RISK REDUCTION IN TRANSPORT SYSTEM IN EMERGENCY CONDITIONS: A FRAMEWORK FOR DEMAND ANALYSIS

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ABSTRACT
The aim of this work is to present a framework of the major contributions which consider demand in evacuation conditions. The production of works related to mobility simulation in evacuation conditions has significantly increased after Katrina event from one side and 9/11 event from the other, even if in the last years the attention is decreased. Several models have been developed, but, in most cases, these are implemented considering an isolated area with a non-system approach. In this work it is proposed a classification of literature models which simulate evacuation conditions and are demand-focused in relation to the effect in the transport system, considering mainly models that deal with natural disasters. The classification is presented, after a brief analysis of literature regarding demand models in the framework of behavioural-topological paradigm, core of transportation system model. The basic elements of the dynamic demand models developed in the literature are then recalled, classified according to the components that explain the dynamic aspects (attributes, parameters, residues). Sequential analysis is then proposed as a tool to highlight the presence of dynamic components.
Keywords: risk reduction, exposure, evacuation, dynamic demand, sequential analysis, transport systems, utility updating.

1 INTRODUCTION

Demand models are a fundamental tool for solving most problems in transport systems planning and management. Several mathematical models to simulate transport demand are proposed in the literature. These are based on various assumptions and can be subdivided in relation to different elements. In most cases, these models belong to discrete choice models [1], [2].

Discrete choice models are usually derived under the assumption of utility-maximizing behaviour by the decision maker and are applied to simulate several choices of transport and mobility, such as mode choice and path choice [2], [3]. Features that are common to discrete choice models are (Fig. 1):

- the choice set formation, which is the set of options that are available to the decision maker;
- the alternative choice probabilities inside the choice set, which derive from utility-maximizing behaviour.

Choice set formation can be simulated by the Manski approach [4], [5].

Alternative choice probabilities, deriving from utility-maximizing behaviour, depend on attributes and hypotheses on random residual distribution. The distribution implies a different specification of the model. Based on the assumptions on the distribution it is possible to define two main classes. The first class is made up of models for which it is possible to express the closed-form probability and it is therefore possible to directly maximize the likelihood function; the GEV (generalized extreme value) models [6] and their different specifications belong to this class: multinomial logit, nested logit and cross-nested logit.

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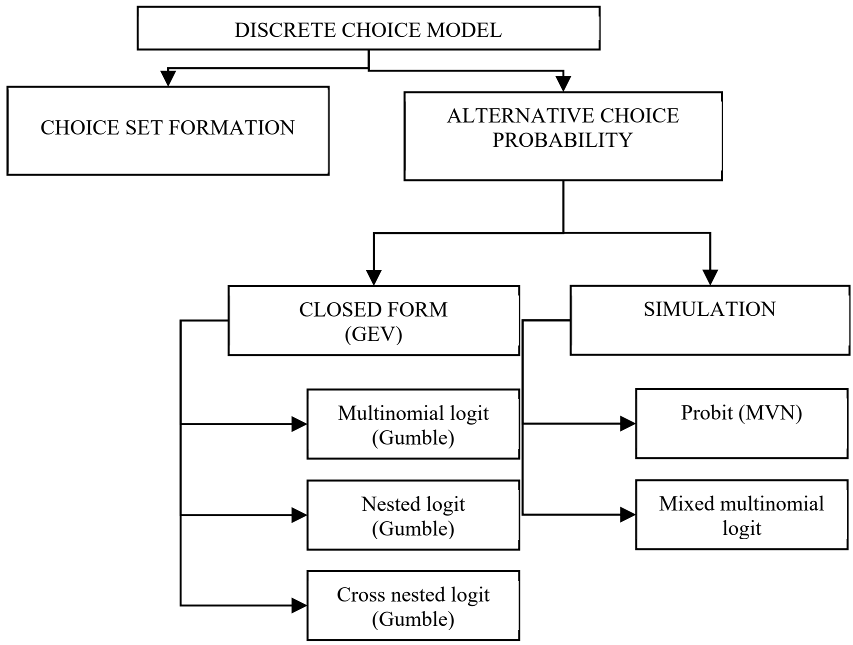

Figure 1: Main features of discrete demand models.

