Disaster risk reduction in urban area: survey design for mobility in evacuation condition*

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Abstract— **The issue of human and natural disasters is becoming increasingly central in all countries, making risk reduction a priority topic. Exposure is the least studied among the three risk components. Research on exposure reduction by means of evacuation is not very thorough. To support evacuation planning, specific models simulating user behaviour in (extraordinary) emergency situations are needed, as existing models are typically based on urban transport conditions in ordinary conditions.**

A survey was developed by analysing and adapting standard questionnaires to emergency scenarios. The result captures user behaviour during disasters, taking into account different types of urban system and the choices that the user must undertake. In addition, the role of emerging Information and Communication Technologies (e-ICT) and users' acceptance of these technologies through Technology Acceptance Models (TAM) is considered.

The results support the development of exposure reduction strategies across all urban transport systems, from those with complete absence of information technologies to those with the most advanced e-ICT. The study offers valuable insights for researchers, planners, and risk managers.

KEYWORDS: Risk, Transportation Risk Analysis (TRA), Transportation System Models (TSM), Information and Communication Technologies (ICT), Technology Acceptance Models (TAM), Exposure, Evacuation.

I. INTRODUCTION

Transport systems play a central role when risk conditions occur in urban areas. The disasters, due to human or natural causes, at the beginning of the 3th millennium have required a considerable effort from the international scientific community. It is worth recalling the Twin Towers with human causes, Hurricane Katrina with natural causes, the tsunami that hit the Fukushima power plant ([1, 2]). States have worked to build a shared knowledge perspective, which has led to two major international strategic agreements: the Sendai Framework (2015-2030) and Agenda 2030 ([3, 4]), with several goals.

Scientific development has led to the formalization of risk in transport systems. The greatest focus was on risk analysis in the transport of dangerous goods [5]. An overall theoretical development has allowed the formalization of risk in its three main components [6]: occurrence, vulnerability, exposure. The study of the three components is usually defined as Transportation Risk Analysis (TRA) ([5, 7]). The exposure component is the one that can effectively counter disasters when the occurrence becomes certainty, and there is no time to reduce vulnerability [8]. The exposure component may be mitigated mainly operating on the evacuation. The issue of evacuation is therefore what directly impacts on the transport system. The study of transport systems is developed within the framework of the theory of Transport Systems Models (TSM). The models that allow the development of TSM concern the study of [9, 10]: demand, supply, interaction between demand and supply. International scientific research has particularly deepened multiple elements of the TSM, in its individual components, from the evolution of choice models (Random Utility Model - RUM, Fuzzy UM - FUM, Quantum - QUM) ([11–15]), to the evolution of each class with greater complexity and capacity of representation ([16–19]). Similar advances have been made for the study of the supply with the development of network analysis ([20–24]), that provides levels of knowledge on the structure of the network in relation to the possibility of reaching significant safe points. Significant advances have been made in the study of interaction with the development of dynamic conditions for updating of utility and choices for different levels of network congestion [9].

An important recent development is the integration of emerging Information and Communication Technologies (e-ICT) inside TSM. This development has led to the evolution of all components of the TSM itself: demand, supply and interaction. The level of perception of e-ICT through Technology Acceptance Models (TAM) has been proposed [25]. TSM is widely studied in literature for ordinary conditions of operation of urban transport systems, while less attention has been given to emergency conditions determined by the presence of risk for

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human-induced events, natural events, or a combination of both. There are few literatures about the presence of information for users in transport systems under risk, as available by the presence of various types of e-ICT. There is, of course, no literature on the user's perception of technologies with a TAM approach.

According to the above considerations, it emerges the importance of having adequate TSM models, developed for Transportation Risk Analysis (TRA), which explicitly consider the role of e-ICT, with the support of TAM analysis to assess user acceptance. A key element of the methodology is the development of a survey based on a reference questionnaire to detect users' choices under identified risk conditions. The topic of this note is therefore the design of a survey that has the aim of increasing the knowledge with respect to the theoretical issues summarized above. After this introduction, the paper is subdivided into four sections. Section 2 analyses the main components that a reference questionnaire must have for a survey on risk reduction by evacuation that considers: TRA, TSM, e-ICT, TAM. Section 3 reports the basic findings obtained in the preparation of the questionnaire with some descriptive results derived from the prototype sample and discusses the interactions between the different structures. The last section summarizes the main elements obtained, proposing a detail of future developments. The work presented is useful for researchers because it offers advances in risk reduction through exposure reduction. It is useful for political decision-makers because it allows them to identify efficient and effective strategies for the population subject to risk. It is useful for planners and risk managers because it allows them to improve plans and their implementations based on the e-ICT available in the individual urban reality of reference.

