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NETWORK DESIGN PROBLEM FOR RISK REDUCTION IN TRANSPORT SYSTEM: A MODELS SPECIFICATION

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ABSTRACT

With the occurrence of natural or anthropogenic events, which can cause damage to people, delayed in time, adequate actions must be implemented to evacuate the population from the areas at risk. In this context, the transport supply system must be adequately designed to facilitate rapid evacuation.

This paper presents the design methodologies of transport networks in the presence of disasters. The design variables considered concern the direction of travel of the links and the regulation strategies to be adopted in the junctions. The objective function considers risk minimization in terms of user exposure. In the problem, the main constraint considered concerns the users' behaviour. In fact, the configuration of the supply system can be optimized but it is necessary to consider that users adopt choice strategies that tend to minimize their disutility. Therefore, the best possible configuration must be found for all users (system optimum), considering that the choices of individual users are with maximum individual utility (user choice).

The paper reports the main characteristics that a decision support system should have in terms of: general framework, model and resolution procedures. The decision support system can be used by the decisions that have to design the transport network through preventive actions or in real time.

Keywords: evacuation, risk reduction transport, network design problem.

1 INTRODUCTION

Problems related to congestion and instability of a transport system, resulting from the presence of users who request its use, are amplified in emergency conditions. The consolidated and adopted methodologies for the design of infrastructures and transport services and for the management of the demand for mobility, in ordinary conditions, can be used, with appropriate specifications, calibrations and validations, also for systems in emergency conditions. These methodologies must be included in the broader theory of risk.

A disaster, deriving from a natural or anthropic cause, produces emergency conditions in a system and all possible actions must be taken to minimize the negative effects on the population.

Considering that the risk has three components (occurrence, vulnerability, exposure), the actions to be implemented in the system may concern: the reduction of occurrence, that is possible for some types of anthropogenic events (reduction of occurrence with prevention actions); the improve of the infrastructure resistance or network connectivity, to be implemented in the long term (reduction of vulnerability with resistance actions); the reduction of the number of users present in the system in the presence of calamitous events that produce delayed effects in time, for example hurricanes, to be implemented in the short term (reduction of exposure with evacuation actions). For more details on the risk components, please refer to section 2.

Activities to reduce the probability of occurrence and to reduce vulnerability are relevant and indispensable. In many cases require high production times and resources. This paper refers to transport system management actions to be implemented in the short term to reduce exposure with dangerous events delayed in time. It is pursued through evacuation actions

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defined by design methodologies. Optimal design of evacuation actions require also evacuation plans and evacuation training.

The design methodologies, together with plans and training, require the definition and study of different components belonging to different areas: the procedure defined in term of planning and programmes [1] and evacuation training of the population [2]; the a priori evaluation of the risk by means of assessment and management models [3]; the transport system analysis by means of mathematical models that allows (i) the analysis of the demand for mobility in terms of user behaviour [4], (ii) the study of the performance of the supply model in terms of disutility for users [5] and (iii) the interactions between supply and demand models [6]; the system evaluation models in order to evaluate the best scenario to apply in order to reduce the risk [7].

The study in depth of the single components is out of the scope of this is paper. In this paper they are considered in a more general context of the network design problem (NDP).

The NDP consists in defining the optimal configuration of the transport network in terms of (a) topology and (b) capacity. In the case of transport systems in emergency conditions, the NDP has to be integrated with vehicle routing problem for the emergency vehicles (i.e. [8], [9].

(a) The design of the topology consists in defining the optimal configuration of the directions and the allocation of the lanes in the road links. The allocation of the lanes involves the definition of the capacity of the links in each direction. One of the first papers concerning the road network topology design has been proposed in [10]. Other design methods have been proposed for the generation of optimal topological configurations under ordinary conditions (i.e. [11], [12]). The problem has been studied by numerous authors. Among all the papers proposed, some examples of methods for the design of the road network in ordinary conditions are cited (i.e. [13], [14], [15], [16]). The road design problem has been extended to the emergency conditions. A method for vehicle assignment in emergency condition is reported in [17]; a method for planning evacuation is reported in [18]; a method for contraflow operation is reported in [19].