The second class includes models that cannot be solved in closed form and for which it is necessary to proceed with simulation methods to obtain the solutions; the multinomial probit [7] and mixed multinomial logit [8] models belong to this class.

In the ordinary situation, the demand for transport plays a central role in defining the conditions of the overall system. Demand interacts with supply, and the overall model, supply–demand-interaction, is studied within the topological-behavioural paradigm, modelled by the equations that define the so-called TSM (transportation system model) [9]. It is necessary to recall that the study of TSM in dynamic conditions implies the use for interaction, of a dynamic process in which both the within day and day to day components are considered. To define the dynamic assignment process, two models must be specified [9]: the choice updating model and the utility updating model. For the choice updating it is useful to recall [10], [11] and for the utility updating [12].

The risk situation is, by definition, a different situation from the ordinary one. The modelling of the risk situation in a transport system, while maintaining the same framework of the TSM formalized for the ordinary situation, implies deep modifications of the individual component models. In this note, the focus is placed on the evolution of demand models in risk conditions. Fig. 2 shows a picture of the field investigated here, placed at the intersection of the demand models with the models that simulate exposure inside the risk conditions, where the risk is considered in his main factors [13], [14]: occurrence, vulnerability, exposure.

The demand models developed for ordinary conditions cannot be directly used for extraordinary conditions, as evacuation to reduce exposure. In this case various problems

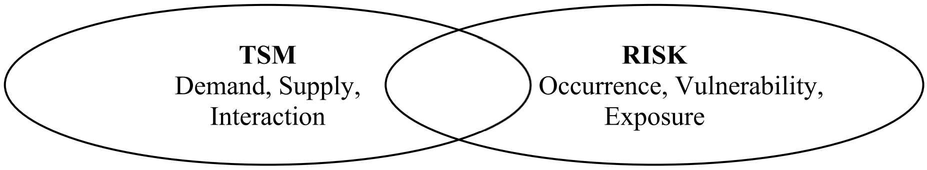

Figure 2: Intersections elements between TSM and risk models.

arise related to the type of event that induces evacuation. The different events and therefore the related effects can be classified with respect to: type of event; effect in time and space; effect in a component of the transport system (demand, supply or interaction).

On the basis of these four classes it is possible to identify an event and the related effect and it is possible to define the cases for which evacuation is necessary, the demand models estimated in the ordinary conditions cannot be applied due to: passage from a decision maker (user) to a multiplicity of decision makers (user, public administrator, security forces); modifications of the choice set of the alternatives, of the attributes of the single alternative, of the parameters of the attributes, of the random residuals.

In the literature, several specifications of dynamic models have been proposed, as regards different elements, such as attributes, parameters or random residuals. In this work are analysed only a set of these, belonging to discrete choice models. These models aren't characterized by a preliminary dynamic analysis of data used to model calibration. Dynamic analysis of these data could allow to:

- justify the use of dynamic relation to simulate user decisions, because dynamic analysis enables to individuate dynamic correlations among data in the time;
- suggest, given a specific kind of correlations among data in the time, the more appropriate dynamic approach to simulate user decisions.

It is important to develop the analysis of demand data relating to the single dynamic phenomenon considering on the one hand the large availability of data provided by the diffusion of the internet, and therefore available for public administrations and on the other hand the increase in internet use by users [15]. The increase of use implies the actualization of the choice and utility, as mentioned above.

A useful approach to analyse recorded data relative to demand in the time is sequential analysis, which explicitly considers the choice sequences. Sequential analysis arose as a science applied to observing social behaviour in psychology. It aims to demonstrate how to record observation data, related to user behaviour, in a way that preserves sequential information, and also how to analyse such data in a way that makes use of its sequential nature. In sequential analysis, data related to user behaviour are recorded and analysed, preserving sequential information and considering a statistical approach.

