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Planning for Risk Reduction in the Transport System at Urban Level

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ABSTRACT

Globally, communities are committing to reduce the risks arising from different types of events. According to the classical formulation, risk comprehends occurrence and magnitude related to the potential damages produced by the event. Magnitude comprehends two components: exposure and vulnerability. It is possible to define specific actions for pursuing risk reduction according to the emergency management cycle and its phases (prevention, preparedness, response and recovery). This paper focuses on the preparedness phase and the transport planning process at the urban level. The process produces decisions about the configuration of the transport system and its components (supply, demand and interactions). Generally, planning decisions concern ordinary conditions but they have to be defined considering also implications for extraordinary situations. The objective of this paper is to present different issues of urban transport planning, one for each risk component. A single emergency event and the relative urban planning activities have been selected. The selected event represents a category of disasters with effects to be reduced with specific planned activities. The issues represent different problems and relative solutions to increase preparedness for emergency events at the urban level with a correct approach to risk assessment for supporting urban transport planning. The paper contributes to clarifying the characteristics of the risk's components and relative urban transport planning activities aimed at reducing risk.

1. INTRODUCTION

Natural and man-made disastrous events are affecting an increasing number of people at the global level. For this reason, risk reduction is a priority to contain disastrous effects related to different emergency events. In the temporal period 1998-2017, the economic losses from disasters increased by more than 150% [1]. The *Sendai Framework for Disaster Risk Reduction* 2015-2030 [2] is the first of the world's policy agenda adopted by member states of the United Nations to pursue disaster risk reduction at the global level. The Framework is strictly related to sustainable development goals (SDGs). Sustainable Development has to be 'riskinformed' to limit losses for people and planet [3].

In this context, increasing knowledge about risk and its components represents a priority. According to the classical formulation, risk comprehends two main components: occurrence, related to the frequency or probability that an emergency event happens, and magnitude related to the potential damages produced by the event. Magnitude can be expressed in terms of: exposure, related to the probability that people and goods are affected by the damages; vulnerability, related to the probability that the system resists the disastrous effects. It is possible to define specific actions for pursuing risk reduction, that in the emergency management cycle are grouped into the following four classes [4]: prevention or mitigation, including actions to undertake in advance; preparedness, including actions to prepare communities to cope with an emergency; response, including action to perform during or immediately after an emergency; recovery, including actions to assist communities to return to an ordinary condition.

Russo and Chilà [5] propose a temporal evolution of the three aspects related to disaster: the dangerous events that evolve from an ordinary to an extraordinary condition; the user's behaviour evolution from a pre-impact phase to a postimpact phase; the planning and management evolution that regards the decision-makers' behaviour. By focusing on this last aspect, the activities of decision-makers are: in the preimpact phase, to plan the system for an emergency condition; in the impact phase, to respond to the effects produced by the emergency event; in the post-impact phase, to bring the system back to an ordinary condition (Figure 1).

The annual report published by United Nations Office for Disaster Risk Reduction [6] appointed urban planning to design resilient cities and reduce the negative effects generated by calamitous events. Urban planning organizes flexible cities for any risks. Cities planned to operate adaptive scenarios, useful to prevent or mitigate calamitous effects, according to the risk categories. The term risk means the probability that a phenomenon can occur in a place, causing damage, more or less estimated. The risk factors concern several possible categories. A compound measure combining the probability and magnitude of an adverse effect [7].

This paper focuses on the planning evolution phase and in particular on the transport planning process at the urban level. The process produces decisions about the configuration of the transport system and its components (supply, demand and interactions). Generally, planning decisions concern ordinary conditions, but they have to be defined considering also implications for extraordinary situations.

The objective of this paper is to present different issues of urban transport planning, one for each risk component. Planning problems and relative solutions to reduce:

• the occurrence risk's component, by focusing on the representative event like a road accident involving a vehicle for dangerous goods transport;

• the exposure risk's component, by focusing on the representative events that allow decisionmakers to implement an evacuation of people;

• the vulnerability risk component, by focusing on the representative event like an earthquake.