(2) The design of the capacity consists in defining the optimal configuration of the regulation parameters at road intersections with methods valid for traffic light and priority junctions. Priority junctions can be treated from a model point of view with appropriate mathematical formulations. Numerous methods have been proposed for the design of traffic light regulation in ordinary conditions. Some methods proposed are cited for single junctions (i.e. [20], [21]) and interacting junctions (i.e. [22], [23], [24], [25]).

(a, b) In ordinary conditions the topology and the capacity are studied inside the same model with heuristic procedures (i.e. [26]). In the SICURO project a general formulation for the risk has been proposed [3] the problem of the link topology design and the light regulation of the junctions has been studied under emergency conditions by experimentation (i.e. [27], [28], [29], [30]).

The main objective of this paper is to present the NDP methodologies that can be adopted for the reduction of exposure in a transport system in emergency conditions. As reported in this section, the design methodologies have been formulated for the system design under ordinary conditions and have been extended for the system design under emergency conditions. The objective of this paper does not concern the formulation of new methodologies. The main purpose of the paper is to report the design methods, specifying them in the case of emergency conditions. The problem is formulated as risk minimization, considering the exposure component, subject to technical, regulatory and behavioural constraints. Behavioural constraints simulate user choices and have a particular relevance to the model reported. The control variables are the travel directions of the links and the regulation strategies to be adopted at the junctions. Respect the paper [31], the specification of the risk is reported, the decision process is specified, the specification of the models is extended and the solution procedure is reported.

The innovation reported in this paper consists in presenting, in a unitary form, the problem of the transport network design for the definition of the optimal configuration to be defined in emergency conditions, in order to evacuate users. The system design is to be considered a Decision Support System (DSS) and therefore must be presented considering (i) a general framework and (ii) the method to be used.

Considering the objectives set for this paper, the contents are divided into the following sections: Sections 2 and 3 report respectively (subsection architecture *.1) the framework and (subsection models *.2) the method to be used in the DSS; Section 4 reports some indication about the solution heuristic procedures; Section 5 contains the main conclusions and possible developments of the research.

2 DECISION SUPPORT SYSTEM: FRAMEWORK

In the presence of dangerous events external to the transport system, it is necessary to plan actions to be implemented that involve different actors who have different roles. It is therefore necessary to define suitable intervention policies and adequate decision support systems.

In this section, there are two sections: the first concerning the architecture in term of decision process; the second with the model adopted for the risk and the objective functions.

2.1 Architecture

People who have to make decisions can be divided into three categories:

- decision makers (public and private) who take decisions for the design and management of the transport system (Fig. 1);
- users who make pre-trip and en-route travel choices (Fig. 2);
- non-user citizens who, even if they do not travel, influence the choices of users and decision makers and have impacts from the transport system.

Decision makers (Fig. 1) make decisions based on two sources of information: past experience and knowledge and skills; DSSs support decisions through the use of models that simplify reality. Reality is the primary source of information and the actions that must be implemented. The decisions to be taken are made up by the decision makers through the optimal actions to be implemented in the transport system. The optimal action will modify the transport system.

The actions taken will also be influenced by external decisions and events, which cannot be controlled and cannot be easily read with the information available, which will affect the functioning of the system.

The actions taken will be implemented in the transport system and will take effect in the reality. Therefore, a decision loop is generated according to the information currently available and considering the evolution of the dangerous events and effects.

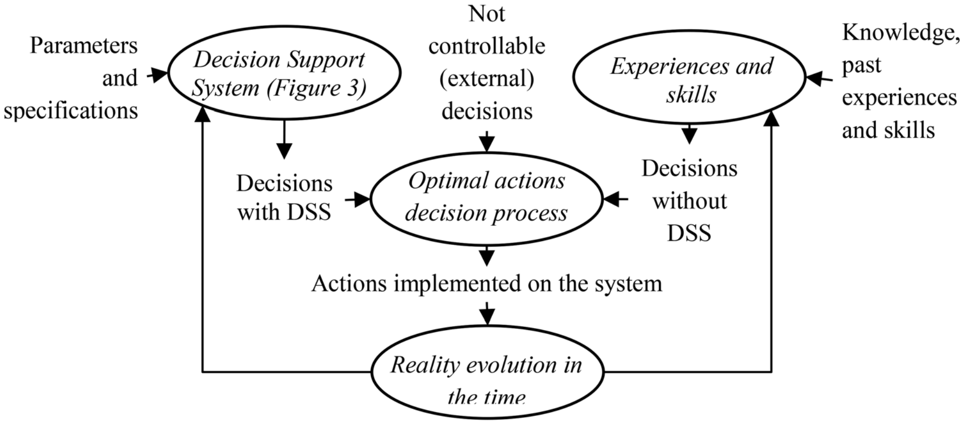

Figure 1: Decision process for decision makers.