The paper is structured as follows: in Section 2 the literature on demand models under risk conditions (exposure) is summarized, in Section 3 the literature on dynamic probabilistic models is given and in Section 4 the basic elements of statistical sequential analysis are recalled. The conclusions summarize the main elements of the analysis carried out on the existing literature, proposing specific indications for the development of the research.

The work presented is of interest both to researchers of transport systems and to planning technicians, because on the one hand it summarizes the bases from which the TSM evolves towards the extraordinary conditions given by risk and on the other it identifies the main limits of use of TSM by signalling possible demand patterns that better represent extraordinary conditions in the commercial software.

2 DEMAND MODELS UNDER EXPOSURE CONDITIONS

On the basis of what has been said in the introduction, the first element of in-depth analysis, in a framework that wants to consider the analysis of the demand, is given by the different demand models that can be defined with respect to events, which are different for their effects in the space and time [13], [16].

In the international literature, the most analyzed natural event is the hurricane, and it can be referred to in order to rebuild the first methodological elements regarding the exposure reduction by means of evacuation. The assessment of demand in hurricane conditions is usually divided into two phases: estimating the total evacuation demand and estimating the departure time [17].

The models studied have very simple analytical structures. Consider that the most commonly used method to estimate demand is the use of evacuation participation rates [18]. A more refined model considers the response curves, in relation to the characteristics of the hurricane. The curves are calculated by relating the proportion of evacuation to the time elapsed since the issuance of an evacuation order [19].

With respect to the premise, in this section only some works are recalled that deal with dangerous events that have effects on the decisions to generate the movement, on the choice of destination and mode of transport, which are the models most influenced by the type of event and of effect. It is useful to suggest some general works relating to the choice of the path [20]–[22]. It is also useful to point out some works that consider the problem of the evacuation of transport systems and in this context also refer to the problems of demand. Daganzo and So [23] propose a strategy for the management of evacuation networks segmented into three classes: non-anticipative (not based on demand forecasting); adaptive (based on real-time traffic information on the whole network); decentralized (based on information available locally in each area of the overall network). Lindell and Prater [24] and Murray-Tuite and Wolshon [25], [26] highlight that there are two important lines of research, the one of social scientists, which studies the behavior of the population, and the other developed by transport engineers who study networks under evacuation; but the authors report that the two lines of research are poorly integrated. A particular attention to the analysis of natural and anthropogenic disasters that have affected millions of people, is the one supported by the Wessex Institute of Technology (WIT), which annually has two conferences on the various aspects of risk in territorial systems; you can refer to the wide-open source reading available on the WIT site starting from [27].

As mentioned above, the risk event most studied and reported in the literature is related to hurricanes. In Brebbia [28] the behavior during all phases of evacuation is analyzed considering some variables: level of risk of the area, decisions of public authorities, type of residence, preventive perception of personal risk, specific threat factors for hurricanes. In Dow and Cutter [29] the decision-making processes of families are analyzed on the basis of which the public decision-maker can plan subsequent evacuations; four issues are examined in the decision-making process: number of vehicles per household; departure times of evacuated families; distances traveled in the evacuation; importance of information in identifying the choice set of specific evacuation routes. Wilmot and Fu [18] assume that the two decisions relating to the execution of the evacuation and the time to carry it out are taken simultaneously; the authors hypothesize that each family continuously updates the information relating to the progress of the approaching hurricane, and in relation to the updating of the information update the choice, until a level of reduced utility is reached such to decide to evacuate in a specific time; the authors propose the use of a model called sequential logit. In Solis et al. [30] different models are compared highlighting the significant characteristics of the families' choice to evacuate due to the hurricane event, studying a sample of 1355 families in Florida.

It is interesting to recall the results achieved and published in the context of a research project financed with European funds, called SICURO, that is one of the few research projects related to anthropogenic delayed effects. As part of the project, several real evacuations of an urban center were carried out. The main results refer to a better understanding of: demand models, considering also SP surveys [31]; supply models with the calibration of the cost functions [32], [33]; design models [34] considering traffic junction regulation [35], [36] and design of the routes for emergency vehicles [37]; appropriate DSS [38], [39] considering multimodality [40], evidencing risk [41], [42]; planning methods [43], comprehensive of evacuation planning [44], [45] training [46], exercises and evaluation tools to reduce risk [47].