The paper contributes to clarifying the characteristics of the risk's components and relative urban planning activities aimed at reducing risk, with the main reference to the transport system. The common finality is to analyse how it is possible to assess risk and then reduce it, working on one or more components. It is necessary to increase preparedness for emergency events at the urban level. Each case represents the contents of a plan-product of the transport planning process for emergency conditions.

Temporal Evolution	Dangerous event	User behaviour	Planning and management
	Pre-impact phase	Threat/Warning	Mitigation/Preparedness
	Impact phase	Impact	Response
	Post-impact phase	Recoil and rescue/Post-traumatic	Recovery

Figure 1. Temporal axis for emergency conditions (adapted from [5])

After this introduction, the paper has four sections. Section 2 recalls the formulation of risk in the transport system and the main elements of planning for reducing each component at the urban level. This section describes the characteristics of each risk component through a representative event and the specific urban planning activities for risk reduction. Section 3, according to the topics analysed in Section 2, presents the characteristics of emergency urban planning in Italy. The final section remarks some conclusive comments.

2. TRANSPORT PLANNING FOR RISK REDUCTION

2.1 Risk formulation in the transport system

According to Russo and Vitetta [8], the analytical representation of risk in the transport system can be formulated as:

$$R = f(O, M)$$

where, O is the occurrence that an emergency event happens; M is the magnitude related to the potential damages produced by the emergency event.

The magnitude can be expressed as a function of two components:

$$M = g(V, E)$$

where, V is the vulnerability risk component related to the resistance of the infrastructure (material and immaterial) when the emergency event occurs; vulnerability can be expressed in terms of a probability that the system resists the disastrous effects; E is the exposure risk component related to the quantity of people, goods and infrastructure affected during and after an event; exposure can be expressed in terms of the probability that people, goods and infrastructures suffer damages produced by the event.

Following this formulation, it is possible to reduce risk with two classes of action:

• *prevention*, including activities designed and implemented to reduce the level of O;

• *protection*, including activities designed and implemented to reduce the level of M.

According to the previous definitions and formulations, the magnitude can be reduced with two classes of activities:

• *resistance*, that has the main aim to reduce the level of V, by increasing the ability of the infrastructure (transport and otherwise) to withstand the event;

• *evacuation*, which has the main aim to reduce the level of E, by increasing the performance of transport infrastructures and services that facilitate mobility in evacuation conditions, by reducing the number of people and goods potential affected by the negative effects of an emergency event.

Figure 2 schematizes risk components along the axes of tridimensional space. Each risk component can be reduced by adopting a specific planning activity. According to the introduced classification, a combination of one or more activities can be planned for risk reduction. Figure 2 reports the specific planning activity aimed at reducing each risk component.

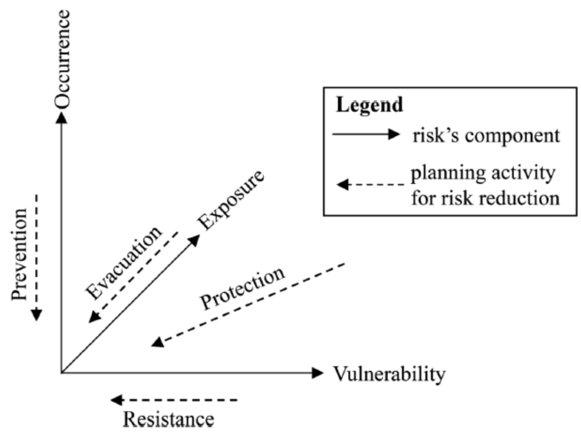

Figure 2. Risk components and planning activities for risk reduction

As far as concerns, the transport system and according to Russo and Rindone [9, 10] planning activities for risk reduction concerns:

•the material assets of the system including interventions that modify the physical characteristics of (material activities):