The decision system is supported by Information and Communication Technology (ICT) systems that provide information deriving from the real system and provide information for the optimization of the transport system and to the users who have to make choices.

Users (Fig. 2) make pre-trip and en-route decisions in relation to past experiences, information received and what they observe directly in the transport system.

Users do not usually experience the scenario in emergency conditions; users tend to make choices while minimizing exposure on a personal level. The managers carry out the actions on the system; the users choice with a user logic with the maximization of his utility.

Users' choices are influenced by network performances (supply sub-system, defined by the manager considering the infrastructural characteristics of the system). User behaviour derives from the choices made (demand sub-system) which depend on the socio-economic system and land, as well as on network performances. The flows and costs observed in the transport system arise from the interaction between network performances and the behaviour of all users (supply-demand interaction).

For the optimal reduction of the exposure component, design is required through the use of transport theory integrated with that of risk (assessment and management). Considering the plans and implementation of the actions provided for by the legislation as indispensable, in relation to the specific area of research, it could be possible to encourage the drafting of evacuation plans in the local area and for public buildings through the use of quantitative calculation methods. In this regard it would be useful to specify, calibrate and validate models and calculation procedures, to evaluate the plans and optimally design some specific actions.

2.2 Model

The risk can be specified considering different formulations in relation to the population considered, the territorial extension and time.

The risk is defined as the expected value of the loss (people, assets) in a defined territorial area, in a defined time interval, due to certain dangerous events.

The risk is generally divided into individual risk and social risk. Individual risk is defined in small territorial areas and derives from all possible dangerous events that can occur

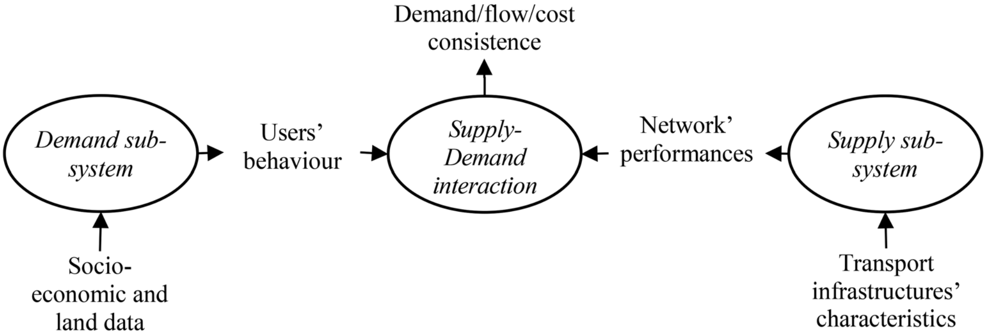

Figure 2: Decision process for users.

(punctual, multi events). Social risk is defined in very large territorial areas and derives from a precise dangerous event and related concatenated events (area, mono event).

The risk depends on three components:

- the occurrence of events;
- the vulnerability, the inverse of the resistance of the system following the occurrence of the event;
- the exposure in term of people exposed to the dangerous event.

Let

- a time t belonging to a time interval T,
- a space point x belonging to a territorial area X,
- an intensity level l of the dangerous events belonging to a set of intensity L,

the risk R is obtained as the product of three probabilistic factors (occurrence O, vulnerability V, exposure N) by means of the probability density function, dependent on x, l, t and concerning [32]:

- $O(x,l,t)$, the occurrence of events,
- $V(x,l,t)$, the vulnerability;
- $N(x,l,t)$, the exposure.

The societal risk is obtained by the expected value respect the space, the intensity level and the time [32]:

$$R = \int_{x \in X} \int_{l \in L} \int_{t \in T} O(x,l,t) \cdot V(x,l,t) \cdot N(x,l,t) dt\ dl\ dx \Big/ \left(\int_{x \in X} \int_{l \in L} \int_{t \in T} dt\ dl\ dx \right). \quad (1)$$

The analysis in transport systems almost always concerns a very large territorial area; therefore, the reduction of social risk is usually considered as an objective function to be minimized. Furthermore, the problem can be extended by considering also the reduction of social risk deriving from multiple concatenated events that can occur.