3 DYNAMIC DISCRETE CHOICE MODELS

In the previous section it has been recalled that in order to simulate some user choices dynamic models should be adopted. In this paper, choice models are classified as:

- non-dynamic, if they give the choice probability without considering system evolution;
- dynamic, if they give the choice probability while considering system evolution.

Under the assumption of random utility models (RUM) let be:

- t the generic current time interval;
- t^{-1} the generic previous time interval;
- n the generic user class;
- j^t the chosen alternative in time t;
- i^t the generic alternative in time t;
- k^{t-1} the chosen alternative in time t^{-1};
- r^{t-1} the generic alternative in time t^{-1};
- X^t, β^t attribute and parameter in t;
- X^{t-1}, β^{t-1} attribute and parameter in t^{-1};
- ε^{t-1}, ε^t random residuals in t^{-1} and in t;

with $j^t, i^t \in C^t$; $k^{t-1}, r^{t-1} \in C^{t-1}$.

In the evolution of the system various cases can happen; in the following are synthetized the more significant:

- evolution of user characteristics or level of service as perceived by the reference user, then $X^{t-1} \neq X^t$;
- evolution in user taste, hence in user evaluation and perception of attributes, then $\beta^{t-1} \neq \beta^t$;
- evolution of random residuals, then $\varepsilon^{t-1} \neq \varepsilon^t$;
- evolution of choice set, then $C^{t-1} \neq C^t$.

In the last case ($C^{t-1} \neq C^t$) an evident discontinuity is introduced in the system, since a new choice alternative arises from t^{-1} to t; this case is the opposite of the sequential case, and cannot be represented as a sequence, just because the process has no linear history, but from a general view it can be considered a point of discontinuity.

Given that $C^{t-1}=C^{t}\equiv C$, it is possible to assume that the choice set is fixed and then it can write, without loss of generality, $k^{t-1}=j^{t-1}$ and $r^{t-1}=i^{t-1}$, using for the same alternative the same representative variable in t and in t^{-1}; formally we can define:

- as a non-dynamic model, the model that gives the probability that user n chooses the generic alternative j independently of time interval as:

  $P^{n}[j^{t}]=prob(U^{n}[j^{t}]>U^{n}[i^{t}]\ \forall j^{t},i^{t}\in C,j^{t}\neq i^{t})=prob(V^{n}[j^{t}]+\varepsilon^{n}_{j}>V^{n}[i^{t}]+\varepsilon^{n}_{i}\forall j^{t},i^{t}\in C,j^{t}\neq i^{t})$
  with
  $P^{n}[j^{t}]=P^{n}[j^{t-1}]$

- as a dynamic model the model that gives the probability that user n chooses the generic alternative j^{t} in t, if $\beta^{t-1}\neq\beta^{t}$ and/or $X^{t-1}\neq X^{t}$, as:

  $P^{n,t}[j^{t}]=prob(U^{n,t}[j^{t}]>U^{n,t}[i^{t}]\forall j^{t},i^{t}\in C,j^{t}\neq i^{t})$
  with
  $P^{n,t}[j^{t}]\neq P^{n,t-1}[j^{t-1}]\ \forall j^{t},j^{t-1}\in C,\ j^{t}\neq j^{t-1}$
  $P^{n,t-1}[j^{t-1}]=prob(U^{n,t-1}[j^{t-1}]>U^{n,t-1}[i^{t-1}]\ \forall j^{t-1},i^{t-1}\in C,j^{t-1}\neq i^{t-1})$

In the following it is analysed the main literature on dynamic models, proposing just some example of these in respect of dynamic element introduced (attributes, parameters, random residuals), without trying to consider all the produced literature. Dynamic models as regard choice set aren't considered in this note, because they cannot be represented as a sequence. It's important to highlight that, in some cases, several dynamic elements are introduced and it is difficult classify the model according to a specific element. Therefore, it is hard to introduce an unequivocal classification of literature models, saving the possibility to introduce blended classification (Table 1).