II. Methodological Components

The investigation to be carried out in order to acquire the elements necessary for the development of the analysis is rather complex. The complexity derives from the need to consider methodological components that derive from different fields of research in an integrated way. To this end it is therefore necessary to analyze (Fig.1) the basic formalizations related to the TRA, then those that allow the development of the TSM and finally in an integrated way the extensions of the TSM that allow to treat the different levels of e-ICT and therefore the TAM impacts. Analysis by e-ICT and TAM does not replace the need to use calibrated and validated TSMs to estimate the performance and impacts of interventions, optimize the supply system, and define demand management strategies, within a planning process.

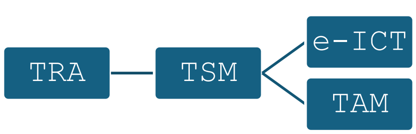

Fig.1 System of methodologies for exposure reduction.

A. *Transportation Risk Analysis*

The first formulation that needs to be defined is the risk analysis in transport. The structure is derived from the studies that over time have been carried out in the industrial field with particular attention to the chemical one, in which the structure is defined as Quantitative Risk Assessment (QRA) ([26–28]). Transport Risk Analysis is an extension of QRA [7]. Developing risk analysis in a transport system implies the need to specify its individual components [6].

Risk (R) can be formalized with:

$$R = O \cdot V \cdot E \qquad (1)$$

in which the individual components represent:

O, occurrence of a disastrous event;

V, vulnerability of the single element of the transport system considered (e.g. road link or node) due to the effects of a disastrous event;

E, exposure to the effects of a disastrous event, of each element of the social system considered, person or movable property.

Equation (1) in its components forms the fundamental basis for any risk analysis. It should be noted that each component, and therefore also the risk, are not constant but depend on variables of space, time, intensity and nature of the calamitous events that could occur. Therefore, the calculation generally requires the solution of models defined in the form of mathematical integrals. The exposure component also depends on the flow of users and congestion and requires the application of models recalled in subsection B.

It is possible to carry out a detailed analysis of the three components, the most advanced formalizations allow to specify three probability functions. This formalization is particularly significant because it allows the field of existence of the risk and of each of its components in the interval [0,1] to be defined.

In general, equation (1) can be represented by a risk surface (Fig. 2) that has the three main components of risk in the three axes. It is useful to define some hypotheses for the development of this work.

With regard to the occurrence (O), it is assumed to know the type of event, and its ability to propagate in the urban area considered.

With regard to the vulnerability (V), it is assumed that the structural state of all the elements of the transport system is known, and therefore the availability of each link/node for the users, the vulnerability therefore considers the physical effects on each link/node, which can be defined as exogenous with respect to the traffic flow.

With regard to exposure (E), each element, person or asset, is considered to have a level of exposure depending on its position in the territory and in the time.

The occurrence component of the risk defines the type of event, in particular it allows to specify the primary event with its duration, and the propagation of the effects. Reference is made to a general network such as the one shown in Fig. 3. Based on the time interval between the primary event at the generic x-point (place of the event) and the effect at the generic y-point (user position), appropriate procedures for reducing exposure by means of evacuation can be developed. Assuming that point z (safe place) is not affected by the event in x, the evacuation should be able to allow, in the available time interval, that the generic user who is in y at the time of the event can reach z.

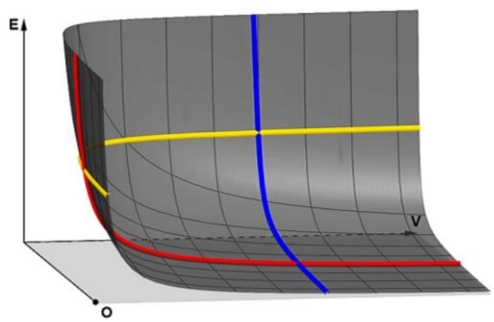

Fig.2 Risk surface.

Having posed the problem in these terms, it is possible to transform it into a problem which can be analyzed by means of TSM (i.e. with network design models and demand management models) inside a more general planning process.

