheng *et al.* [41]. A multinomial logit model was used to investigate the effect of risk areas in the path, or projected path, of a hurricane, and socio-economic and demographic characteristics on destination choice behaviour.

Russo and Chilà [2, 16] propose:

- a model simulating only destination choice, for different user categories;
- a model simulating mode and destination choice jointly, for different user categories.

3.3 Mode and route choice

Demand model for evacuation conditions focus on one mode of evacuation (predominantly cars) with little attention to multi-modal evacuation using both cars and mass transit [27, 39]; this topic is still largely missing in most emergency evacuation studies. This lack is particularly important in cities where the percentage of use of the transit is significant. Abdelgawad and Abdulhai [27] propose a general framework able to simulate demand of evacuation both by the private cars and public transport. In Russo and Chilà [2, 16] a model simulating modal choice in evacuation conditions is proposed for different user categories, considering the alternatives car and pedestrian. The model has been experiment using data obtained during the research project SICURO, in a context characterize by a very low percentage of transit modal choices.

In relation to the route choice, Chen and Xiao [42] propose a model including the evacuation route construction algorithm and traffic flow assignment algorithm. Pel *et al.* [43] specify a route choice model implementing evacuation of the metropolitan area of Rotterdam, highlighting the importance of traveller information and compliance with the evacuation model. Sbayti and Mahamassani [28] propose a model that gives in output departure time and route, between a selected set of origin nodes and destinations, for each evacuee.

A model simulating path choice for emergency vehicles was proposed by Vitetta *et al.* [44–46]. In these papers procedures to be planned and activated in emergencies in order to allow the evacuation of less able users and designs the optimal path for emergency vehicles are proposed. Advanced dynamic models are proposed in Vitetta *et al.* [45] and Polimeni and Vitetta [47]. Vitetta *et al.* propose the interaction of demand and supply in emergency conditions [49–53]; for a general approach to this theme we recall Russo and Chilà [54].

4 Synthesis and conclusions

In the following table (table 1) we propose a synthesis of literature approach to simulate the four-stage demand model in evacuation conditions, in respect of ordinary conditions, and we recall some literature references. From literature examination emerges that:

1. in the majority of cases, a complete set of integrated tools for assessing demand is lacking;
2. the availability of RP data related to hurricane dangerous events has produced, in the last years, an increasing of statistical papers based on

historical data, able to simulate only a specific kind of demand in evacuation conditions;

3. moreover, only a few of literature papers deals adequately with human behaviour in emergency conditions.

Table 1: A synthesis of demand models for evacuation conditions.

Four-stage demand model	Some references for evacuation conditions	Linked to a model system	Data	Behavioural / Probabilistic approach
Generation and departure time	Baker (1991)	No	RP	/
	Mei (2002)	No	RP	No
	Fu and Wilmot (2004)	No	RP	Yes
	Dow and Cutter (2002)	No	RP	Hybrid prob./stat.
	Wilmot and Mei (2004)	No	RP	No
	Chen and Zhan (2006)	No	RP	Hybrid prob./stat.
	Sbayti and Mahamassani (2006)	No	Num. example	Yes
	Russo and Chilà (2007, 2008, 2009, 2010)	Yes	RP, SP p.c.*, SP	Hybrid prob./stat.
	Solis *et al*. (2009)	No	RP	Yes
	Abdelgawad and Abdulhai (2010)	Yes	SP	No
	Hasan and Hukkussuri (2011)	No	Num. example	Yes
Distribution	Han *et al*. (2006)	No	RP	Yes
	Chiu *et al*. (2006)	Yes	Num. example	Yes
	Russo and Chilà (2007, 2008)	Yes	SP p.c.*	Yes
	Chen *et al*. (2008)	No	RP	Yes
	Abdelgawad and Abdulhai (2010)	Yes	SP	No
Modal choice	Russo and Chilà (2007,2008)	Yes	SP p.c.*	Yes
	Abdelgawad and Abdulhai (2010)	Yes	SP	No
Route Choice	Chen and Xiao (2006)	No	Num. example	No
	Chiu *et al*. (2006)	Yes	Num. example	Yes
	Sbayti andMahamassani (2006)	No		No
	Vitetta *et al*. (2007,2008,2009)	Yes	SP p.c.*	Yes
	Pel *et al.*	No	SP p.c.*	Yes
	Vitetta and Polimeni (2011)	Yes	SP p.c.*	Yes

* SP with physical check

Therefore, it should be:

1. to specify and to calibrate a model system able to simulate each step of user's decision process according to a behavioural approach or, at least, according to an hybrid statistical – probabilistic method;
2. to test the different typology of SR surveys for evacuation conditions, including also the recent SP-off-RP method;
3. to include psychological factors related to user behaviour in emergency conditions, in the proposed models.