Table 1: Dynamic model: example.

Evolution in user taste ($\beta^{t-1}\neq\beta^{t}$)	Evolution of user characteristics or level of service ($X^{t-1}\neq X^{t}$)	Evolution of random residuals($\varepsilon^{t-1}\neq\varepsilon^{t}$)
	Manski and Sherman [48]	Russo [53]
Hensher and Le Plastrier [52]	Hensher and Le Plastrier [52]	
	Train [49]	
Nielsen and Sørensen [51]	Nuzzolo et al. [50]	Wilmot and Fu [18]
	Cascetta [9]	Cascetta [9]

Dynamic models as regard attributes are the most common in the literature. Among these, can be recalled models proposed in Manski and Sherman [48] and Train [49]. In these cases, a dynamic attribute is introduced in the systematic utility specification; this attribute is named as transaction search cost, a dummy variable which is equal to 0 if $k^{t-1}=j^{t}$ in the time t, equal to 1 otherwise. In Nuzzolo et al. [50] a dynamic path choice model for high frequency services introducing three kinds of attributes is proposed: constant attributes, which do not change from day to day and from one time to another; current and updated attributes, relative to within-day updating; attributes forecast by users on the day-to-day learning process.

In relation to distribution of parameters, in Nielsen and Sørensen [51] it is proposed a model considering a distribution of β parameters among individuals belonging to a given sample. It estimates a model for each data record and compares the estimates for all these models to assess the shape of the distribution. Estimations are performed on smaller subsets of data since it is not possible to perform model estimation for each individual except for very special data sets. The paper consider distribution inside the sample, but it doesn't analyse the evolution in the time.

A first rough hybrid model between these two classes (dynamic as regard attributes and parameters) can be considered the one proposed in Hensher and Le Plastrier [52]. They propose a discrete choice model simulating vehicle ownership, developing a series of linked choice models to explain household vehicle holdings and adjustments in the holdings over time. They suppose that the household periodically considers vehicles owned and decides on maintenance of the status quo, adjustment in the number of vehicles or adjustment in fleet composition.

Finally, in relation to dynamic models as regard random residuals, in Russo [53] it is proposed a dynamic discrete choice model applied to path choice simulation for high frequency services. In this case, if t^1, t^2, … is the run arrival time sequence and j^1, j^2, … the relative run sequence, the total unconditional probability of choosing a run arriving at t^w is defined through the probability of boarding and the probability that the users did not board the previous runs. This is equal to one minus the probability associated with the set of runs already passed.

Similarly, Wilmot and Fu [18] propose a sequential binary logit model to simulate the probability of a household evacuating at each time period before landfall. In the choice mechanism a temporal segmentation of the departure time is considered. In each time a household can choose whether or not to evacuate. Of course, if the household chooses not to evacuate, the choice is reconsidered at the next time and so on.

A hybrid model between dynamic models as regard attributes and random residuals is proposed in Cascetta [9], whit a model simulating day-to-day dynamic path choice behaviour, including two phenomena which are not highlighted in the equilibrium approach: user learning and forecasting mechanisms (utility updating model); user choice updating behaviour (choice updating model).

4 SEQUENTIAL DATA ANALYSIS

Literature models described in the previous section introduce dynamic evolutions of several phenomenon, but they aren't characterized by a statistical structure which allow to analyse the given dynamic phenomenon in the sample database and to highlight, if exists, a specific lag. In the literature which deal with data analysis, structure which allows to carried out dynamic analysis of phenomenon exists.

Sequential analysis arose as science applied itself to observing social behaviour in psychology. Sequential analysis aims to demonstrate how to record observation data, related to user behaviour, in a way that preserves sequential information, and also how to analyse such data in a way that makes use of its sequential nature [54], [55]. The main question to be analysed concerns whether or not specific transition frequencies from an antecedent to a consequent state differ from what would be expected if the two states were independent.

In sequential analysis, data related to user behaviour are recorded and analysed, preserving sequential information. Sequential analysis requires that data must be collected in a systematic way. The analyst must set the recording unit, which can be an interval or an event.