•linear infrastructures and transport network links dedicated to evacuation routes (e.g., use of an urban transportation sub-network only for emergency vehicles);

•punctual infrastructures and transport network nodes reserved for assembly points to reach during an evacuation (e.g., areas for emergency vehicles, refuge areas);

•the non-material assets of the urban system including learning, training and exercising processes (discussion and operation based) [11], and others concerning telematics or intelligent transportation systems (ITS) or more in general information and communication technologies (ICT) (non-material activities);

•the rules of the system, including interventions that concern regulations (e.g., definition of actors, roles and responsibilities involved in all phases of the emergency management cycle), management of individual (contra flow measures, demand management, …) and collective mobility (e.g., transit services for people with special needs) (governance activities).

Table 1 summarises transport planning activities classes and their relative contribution to risk reduction. Each class contributes to the reduction of one or more components (see also Figure 2). The level of reduction is represented in a qualitative way. It is possible to combine activities belonging to different classes into a planned scenario, for designing a transport system in emergency conditions [12]. For an ex-ante evaluation of effects produced by each scenario, the contribution to risk reduction can be estimated by adopting transport system models (TSMs) [13-15]. The aim is to estimate the influence of planned scenarios on user behaviour [16-18] inside a decision support system (DSS) [19, 20]. Real effects can be monitored *in-itinere* and ex-post evaluations adopting ICT tools [21].

Table 1. Classes of planned activities for risk reduction concerning each component

Class of activities	**Occurrence reduction (prevention)**	**Exposure reduction (evacuation)**	**Vulnerability reduction (resistance)**
material activities	**	*	***
Non-material activities	**	***	*
Governance activities	***	***	**

* Low contribution; ** medium contribution; *** high contribution.

The following sections focus on each component and on the possible urban planning activities for reducing potential negative effects. Each section describes the main characteristic of each risk component by referring to a representative event and the possible planning activities for risk reduction. The selected event represents a category of events that requires planning and implementation of one or more activities belonging to the classes in Table 1.

2.2 Planning for the reduction of the occurrence on an urban scale

This section focuses on the occurrence component and relative prevention planning activities aimed at risk reduction, in the field of transport. Section 2.2.1 describes the main occurrence's characteristics by referring to the road accident event connected to the release of dangerous goods. The event represents a category of disasters with effects that can be reduced mainly with prevention activities. Section 2.2.2 describes the possible urban planning activities aimed to reduce occurrence by increasing prevention.

2.2.1 The occurrence characteristics

The occurrence is measured using the probability that an accident may happen. At the urban level, one of the more frequent events is a road accident involving a vehicle transporting dangerous goods. Dangerous goods are substances and products that, for their physical and chemical properties, represent a hazard for people and the environment. In this context, transport risk analysis (TRA), which derives from quantitative risk analysis (QRA) developed for fixed plants, plays a relevant role [22]. Following the TRA consolidated approaches, it is possible to express the occurrence probability for road transport of dangerous goods with the following formulation [23]:

$$O = P_0 \cdot P_1 \cdot P_2 \cdot P_3 \cdot P_4$$

where, P_0 is the probability that a road accident occurs; P_1 is the probability that a road accident involving at least one heavy good vehicle occurs; P_2 is the probability that a road accident involving at least one heavy good vehicle transporting dangerous goods occurs; P_3 is the probability that a heavy vehicle transporting dangerous goods, after a road accident, releases dangerous goods; P_4 is the probability that, after a road accident with the release of dangerous goods, a disastrous event occurs.

Leaving from the probability P_4, it is possible to classify the disastrous events concerning the following physical dimensions and their consequent disastrous effects:

• temperature as a consequence of a fire;

• overpressure as a consequence of an explosion;

• concentration of a substance in the air as a consequence of a dispersion or a gas cloud.

Each road accident involving dangerous goods may belong to one or more of these types.