References

[1] Russo F. and Chilà G., Models in road evacuation: role of the informer in user behaviour. *Proceedings of Sustainable City 2012*, 7th International Conference on Urban Regeneration and Sustainability, Brebbia C. A. (ed.), WIT Press, Southampton, 2012.

[2] Russo F. and Chilà G., Safety of users in road evacuation: demand models. *WIT Transactions on the Built Environment, Volume 96, Urban Transport XIII, Urban Transport and the Environment in the 21st century,* Brebbia C. A. (ed.), WIT Press, Southampton, pp. 773-782, 2007.
[3] Russo F. and Vitetta A., Risk evaluation in a transportation system. *International Journal of Sustainable Development and Planning*, 1 (2), pp. 170-191, 2006.
[4] Russo F. and Vitetta A., The road network design problem to improve the safety during exogenous flow perturbations. *Proc. of the 29th ISATA Conference*, Florence, 1996.
[5] Russo F. and A. Vitetta, Risk in anthropic environments: methodologies for risk evaluation and exposition reduction. *Environmental Health Risk III*, Brebbia *et al.*, WIT Press, Boston, 2005.
[6] Russo F. and Vitetta A., Safety of users in road evacuation: General methodology and main results. WIT Transactions on the Built Environment, Volume 96, Urban Transport XIII, Urban Transport and the Environment in the 21st century, pp. 763-772, 2007.
[7] Russo F. and Chilà G., Dynamic approaches to demand model in evacuation conditions. *WIT Transactions on the Built Environment, Volume 111, Urban Transport XVI, Urban Transport and the Environment in the 21st century,* Brebbia C. A. (ed.), WIT Press, Southampton, pp. 303-312, 2010.
[8] Russo F. and Chilà G., Demand models in road evacuation: a synopsis of recent contributions. *WIT Transactions on the Built Environment, Volume 116, Urban Transport XVII, Urban Transport and the Environment in 21st Century,* Pratelli and Brebbia C. A. (ed.), WIT Press, Southampton, pp. 601-614, 2011.
[9] Russo F. and Rindone C., Safety of users in road evacuation: planning internal processes and guidelines. *WIT Transactions on the Built Environment, Volume 96, Urban Transport XIII, Urban Transport and the Environment in the 21st century,* Brebbia C. A. (ed.), WIT Press, Southampton, pp. 825-834, 2007.
[10] Russo F. and Rindone C., Safety of users in road evacuation: the logical framework approach in evacuation planning. *WIT Transactions on the Built Environment, Volume 101, Urban Transport XIV, Urban Transport and the Environment in the 21st century,* Brebbia C. A. (ed.), WIT Press, Southampton, pp. 751-760, 2008.
[11] Russo F. and Rindone C., Safety of users in road evacuation: Modelling and DSS for LFA in the planning process. *WIT Transactions on Ecology and the Environment, Volume 120, Sustainable Development and Planning IV, vol.1*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 453-464, 2009.
[12] Russo, F. and Rindone C., Planning in road evacuation: classification of exogenous activities. *WIT Transactions on the Built Environment, Volume 116, Urban Transport XVII, Urban Transport and the Environment in 21st Century,* Pratelli and Brebbia C. A. (ed.), WIT Press, Southampton, pp. 639-651, 2011.

[13] Russo, F. and Rindone C., The planning process and logical framework approach in road evacuation: a coherent vision. *WIT Transactions on the Built Environment, Volume 117, Safety and Security engineering IV*, Guarascio M., Reiners G. Brebbia C. A. and Garzia F. (ed.), WIT Press, Southampton, pp. 415-425, 2011.

[14] Vorst H.C.M., Evacuation models and disaster psychology. *Science Direct*, vol. 3, pp. 15-21, 2010.

[15] Naser M. and Birst S.C., *Mesoscopic Evacuation Modeling for Small- to Medium-Sized Metropolitan Areas.* Department of Transportation, University Transportation Centers Program, North Dakota State University, 2010.

[16] Russo F. and Chilà G., Safety of users in road evacuation: RP vs. SP surveys in demand analysis. *WIT Transactions on the Built Environment, Volume 101, Urban Transport XIV, Urban Transport and the Environment in the 21st century,* Brebbia C. A. (ed.), WIT Press, Southampton, pp. 703-713, 2008.