Depending on how data were recorded, the analyst can extract different representations from the same recorded data for different purposes.

Historically, there are at least four forms, termed the Sequential Data Interchange Standard:

- event sequences: a single stream of alternatives is presented without any information concerning time, whether onsets or offsets;
- state sequences: they are identical to event sequences, with the simple addition of timing information;
- timed-event sequences: this is a useful and general-purpose format, used if alternatives can co-occur and if their onset and offset times were recorded;
- interval sequences: this is designed to accommodate interval recording in a simple and straightforward way; alternatives are simply listed as they occur and interval boundaries are represented by commas.

Sequences are analysed in respect of transitional probabilities, so-called even if they recall the probability definition only as frequency. These probabilities are one kind of conditional probability. It may be recalled that an unconditional probability is just the probability of a particular target event occurring relative to a total set of events. A conditional probability is the probability of a particular target event occurring relative to another given event which happened. A transitional probability is defined as a kind of occurring conditional probability, which is distinguished from other conditional probabilities in that the target and the given events occur at different and sequent times. Therefore, by analysing realized data using transitional probabilities it can be obtained further information about their succession in time.

Data collected sequentially are summarized using a transition frequency matrix and a second matrix (so-called) transition probability matrix. The transition frequency matrix is a square matrix which has the same number of rows and columns as events; its generic element ϕ_{ij} represents the transition frequency from i to j (Table 2). These frequencies can also be converted by dividing each ϕ_{ij} by the row total of row i. The results can be arranged in a matrix so-called transition probability matrix (Table 3). The rows of this matrix sum to one.

Table 2: Transition frequency matrix.

		t		
		i	j	
t^{-1}	i	ϕ_{ii}	ϕ_{ij}	ϕ_{i+}
	j	ϕ_{ji}	ϕ_{jj}	ϕ_{j+}
		ϕ_{+i}	ϕ_{+j}	

Table 3: Transition probability matrix.

		t		
		i	j	
t^{-1}	i	π_{ii}	π_{ij}	π_{i+}
	j	π_{ji}	π_{jj}	π_{j+}
		π_{+i}	π_{+j}	

As regards transitional probabilities, in order to indicate the temporal displacement between target (in the current time) and given (in the previous time) event, the word lag is used.

5 CONCLUSIONS

In this paper a framework of demand models has been proposed, in relation to risk reduction in transport systems. The reduction considered is that deriving from the possible modification of exposure which is one of the crucial factors of risk together with occurrence and vulnerability. In the context of exposure, the role of evacuation was analysed.

A first point to highlight emerges from the available literature: mainly models dealing with natural disasters have been presented, while those of the anthropogenic type have a reduced presence in the literature despite some global focal events such as 9/11 or Chernobyl or Bhopal.

In the introduction, a synthetic structure of the literature related to the demand models developed in the context of the topological-behavioural paradigm, the basic nucleus of the transportation system model, has been proposed. The limits of the use, for evacuation, of the demand models developed for ordinary conditions were therefore highlighted. It was also noted that the diffusion of internet access profoundly modifies the situation in extraordinary conditions even more than in the past. From this another notable point (second) emerged: the need to develop the basic components (choice and utility updating) for the calibration and application of assignment models by means of a dynamic process.

The basic elements of the dynamic demand models currently available in the literature were then recalled, classified according to the components that explain the dynamic aspects: attributes, parameters, residues. A third point emerged from this survey: the lack of a statistical analysis of the dynamic phenomena significant for the demand. On this basis, it appears interesting to use sequential analysis as a tool to highlight the presence of dynamic components. The application of sequential analysis can reveal stochastic sequential patterns among the data collected over time, thus allowing to obtain additional information compared to traditional models.

On the basis of the points that have emerged, future objectives for the research are: (a) to study the evacuation related to anthropogenic event; (b) to analyse the data of evacuations carried out by means of sequential analysis; and (c) the development of models for updating utility and choice. The updating models should be specified and calibrated firstly for the ordinary conditions of path choice and then for the extraordinary conditions of evacuation.

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