2.2.2 Urban planning activities

Urban planning plays a relevant role in reducing occurrence risk components. In the specific case of dangerous goods transport, different actions offer potential contributions for risk reduction. The final aim is to design transport system features to ensure an acceptable risk level. As first point, it is possible to design routes and upgrade existing roadways to allow safe transportation of dangerous goods.

In relation to material infrastructures, it is possible to plan interventions for reducing road accidents in general and road accidents involving heavy vehicles. Literature reports theories and applications in the context of a road accident and relative interventions to reduce the occurrence probability.

In relation to non-material activities, it is possible to recall the ICT for monitoring road transport of dangerous goods and DSS for developing TRA (e.g., TRAT-GIS; QRAM; ARI-PAR-GIS; EHHRA-GIS) [24]. ICT and DSS are useful tools to support ex ante and ex post evaluations of effects produced by interventions on road risk management.

In relation to governance activities concerning rules, it is important to underline that the transport of dangerous goods is regulated at international level. There are international agreements that regulate the transport of dangerous goods by road and rail. According to international agreements, the Dangerous Good Safety Advisor (DGSA) ensures that rules for transport of dangerous goods by road, rail and inland are respected [4].

In relation to governance activities for configuring services, it is important to recall emergency services that are activated to face consequences of accidents involving dangerous goods. In Italy, the confederation of chemical operators has activated the 'Servizio Emergenze Trasporti' (SET) [25]. This is a cooperation program that involves industrial operators and public authorities with the aim to prevent and manage accidents during transport and logistics activities in the chemical supply chain.

2.3 Planning for the reduction of the vulnerability on an urban scale

This section focuses on the vulnerability component and relative resistance planning activities aimed at risk reduction. Section 2.3.1 describes the main vulnerability's characteristics by referring to the earthquake event. The event represents a category of disasters with potential effects that can be reduced mainly with material interventions to increase the resistance of infrastructures. Section 2.3.2 describes the possible urban planning activities aimed to reduce vulnerability by increasing resistance.

2.3.1 The vulnerability's characteristics

Vulnerability is the probability that an emergency event causes a level of physical damage. At the urban level, the earthquake is one of the most representative events of the need to reduce vulnerability. In this case, the probability measures that, in a certain time interval, the consequences of the seismic event exceed a threshold. The seismic risk depends on several factors as the danger, the local physical, geological and geomorphological conditions. Urban vulnerability is related to the resistance of infrastructures that contribute to the reduction of the potential losses produced by the disastrous event.

Here are recalled the definitions reported in the guidelines produced by the Umbria region in Italy for urban planning [26]. Guidelines indicate that building vulnerability is segmented into: (1) direct vulnerability of a specific element that depends on its structural characteristics; (2) induced vulnerability or the damageability of an element in relation to its interactions with the built context and (3) deferred vulnerability or the effects of potential damage, visible in the phase following the seismic event.

2.3.2 Planning activities aimed at vulnerability reduction

Urban planning aimed at reducing urban vulnerability is based on evaluation criteria, concerning the three macro-categories potentially exposed to risk:

•the settled population, including workers, students, users and tourists;

•the physical elements, including residential and monumental building heritage, strategic equipment of collective interest, infrastructural networks;

•the economic activities, including manufacturing, industrial and artisanal businesses.

The urban plan for risk reduction assigns an important role to public space during the impact phase. The plan interconnects the system of public spaces and functions of the historic centre with the external systems [27-29].

To obtain a substantial risk reduction, it is necessary to analyse the location and distribution of the population, the urban functions, historical assets and urban activities. The integrated planning approach consists of three phases: risk analysis; multi-criteria analysis, to compare different scenarios; planning scenario.

The minimum urban structure (SUM) is a possible solution for increasing the urban vulnerability. SUM is an integrated system of routes, spaces, urban functions and strategic buildings, planned in response to the earthquake in the emergency phase. It supports the resilience of economic, social and relational activities, after the seismic event. The SUM constitutes a solution to increase the urban resistance to an earthquake, also concerning collateral events, such as fires, landslides, hydrogeological phenomena, etc.