[17] Russo F. and Chilà G., Safety of users in road evacuation: Modelling and DSS for demand. *WIT Transactions on Ecology and the Environment, Volume 120, Sustainable Development and Planning IV, vol.1*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 465-474, 2009.

[18] Russo F. and Chilà G., A statistical approach to analyse user behaviour in road evacuation. *WIT Transactions on the Built Environment, Volume 117, Safety and Security engineering IV*, Guarascio M., Reiners G. Brebbia C. A. and Garzia F. (ed.), WIT Press, Southampton, pp. 377-390, 2011.

[19] Ortuzar, J. and de D. Willumsen, L.G., *Modelling Transport,* John Wiley & Sons Ltd, Chichester, 2006.

[20] Cambridge Systematics, *Travel Survey Manual*, Prepared for U.S. Department of Transportation, U.S. Environmental Protection Agency, 1997.

[21] Lee-Gosselin M.F.H., Scope and Potential of Interactive Stated Response Data Collection Methods. *Proceedings of Conference on Household Travel Surveys: New Concepts and Research Needs*. Transportation Research Board, Conference Proceedings 10, pp. 115-133, National Academy Press, Washington DC, 1996.

[22] Train K. and Wilson W.W., Monte Carlo analysis of SP-off-RP data. *Journal of Choice Modelling*, 2(1), pp. 101-117, 2009.

[23] Domencich T.A., McFadden D. *Urban travel demand: a behavioural analysis*, American Elsevier, New York, 1975.

[24] Ben Akiva M., Lerman S., Discrete choice analysis: theory and application to travel demand, MIT Press, Cambridge, MA, 1985.

[25] Train K., *Qualitative choice analysis*. MIT Press, Cambridge, MA, 1993.

[26] Cascetta E., *Transportation systems engineering: theory and methods*, Kluwer Academic Press, 2001.

[27] Abdelgawad, H. and Abdulhai B., Towards a Complete Evacuation Demand and Supply Modeling and Management Process. *Proceedings of 12th WCTR*, July 11-15, 2010 – Lisbon, Portugal, 2010.

[28] Sbayti H. and Mahmassani H. (2006), Optimal Scheduling of Evacuation Operations. *Transportation Research Record: Journal of the Transportation Research Board* 1964(1), pp. 238-246, 2006.
[29] Chen X. and Zhan F., Agent-Based Modelling and Simulation of Urban Evacuation: Relative Effectiveness of Simultaneous and Staged Evacuation Strategies. *Journal of the Operational Research Society* 59, pp. 25-33, 2006.
[30] Mei B., *Development of Trip Generation Models of Hurricane Evacuation*. Louisiana State University and Agriculture and Mechanical College. Master of Science, 2002.
[31] Baker E.J., Hurricane evacuation behavior. *International Journal of Mass Emergencies and Disasters*, Vol. 6, pp. 287-310, 1991.
[32] Dow K. and Cutter S.L., Emerging Hurricane Evacuation Issue: Hurricane Floyd and South Carolina. *Natural Hazard Review*, 18, 2002.
[33] Wilmot C.G. and Mei B., Comparison of Alternative Trip Generation Models for Hurricane Evacuation. *Natural Hazards Review*, 2004.
[34] Solis D., Thomas M., Letson D., Determinants of household hurricane evacuation choice in Florida. *Presentation at the Southern Agricultural Economics Association Annual Meeting*, Atlanta, Georgia, January 31-February 3, 2009.
[35] Hasan S. and Hukkussuri S., A Threshold Model of Social Contagion Process for Evacuation Decision Making. Preprint submitted to *Transportation Research Part* B, 2011.
[36] Wilmot C.G. and Fu H., A sequential logit dynamic travel demand model for hurricane evacuation. *Transp. Research Record*, 1882, pp. 19-26, 2004.
[37] Russo F. and Chilà G., A sequential dynamic choice model to simulate demand in evacuation conditions. *WIT Transactions on Ecology and the Environment, Volume 141, Risk analysis VII & Brownfields V*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 431-442, 2010.
[38] Chilà G., Sequential methods for user choices: tests and properties applied to a panel database. *WIT Transactions on the Built Environment, Volume 101, Urban Transport XIV, Urban Transport and the Environment in the 21st century,* Brebbia C. A. (ed.), WIT Press, Southampton, pp. 121-131, 2008.
[39] Chiu Y., Villalobos J., Gautam B. and Zheng H., Modeling and Solving the Optimal Evacuation Destination-Route-Flow-Staging Problem for No-Notice Extreme Events. *Proceedings of the 85th Transportation Research Board, Washington, DC*, 2006.
[40] Han L., Yuan F., Chin S. and Hwang H., Global Optimization of Emergency Evacuation Assignments. *Interfaces*, 36 (6), pp. 502-513, 2006.
[41] Cheng, G., Wilmot C.G. and R.J. Baker. A destination choice model for hurricane evacuation. *Transp. Research Board Annual Meeting*, 2008.
[42] Chen Y., Xiao D., Emergency Evacuation Models and Algorithms. *Journal of Transportation System Engineering and Information Technology*, Vol. 8, 2006.