The design of the transport network for risk reduction concerns the optimization of the supply and the demand management for the rapid removal of people from the area with imminent danger, therefore the concept of resilience assumes particular importance.

In the context of risk management, resilience is a measure of how much the system keeps moving users with an acceptable level of service in the presence of external events, such as disasters [33, 34, 35].

As for risk, social and individual, resilience can also be individual if it refers to the single user (for example resilience referred to a person following a road accident) or social if it refers to a population (for example resilience referred to a population that must go away from a hazardous area).

In the presence of disasters occurring in transport systems, it is necessary to consider that:

- system optimization interventions can take place for events that have a sufficient time interval between the instant of occurrence of the event and the instant of time that produce an effect on the transport system; it can be assumed also as a measure of the resilience;
- that the design of the system cannot affect the occurrence of events, as they are external to the system;
- that the vulnerability of the system is predetermined, as it depends on the characteristics of the infrastructures and vehicles present in the system; considering that the nature of the problem considered foresees short intervention times, even the vulnerability of the system cannot be changed.

Following the reported considerations it is possible to affirm that:

- (objective function $\phi(\mathbf{y}, \mathbf{f})$) the minimization of the societal risk is equivalent with the minimization of the exposure $\left(\int_{x \in X} \int_{l \in L} \int_{t \in T} N\left(x,l,t\right)\ dt\ \ dl\ \ dx \,/\left(\int_{x \in X} \int_{l \in L} \int_{t \in T}\ \ dt\ \ dl\ \ dx\right)\right)$, considering that in the considering problem, occurrence and vulnerability are constants; the minimization of the exposure can be considered as a proxy variable of the resilience maximization;
- (actions $\mathbf{y}$) the actions concern the optimization of the offer system that can be configured to minimize the exposure of users in the system, i.e. the number of users who can suffer damage from the occurrence of the calamitous event;
- (users flows $\mathbf{f}$) the flows of users in the transport system derive from the evacuation of users who leave the dangerous areas and which are added to the other flows of users present in the system in the non-risk areas.

3 DECISION SUPPORT SYSTEM: METHOD

This section contains two sub-sections respectively reporting the DSS architecture and models.

3.1 Architecture

For transport system in emergency conditions, the DSS to be adopted in the NDP has a general structure (Fig. 3) strictly connected with the risk components. In this section, the letters in parentheses refer to the items in Fig. 3.

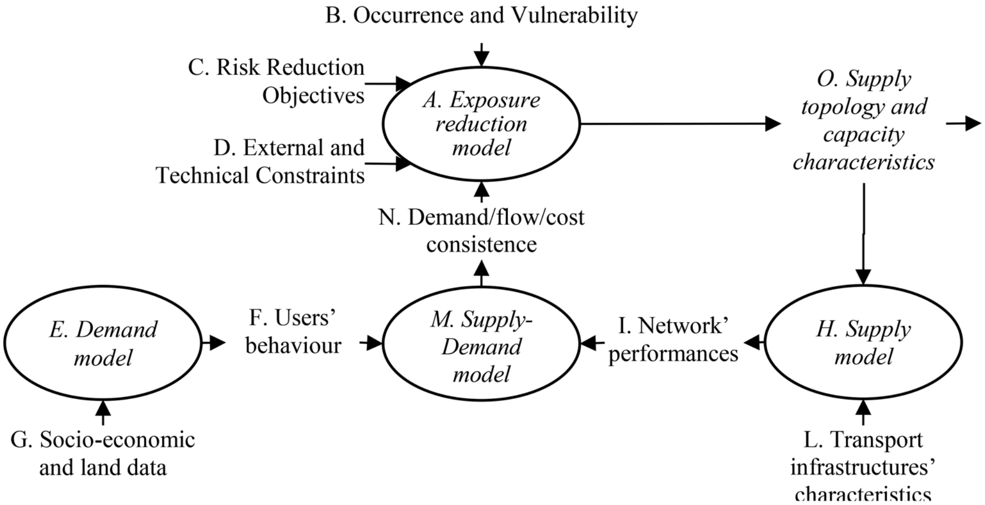

Figure 3: Decision support system: general framework.