The resilience of the city depends on the planning capacity of the SUM. The urban plan defines the SUM by answering the question: What must resist if the earthquake happens?

The SUM is an organized planning process based on data analysis, integrated forecasting of the results and urban regeneration projects. The urban plan analyses and interprets the places. Moreover, the plan organizes the resilience of the city, increasing sustainable development, with urban regeneration projects.

The SUM planning, through the design of public spaces, is an opportunity for urban regeneration. It is a new concept of urban land use, based on the system of networks of squares, green areas, emergency areas, streets and pedestrian walks. It is an opportunity for planning the sustainable development of the territories.

The resistance of cities during an earthquake depends on the asset of infrastructures. Therefore, to reduce urban vulnerability, the plan must carefully decide the layout of the infrastructures.

2.4 Planning for the reduction of the exposure on an urban scale

This section focuses on the exposure components. Section 2.4.1 describes the main exposure's characteristics by referring to the disasters with delayed effects in the time [16] as the tsunami. This category of disasters allows emergency managers to implement evacuation procedures, not varying the asset of the material infrastructures. Section 2.4.2 describes the possible urban planning activities aimed to reduce exposure through an efficient and effective evacuation procedure.

2.4.1 The exposure characteristics

The exposure risk component is measured employing the probability that a quantity of people or goods are present in the affected area of potential damages (see Section 2.1). At the urban level, it is relevant to increase the knowledge of exposure component and mobility in evacuation conditions.

The knowledge of available resources allows planners to individuate evacuation routes to safe areas. A dynamic DSS transmits data by means ICT to the population to mitigate risks and increase resilience against the dangers of natural disasters [19, 20]. Smart urban planning promotes the collaboration among agencies involved in the planning process, for example through integration, and sharing of information and data for increasing the knowledge of the space environment pre and post-disasters [30].

2.4.2 Urban planning activities

Knowledge of exposure's component is translated into an evacuation plan which is one of the main actions to reduce risk at the urban level. The plan defines resources, organisation and operations that allow people to reach safe areas, deciding when, where, on which transportation mode and by which path each evacuee should travel [7].

Resources comprehend different typologies:

•human resources or people with specific emergency management capabilities;

•equipment and instrumental resources to assist emergency managers and operators (e.g., traffic barriers, cones).

The knowledge of available resources allows to planners in the definition of the evacuation routes to safe areas, for reducing evacuation times, and then exposure.

One of the main elements of an evacuation plan is the definition of the optimal use of the available resources to perform evacuation operations. For instance, an effective evacuation plan contains the transport network design in emergency conditions that allows rapid routing of evacuees to the safety zone.

Resources allocation is supported by ICT tools for monitoring [21] and specific methodologies for transport network design in evacuation conditions that became traffic control and management strategies [31-35]. Collected data, methods and models represent the content of a dynamic DSS that performs two different functions:

•to support decision-makers to define planned actions to be implemented during an evacuation;

•to communicate with the population to orient travel choices in evacuation conditions.

3. EMERGENCY URBAN PLANNING IN ITALY

3.1 The emergency planning process and preparedness

Italy regulates the Civil Protection sectors with national and regional laws that define [36]:

• the types of emergency events (‘type a’, ‘type b’, ‘type c’), roles and competencies;

• the activities and civil protection tasks, in relation to the type of event (*prevision/prevention, response, recovery*);

• the components of the national service of civil protection (national, regional and local public administration, group of volunteers).

Preparedness activities constitute the main contents of the ‘prevention’ task, including alerting, emergency planning, training, dissemination of knowledge of civil protection as well as information to the population and exercise preparation and implementation.