B. Transportation System Models

The problem that arises is to study the relationships between transport demand, supply, and therefore their interaction [9]. Schematically it can be assumed that the vector h of the average path flows, between a pair of origin and destination nodes, is obtained as the product of the demand flow d, by the probability of choosing the path. If P is the matrix of probability of choosing the paths, which depends on the path costs and on the socio-economic characteristics of the user SE we have:

$$h = P\,(SE, C)\; d \qquad (2)$$

Furthermore, it can be assumed that the demand vector d depends on the attributes of the system of activities SE and the vector g of path costs:

$$d = d(SE, g) \qquad (3)$$

By combining the equations (2) and (3), we finally obtain:

$$h = P(SE, g)\; d(SE, g) \qquad (4)$$

From path flows h, one can move on to arc flows f via the path incidence matrix Δ ($f = \Delta\, h$). In case of congested networks, the link costs c depends, in turn, on the flows f equation (4) can finally be written as:

$$f^{*} = \Delta\; P(c(f^{*}))\; d(c(f^{*})) \qquad (5)$$

For the purposes of the overall formulation, it is necessary to highlight that the matrix P represents all the choices that users undertake. In the context of the evacuation problem that has arisen, the choices are related to the transport mode and the path to be used. Considering a given mode, the matrix P can be formalized as:

$$P = P(\beta, SE, c)$$

where β is the vector of the parameters to be calibrated.

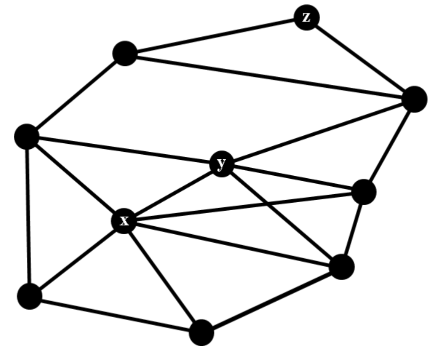

Fig. 3 Reference network: x place of the event; y user position; z safe place.

The formulation presented for ordinary conditions has been developed for some components of the emergency conditions given by an evacuation. The models developed for evacuation concern: demand [29, 30], supply ([31, 32]) and their interactions for the design ([33, 34]). During the preparatory phase, with respect to the occurrence of an event, it is necessary to develop, together with the modeling of the mitigation plan, a series of actions aimed at increasing the knowledge of decision makers and users about the emergency [35].

The estimation of the β vector is the main element for the evaluation of the matrix P and, through (4) or (5), of the path flows and costs, and of the evacuation times, that has not investigated [36]. The path times allow the comparison between the interval between the event in x and the effect in y, and the time of displacement between y and z, previously defined as the safe place. The estimation of β in the general conditions of an urban transport system where no information is available to the user therefore becomes the first response that must be available for the evaluation of evacuation. To highlight the lack of information systems, this vector is denoted by β_{NeICT}

C. Emerging Information and Communication Technology

In transport systems e-ICT are becoming increasingly important. These technologies are called emerging, because although they are mature in other industrial sectors, they are still being developed in the urban transport sector. There are many technologies, but it is possible to aggregate them into some main classes [30].

The first class to consider is the one commonly referred to as the Internet of Things (IoT). This class includes two sets: that of physical objects "things", i.e. physical elements integrated with sensors, software and other technologies that allow the detection and exchange of data relating to the element itself; set of elements that make up a telematic network that connects physical objects to each other and with other devices and systems.

The second class is the one called Blockchain (BC). The latter was born with completely different characteristics from the former, but conceptually it can be traced back to the former, replacing material objects with immaterial values. For this reason, it is often also referred to as the Internet of Value (IoV).

The typical structure of a BC is given by a set of blocks of data, organized in locked and removable sequences. The technology is fully developed in trade and logistics.

The third class is the one defined as Big Data (BD). Also, for this class it is not direct to define the set to which the individual element belongs, and it is also not possible to define a limit amount of data to which the BD set belongs. An indirect definition arises from the difficulty of defining the potential limit. It is a BD when the data set is so large that it requires the use of specific algorithms for data extraction in pre-defined times. A greater specification, in line with those seen for the first two classes, defines data warehouse as the set of data from various systems and data mining as the search and extrapolation algorithms. Therefore, as mentioned in general, the term BD is used to include all subclasses.