[43] Pel A.G., Hoogendoorn S.P., Bliemer M.C.J., Evacuation modeling including traveler information and compliance behavior. *Science Direct*, 2010.
[44] Vitetta A., Quattrone A. and Polimeni A., Safety of users in road evacuation: design of path choice models for emergency vehicles. *WIT Transactions on the Built Environment, Volume 96, Urban Transport XIII, Urban Transport and the Environment in the 21st century*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 803-812, 2007.
[45] Vitetta A., Quattrone A. and Polimeni A., Safety of users in road evacuation: algorithms for path design of emergency vehicles. *WIT Transactions on the Built Environment, Volume 101, Urban Transport XIV, Urban Transport and the Environment in the 21st century*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 727-737, 2008.
[46] Vitetta A., Quattrone A. and Polimeni A., Safety of users in road evacuation: Modelling and DSS for paths design of emergency vehicles. *WIT Transactions on Ecology and the Environment, Volume 120, Sustainable Development and Planning IV, vol.1*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 485-495, 2009.
[47] Polimeni A. and Vitetta A., Dynamic vehicle routing in road evacuation: a model for route design. *WIT Transactions on the Built Environment, Volume 116, Urban Transport XVII, Urban Transport and the Environment in 21st Century*, Pratelli & Brebbia C. A. (ed.), WIT Press, Southampton, pp. 627-638, 2011.
[48] Polimeni A. and Vitetta A., Dynamic vehicle routing in road evacuation: route design experimentation. *WIT Transactions on the Built Environment, Volume 117, Safety and Security engineering IV,* Guarascio M., Reiners G. Brebbia C. A. and Garzia F. (ed.), WIT Press, Southampton, pp. 391-402, 2011.
[49] Vitetta A., Musolino G. and Marcianò F.A., Safety of users in road evacuation: Supply and demand-supply interaction models for users. *WIT Transactions on the Built Environment, Volume 96, Urban Transport XIII, Urban Transport and the Environment in the 21st century*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 783-792, 2007.
[50] Vitetta A., Musolino G. and Marcianò F. A., Safety of users in road evacuation: calibration of cost functions and simulation. *WIT Transactions on the Built Environment, Volume 101, Urban Transport XIV, Urban Transport and the Environment in the 21st century*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 715-725, 2008.
[51] Vitetta A., Musolino G. and Marcianò F.A., Safety of users in road evacuation: Modelling and DSS for transport supply and supply-demand interaction. *WIT Transactions on Ecology and the Environment, Volume 120, Sustainable Development and Planning IV, vol.1*, Brebbia C. A. (ed.), WIT Press, Southampton, pp. 475-484, 2009.
[52] Marcianò F.A., Musolino G. and Vitetta A., Within day traffic assignment and signal setting in road evacuation: a procedure with explicit path enumeration. *WIT Transactions on the Built Environment, Volume 117,*

Safety and Security engineering IV, Guarascio M., Reiners G. Brebbia C. A. & Garzia F. (ed.), WIT Press, Southampton, pp. 403-414, 2011.

[53] Musolino G. and Vitetta A., Short-term forecasting in road evacuation: calibration of a travel time function. *WIT Transactions on the Built Environment, Volume 116, Urban Transport XVII, Urban Transport and the Environment in 21st Century,* Pratelli & Brebbia C. A. (ed.), WIT Press, Southampton, pp. 615-626, 2011.

[54] Russo F. and Vitetta A., Reverse assignment: Calibrating link cost functions and updating demand from traffic counts and time measurements. Inverse Problems in Science and Engineering, Volume 19, Issue 7, pp. 921-950, 2011.