According to the objective of this paper, in the following the focus is on the planning activities. The Italian Law [37] imposed the obligation to coordinate the plans and programs for the management, protection and rehabilitation of the territories with the emergency civil protection plans, adopted at different territorial scales and in particular:

• at national scale, the prevention and rescue programs for reducing various risk hypotheses, with specific emergency measures;

• at regional scale, the regional prevention and protection programs, for following the national indications;

• at local scale, the provincial prevention programs, for following the national and regional programs, the Prefect’s plan to deal with the emergency throughout the province, the Municipal Emergency Plan (PEC), or inter-municipal plan, for following the criteria and procedures set out in the operational guidelines adopted by the National Department of Civil Protection and by the regional councils.

In July 2021 the Italian Government published guidelines for producing the Civil Protection territorial Plans [38]. The guidelines implement the ‘Codice della protezione civile’ (Code) that introduced the necessity to regulate the modalities of organization and development of civil protection planning (‘monitoring, updating and evaluation’). The aim is to guarantee a coordinated framework at the national level for integrating civil protection systems at all territorial levels, respecting at the same time the autonomy of the Regions. The specific objective is to uniform the planning methodology at different territorial levels for the management of the activities connected to the calamitous events. The code establishes that territorial planning levels are: national, regional, sub-regional (provincial/Città Metropolitana; optimal territorial and organizational scope); local (towns).

3.2 Urban planning for reducing the occurrence component

As far as concerns urban planning for reducing the occurrence and the specific case of a road accident involving dangerous goods, the Code reports specific indications for urban planning. National services of civil protection support local administrations with management activities to assist local emergency operators and the population. For the specific risk related to the transport of dangerous goods, planning has to consider the national directives that concern coordination in the case of a road accident that produces consistent damages. In particular, national directives define communications and information flows, the coordination’s operations in the location of the accident, and the modalities to assist and inform the population. By focusing on the occurrence topic, specific planned activities are: to identify hazardous materials and to individuate extension of the impacts generated by the accidents.

3.3 Urban planning for reducing the vulnerability component

As far as concerns urban planning for reducing vulnerability, it is important to underline that some Italian regions have published laws to reduce vulnerability.

For instance, in 2005 the Umbria Region introduced a law that defines the activities for the reduction of seismic vulnerability, in the planning process at the urban level. The prevention and reduction of seismic risk become an integral part of the ordinary process of governing the territory [39]. In 2010, according to this law, region published the guidelines that define the minimum urban structure in the general regulatory plan. The guidelines identify the SUM as the essential activity to reduce seismic vulnerability at the urban level, through objectives and interventions concerning the structural and operational part of the urban territorial plan [40].

The resistance of the urban infrastructures to earthquake’s effects produces different benefits for emergency management. For the response phase, the SUM allows emergency managers to increase the operative’s efficiency of aids coordination. For the recovery phase, the SUM facilitates the recovery of the urban functions in the long term. SUM design individuates the critical factors that must be solved to ensure the best urban performances in the case of a seismic event. The SUM identification is useful for defining priorities in an integrated urban planning process, whose coordination among different public entities assumes a relevant role.

3.4 Urban planning for reducing the exposure component

As far as concerns urban planning for reducing exposure, it is important to underline the Code promotes evacuation planning for local administrations. At this level, the local administrators have to define the safe areas and the routes for reaching them in the case of a tsunami that belongs to the category of events for which it is important to reduce the exposure component. Routes and safe areas constitute the contents of an evacuation plan. Specific attention is on the exercises that are classified according to the criteria related to the space (international, national regional, local exercises) and modality of execution. Local administrators have to organise and implement:

•Command post exercise - CPX, for testing operative centres and their capacity of interrelations;

•Field exercise - FX, for testing specific operative modules in real contexts;

•Full-scale exercise - FSX, for testing (prevention, alerting, management) a planned scenario involving operative modules and population;

•Table top (TTX) for testing emergency plans and in particular specific scenarios in an artificial environment

•Discussion-based exercise (DBX) for discussing and comparing hypothetic risk's scenarios.

Note that the guidelines do not report operative indications for network design, or simulation tools of the transport system in emergency conditions.