3.1.1 Problem

As reported in the introduction, the risk has three components: occurrence, vulnerability and exposure [3]. Each component is defined by a probability with the exception of the social risk case where the exposure is defined by a quantity in term of people. In the case of the transport network design, it is assumed that the first two components (B.) are defined a priori (it is the case of the occurrence of calamitous events in a transport system with predefined vulnerability). Therefore, the reduction of risk, in this case, coincides with the exposure reduction (A.).

The NDP consists in designing the network. Considering that in the case studied occurrence and vulnerability cannot be modified, the risk reduction coincides with the exposure reduction. Therefore the objective function (A. in Fig. 3) has the following inputs and constraints:

- the inputs of the problem are the objectives (C.) consisting in the reduction of the risk and the occurrence values of the event and the vulnerability of the system (B.), which as reported they are prefixed and therefore are not variables of the problem;
- the constraints are of external, technical (D.) and behavioural (E.–N.), or of consistency between performances, flows and demand.

The model gives as outputs the topological and capacity configuration of the network (O.). It should be noted that the output of the design model is also the input of the behavioural constraint, through the supply model, that is of a non-linear type. For this reason, heuristic procedures [26] must be applied to solve the problem in real size transport systems. More details about the solution procedure are reported in Section 4.

3.1.2 Objective function

The objective of the NDP is the risk reduction. The exposure is reduced with evacuation action. Evacuation has the purpose of making people move away and therefore reduces the number of people present in the system when the calamitous event generates effects in the system. The objectives to be pursued with the reduction of exposure are mainly of two types: to minimize the evacuation time of the last user who leaves the system from the areas at risk; evacuate all people from the dangerous area (or, if it is not possible, maximizing the number of people evacuated before the dangerous effects).

3.1.3 Technical and external constraints

The external and technical constraints (D.) must be respected and that cannot be modified with the project. Some examples of technical constraints are the number of emergency vehicles available, the size of the safe areas. Some examples of external constraints are laws, regulations and guidelines.

3.1.4 Behavioural constraint: transport model

Users make choices with pre-trip and en-route choices based on maximizing perceived utility. The choices are made autonomously (user choice) according to the information and the supply system made available. In the NDP the users' choice are modelled through behavioural constraints. Considering that the choices of the users are modelled through models of interaction between supply and demand, as will be specified later, the behavioural constraint is of a non-linear type.

3.2 Models

The architecture of the problem must be structured through the specification of an objective function to minimize and a suitable transport models.

3.2.1 Problem

The specification of the NDP is reported in the eqns (2), (3) and (4):

$$\left\{\begin{array}{llll} \textit{Minimum}_{y} & \phi(\mathbf{y},\mathbf{f}) & \text{//}\mathbf{y}^{*}\text{ is the optimal value of }\mathbf{y} & \text{Equation (2)} \\ \text{Subject to} & & & \\ \mathbf{y}\in\psi_{\mathrm{ETy}}; & \mathbf{f}\in\psi_{ETf} & \text{//external and technical constraints} & \text{Equation (3a)} \\ \mathbf{f}=\xi(\mathbf{f},\mathbf{y}); & \mathbf{f}\in\psi_{Bf} & \text{//behavioural constraint} & \text{Equation (3b)} \end{array}\right.$$

with

- **f** the vector of link flow;
- **y** the vector of decision variables (links direction and junction regulations);
- **y*** the value of **y** in the minimum point of the objective function that respects all the constraints;
- $\phi(\mathbf{y},\mathbf{f})$ the objective function specified in section 3.2.2;
- ψ_{ETy} and ψ_{ETf} respectively the feasible set of the vector **y** and **f** with reference to the external and technical constraints specified in section 3.2.3;
- $\xi(\mathbf{f},\mathbf{y})$ the loading flow function specified in section 3.2.4;
- ψ_{Bf} the feasible set of the vector **f** with reference to the behavioural constraint.

The output (O.) of the design model is given by the value y* of the vector y which minimizes the objective function $\phi(\bullet)$. The vector y contains the design variables that define the topological configuration of the network (discrete variables) and the traffic light regulation strategy at junctions (continuous variables).