The fourth class is the one to which structures called Artificial Intelligence (AI) belong. In general, AI is defined as algorithms that, after analyzing data sets, produce an ordered set of decisions on a question asked. The AI can produce the entire system or the first decision of the system. For example, in the case of paths, the AI can present the probabilities of choosing the paths, or directly the path with the highest probability. In the literature, there are various classifications within AI, based on the type of algorithms used for sorting and on the data sets on which it operates.

It is possible to recall another class that has recently developed, the Digital Twins (DT). In an extremely synthetic way, it is possible to define the belonging to this class of all systems that allow us to simulate the real world. So, DTs are composed of elements belonging to two sets. On the one hand, the set of models that allow the functioning of a system to be quantitatively formalized with the relative hardware, and on the other hand, the set of devices that allow interaction between the models and the analyst, planner or user. There are further classes of e-ICT that are beginning to appear in the literature with the first experiments, but they have not yet reached an adequate level of technological maturity in any field. Based on what it has seen in this section, it is possible to reconsider what discussed in the previous section. In fact, all dimensions of choice can be influenced by the presence of e-ICT. The role of e-ICT is decisive both in the choices analyzed with static TSMs and in those analyzed with dynamic TSMs. In light of this, it is possible to define a new vector β of parameters which, in order to highlight the role of e-ICT for its estimation, is indicated with $\beta_{YeICT.}$

D. Technology Acceptance Model

TAM have been proposed after the development of e-ICT. These models introduce the level of acceptance by users of individual technologies, or their integration [25]. The models allow to evaluate, at different scales, the behavior of users in accepting e-ICT.

TAM approach is developed starting from the utilities defined in the study of behavioral models ([11, 12, 14]). TAM [25] introduces two levels of acceptance.

In a first level, the Perceived Utility (PU) in the acceptance of technologies is defined: "The degree to which a person believes that using a particular system would enhance their job performance".

In a second level, the Perception of Ease of Use of new technologies (PEU) is defined: "The degree to which a person believes that using a particular system would be free from effort".

The two levels therefore express subjective judgments of the user. They do not refer to the objective value of the generic attribute but to the qualities that the user associates with it. So even if, in theory, the attribute provided by the e-ICT was fully correct, the generic user assesses whether:

1. (PU) attribute improves its ability to choose;
2. (PEU) technology that is proposed to it is more or less complex to use.

TAM approach allows the user's judgment on necessity and ease to be considered in the choice regardless of the goodness of the data provided. The value of the attribute can be of various types, from the base value of a binary variable 0/1, to that on a quantitative scale, to that on a qualitative scale. In the latter case, it is proposed, in the literature, to use appropriate scales such as the Likert scale by using scores in a variety of ways.

On the basis of what has been seen in this section and the formulations of the two previous sections, the β vector can be further evolved by explicitly considering the TAM approach, expressing the aliquot of parameters affected by the TAM as $\beta_{TAM.}$ Schematizing what has been presented so far, it is possible to subdivide the vector β into different main parts:

- β_{NeITC} parameters not subject to, or not known through, e-ITC;
- β_{YeITC} parameters known through e-ICT;
- β_{TAM}: parameters known by e-ICT and evaluated by TAM.

Considering that generally all types of parameters are present in the vector β, because TAM is not applicable to all types, and is only experimental compared to the more advanced ones.

III. Operational Results for the Design Survey

The methodological structures, originating from different research fields, integrated into the overall model proposed in the previous chapter, allow to obtain a first significant result with the definition of an operational structure for design survey. The data collected with the questionnaire administered to a group of users allows the development of descriptive and probabilistic behavioral statistical analyses regarding the choices made by users in real cases or choices that users could make in realistic cases proposed. On the basis of what has been seen above, it immediately emerges that the basic structure must be subdivided into two sections. The first section (subsection A) concerns the definition of the occurrence and the exogenous vulnerability conditions of the system, with questions relating to the more general current conditions of urban transport systems, i.e. the absence of e-ICT related to evacuation conditions. The second section (subsection B) concerns the conditions in which in the urban system considered and subject to the same exogenous conditions defined in the first section, there is an integrated e-ICT system, in the second part of this section the TAM questions are asked, relating to the e-ICT system described,

A. *The design of the basic framework*

In order to clearly separate the user's attention with respect to the different types of questions, it is necessary to separate the administration of the two questionnaires temporally. This allows the respondent to focus on a specific scenario. The first section of the questionnaire, as mentioned, is separated into different homogeneous parts.