3.5 Advancement of the urban planning process

In Italy, the emergency plan at the local level is the PEC ('Piano di Emergenza Comunale') which defines the operational procedures to be implemented when an emergency event occurs. Starting from the analysis of the current asset of the territory and the potential risk scenarios, the PEC must report the indications about the procedures (e.g., assistance to the population) and the monitoring activities in case of an emergency event.

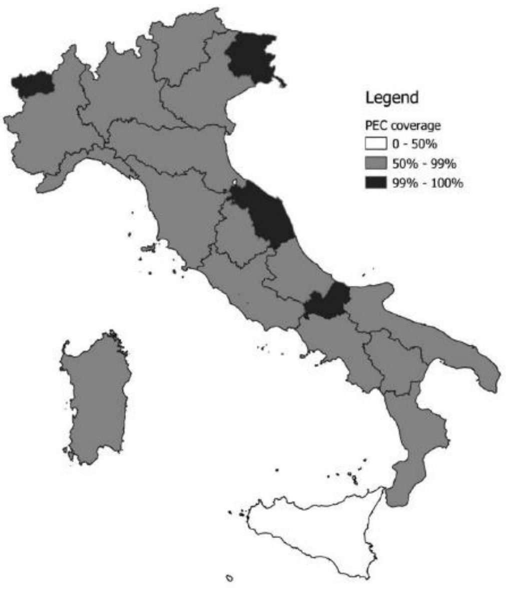

Figure 3. C overage of emergency local plan at the urban level in Italy
(Source: Italian Department for Civil Protection, 2021 [41])

The PEC is organized into three parts: the *general* part with information about physical and socioeconomics characteristics of the territory; the *planning* part with objectives to pursue, planning activities and involved operators and their roles; the *intervention model* that assigns command and control responsibilities.

Figure 3 describes the emergency local plan coverage adopted at the urban level in Italy. Note that in the great part of the region the national coverage rate is high. Nevertheless, a great part of these plans has to be updated according to recent guidelines [40]. However, adopting a plan alone does not represent a high level of preparedness. For instance, at European level, the lack of standardization in current disaster training methods represents a gap in the command, control and communication levels.

4. DISCUSSION AND CONCLUSIONS

Effects of disastrous events can be limited by reducing risk and their components. Integrated planning for ordinary and extraordinary conditions allows decision-makers to face emergency conditions produced by different kinds of events. Planning for individuating the optimal combination of activities increases communities' preparedness.

This paper has investigated transport planning activities at the urban level aimed to reduce each risk component. In particular, the focus of this paper is on the contribution of each planning activities class to reduce one or more risk components. For reducing the occurrence component, it is necessary to plan mitigation activities that mainly modify the institutional asset of the urban transport system. For reducing the exposure component, it is necessary to plan evacuation activities that improve the performance of the urban transport system in emergency conditions, keeping the physical structure and the system unchanged. For reducing the vulnerability component, it is necessary to plan activities that mainly modify the physical asset of the urban transport system to increase the resistance level of the system. The specific Italian case study shows a partial reproduction of the illustrated planning activities. The analysis of national and regional guidelines shows a set of limits that require more integration between science and rules. The exercises proposed by Italian guidelines could produce a great quantity of data and information useful to support the construction of TSMs available in the literature.

Further developments regard different directions of investigation. The first direction concerns the quantitative estimation of transport planning's contribution to risk reduction. TSMs and ICT integrated into an ITS can support integrated planning for ordinary and extraordinary conditions and decision-makers. The second direction concerns the role of emergency planning in a smart city. Theories, rules and implementation should converge for reducing risk and relative components. This implies more insight to increase risk knowledge that should guide the definition of procedures and roles and then the capability to face emergency conditions. The third direction concerns the effects of planning implementation on user behaviour. It is necessary to investigate how improvements in knowledge, procedures and planning could increase the trust level of the population in the institution that manages emergency conditions.

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