3.2.2 Objective function

The objective function (*minimum* $\phi(\mathbf{y}, \mathbf{f})$) models risk reduction (C.). Considering that the occurrence and the vulnerability are predefined (B.) in this specific case of evaluation, the objective function (A) is the reduction of the probability of presence of people (individual risk) or of the total number of people (social risk) in the areas at risk. Therefore the objective function can consider one of the following two criteria:

- minimum of the total evacuation time of all users;
- evacuate all people from the dangerous area or, if it is not possible, maximizing the number of people evacuated in a pre-established time and generally coinciding with the expected time of production of the negative effects on users.

3.2.3 Technical and external constraints

The technical and external constraints (D.) can be indicated by belonging to the vectors **y** and **f** to the respective feasibility sets ψ_{ETy} and ψ_{ETf} ($y \in \psi_{ETy}$; $\mathbf{f} \in \psi_{ETf}$).

Very often these constraints are expressed by means of linear inequalities. For example: the constraint regarding the number of emergency vehicles available is expressed as the number of vehicles used for evacuation less than or equal to the number of emergency vehicles available; the constraint regarding the size of safe areas is expressed, for each area, as the number of vehicles destined in each area below the capacity of the specific area; the number of lanes lower than and equal to a predetermined value.

3.2.4 Behavioural constraint: transport model

Users choose travel alternatives while maximizing perceived utility (from E. to N.). In the case of choice in emergency conditions, generally the perceived utility is equal to the perceived travel time considering that each user wants to reach a safe place in the shortest possible time. The system manager organizes the configuration of the supply system and can indicate the optimal travel alternatives; the user chooses the alternative that he considers the best, based on the information available.

To simulate user' behaviour (behavioural constraint) it is necessary to define the following transport system models, adopting the approach consolidated for the analysis of transport systems [36]):

- demand model (E.) that models user behaviour (F.) starting from socio-economic data (G.);
- supply model (H.); it models the performance of the system (I.) starting from transport infrastructure characteristics; it should be noted that the supply model has as input also the supply topology and capacity characteristics (O.) and it has as output of the design model and which will be reported in the next paragraph;
- supply-demand interaction model (M.) which provides as output the consistency between demand, flow and costs (N.) and takes as input the behaviour of users and network performances.

The supply model is defined with three equations (the consistency between link flows and paths flows, eqn (4); the link cost functions eqn (5); the consistency between path costs and link costs eqn (6)):

$$\mathbf{f} = \Delta(\mathbf{y}) \cdot \mathbf{h}, \qquad \text{Equation (4)}$$

$$\mathbf{c} = \gamma\left(\mathbf{f},\mathbf{y}\right), \qquad \text{Equation (5)}$$

$$\mathbf{g} = \Delta\left(\mathbf{y}\right).\mathbf{c}, \qquad \text{Equation (6)}$$

with

- $\Delta(\mathbf{y})$ the link-path incidence matrix;
- $\boldsymbol{\gamma}(\mathbf{f}, \mathbf{y})$ the link costs function vector;
- **g** the path costs vector (not considering non additive costs for simplicity sake);
- **h** the path flow vector;
- **c** the link cost vector;
- **f** the link flow vector.

The demand model is defined with three equations (the demand functions considering generation, distribution and modal split levels, eqn (7); the path choice-origin destination pairs functions, eqn (8); the consistency between path choice and demand, eqn (9)):

$$\mathbf{d} = \varphi\left(\mathbf{g},\, \mathbf{y}\right), \qquad \text{Equation (7)}$$

$$\mathbf{P} = \boldsymbol{P}\left(\mathbf{g},\, \mathbf{y}\right), \qquad \text{Equation (8)}$$

$$\mathbf{h} = \mathbf{P}\cdot\mathbf{d}, \qquad \text{Equation (9)}$$

with

- $\boldsymbol{\varphi}(\mathbf{g}, \mathbf{y})$ the demand functions vector at the generation, distribution and modal split levels;
- $\boldsymbol{P}(\mathbf{g}, \mathbf{y})$ the path choice functions matrix relative to the origin-destination pairs;
- **d** the demand vector at the generation, distribution and modal split levels;
- **P** the path choice vs origin-destination pairs matrix.