The first part of the questionnaire relates to the definition of the risk scenario. The respondent is presented with the conditions of the risk which he/she is subject to. The occurrence is defined and the conditions of vulnerability of the transport system are defined and described. Finally, the risk area is defined and the safe place to reach is presented. Referring to Fig. 3, the point x where the event was generated, the point y where the user is located and the point z to be reached because it is a safe place is indicated.

In the second part, the socio-economic conditions of the respondent are examined. The answers define the framework of the attributes described in section 2 in a synthetic way with SE. From this section it is possible to obtain both the statistical analyses on the overall sample interviewed, and in the subsequent calibration the part of the overall vector β_{SE} relating to socio-economic attributes indicated by SE.

In the third part, information is requested regarding the means usually used to move around the urban area, and the means available at the time of the interview.

The fourth part is the most complex because it concerns all the path choices that the user makes in the risk conditions defined in the first part. Various alternative routes are presented and the question is asked which one would be chosen. The questions are of the Stated Preference type, relating to "what if". It should be noted, however, that the whole infrastructural and information situation is real.

B. *The design of advanced framework*

The design of the second section of the survey concerns the choices made when information is provided to the user through e-ICT. The second questionnaire is subdivided into different parts. The scenario in terms of occurrence, vulnerability and exposure is identical to that defined in the first questionnaire. The structural modification is in the presence of e-ICTs of various types. The presence of particularly advanced e-ICT introduces a second level of SP, because now the scenario is realistic, in the sense that the information could be there as can happen in particularly equipped urban areas, but it is not real.

The first part is similar to the fourth part of the first questionnaire, but the information to the user is explicitly introduced. Each possibility of diversion from the path chosen by the user is provided with information on the evolution of the event and its effects.

The second part concerns questions that refer to the basic TAM approach, i.e. judgments are asked on the validity of the information received and on the ease of understanding the information received. The questions related to this part are asked halfway through the first part.

The third part concerns the user's assessment of evacuation plans, and aims to investigate the perception that users have of the plans prepared by the Municipality for evacuation. This part is particularly interesting for building the DT as it highlights the user's perception with respect to the entire public protection plan.

C. *Aggregate structure of the sample*

Preliminary descriptive analyses, which were carried out on a prototypical sample, provide an overview of the main characteristics of the respondents including demographic attributes, educational background, employment status and the main mode of transport used to move around the urban area under study (Tab 1). These initial results help to define the general profile of the sample and are used as a basis for more in-depth analyses involving the analysis of behaviour at lag 0 and lag 1 and the application of dynamic models for the updating of choices and utilities.

Table 1. Composition of the sample and modal preference.

Socio-economic data		
Gender	Male	80%
	Female	20%
Age	< 25	89%
	> 25	11%
Level of education	High school graduate	92%
	University degree	8%
Employment status	Employed	6%
	Student	94%
Main transport mode	Car	76%
	Motorbike	2%
	Public transport	19%
	Walking	3%

IV. Discussion and Conclusion

The results obtained are interesting because they allow to build an articulated survey design, which has as a reference the four sets of in-depth analysis central to risk reduction through evacuation. Today this issue is crucial in the evaluation of urban areas conditions, which are increasingly subject to anthropogenic or natural risks. The proposed work and the survey design consider in an integrated way the following approaches: TRA, TSM, e-ICT, TAM. The work is therefore particularly innovative, and is useful to researchers in the four sectors concerned because it allows an advanced and integrated reading of different scientific areas. The work is useful for policy makers, planners and emergency managers, because it directly offers a survey design that can be used in all contexts working on the preparation of advanced risk reduction plans.

This work constitutes the basis for developing dynamic models of updating utility and updating of choices that can be implemented in real contexts to improve the evacuation of users and therefore to reduce risk, using e-ICT. The direct developments concern the specification in relation to the different types of attributes to be evaluated, for each of the innovative e-ICT and TAM sections. It is necessary to analyze the results obtainable from the survey prepared using adequate statistics for each e-ICT and TAM component. It is therefore important to develop a cross-statistical analysis between e-ICT and TAM. Current work and future developments are part of the pursuit of the goals of the 2030 Agenda for sustainable development.

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