In a static context, the behavioural constraint can be described through eqn (10) which is obtained through eqns (4)–(9):

$$\mathbf{f} = \boldsymbol{\Delta}\left(\mathbf{y}\right)\cdot P(\boldsymbol{\Delta}\left(\mathbf{y}\right)'\cdot \gamma\ \left(\mathbf{f},\mathbf{y}\right),\mathbf{y})\cdot \varphi(\boldsymbol{\Delta}\left(\mathbf{y}\right)'\cdot \gamma\left(\mathbf{f},\mathbf{y}\right),\mathbf{y}). \qquad \text{Equation (10)}$$

It express the fixed point dependency of the flow vector f from the design variables y and the same flow vector f, reported in compact form in eqn (11):

$$\mathbf{f} = \xi\left(\mathbf{f},\mathbf{y}\right), \qquad \text{Equation (11)}$$

with $\boldsymbol{\xi}\left(\mathbf{f},\mathbf{y}\right)$ the loading flow function.

The model (10) gives the flow and the performances on the transport system in term of user equilibrium flow considering stationary condition. In emergency conditions, users move in a system that they do not know in terms of supply configuration and in terms of travel and therefore congestion. The supply subsystem may have some links that cannot be used or with modified configurations with respect to the ordinary condition. The demand subsystem has: a number of users who move differently from the ordinary condition; the origins and destinations of the travels are between the origin and the safe places, therefore different from the conditions that the user usually knows.

In emergency condition, static equilibrium assignment models cannot be used or can only be used to obtain general indications. In these considerations dynamic models must be used because it better represent the users' behavior.

In dynamic context two main approaches are proposed [36]: day-to-day and/or within-day dynamic models. The day-to-day dynamic approach considers the evolution of the system, between stationary or non-stationary states, from one period to another, considering the choices of the users and the performances influenced by the current condition of the system and by a memory effect; in general, the evolution of the system between stationary states is assumed, therefore it is an approach that is preferable not to adopt in emergency conditions. The within-day dynamic approach considers the evolution of the system in space and time within a period; therefore in emergency conditions it is preferable to adopt this approach which best represents the evolution of the real system.

The within-day dynamic approach can be developed considering three different levels of aggregation of users or moving vehicles (traffic units): microscopic, it individually simulates the moving traffic units; macroscopically, it simulates the traffic units in a continuous aggregate way, assimilating it to a fluid; mesoscopic, intermediate approach, simulates traffic units through more or less large groups.

The use of dynamic models requires the calibration of a large number of model parameters. The system is difficult to observe in emergency conditions therefore the calibration of the parameters of the models takes place by analogy in ordinary conditions. Therefore, even if the three approaches reported can be used, it is preferable to use a mesoscopic approach that requires a more limited number of parameters to be calibrated and models to specify.

Also in dynamic cases, a symbolic formulation similar to eqn (11) can be adopted. In this case, the variables depend also on the time.

4 PROCEDURE AND RESULTS

The model has a nonlinear objective function, nonlinear constraints and integer and continuous control variables. In problems of real dimensions, exact procedures cannot be applied to find the solution. Heuristic solution procedures have been proposed in the literature.

A procedure that provides a result close to the optimal one with reasonable processing times is outlined in Fig. 4. The procedure is applied through two levels (more details is reported in [26]), described in the following sub-sections: an first external level that generates topological solutions of the network transport (discrete variables) by heuristic or meta-heuristic procedures; an second inner level that solves the problem of optimal regulation of traffic light at junctions within a procedure for assigning flows to the network, obtaining the control variables in terms of duration of the green periods (continuous variables) and succession of the green periods (discrete variables). The stop test is generally carried out by evaluating the reductions of the objective function in the last iterations.

4.1 Network layout

The optimal topology configuration is solved in the first level of the procedure. The main heuristic procedures proposed for the solution of the NDP are [26]: hill climbing; genetic algorithm; simulating aneling; tabu search; hybrid (combination of previous methods).

The hill climbing proceed starts from a solution and in each iteration the best neighbouring solution is chosen by changing one (single step) or two variables (double step). The genetic algorithm proceeds from a set of solutions (population) and in each iteration three probabilistic operators are applied: reproduction (selection of the best solutions); crossover (cross between solutions); mutation (modification of one or more variables). The simulating aneling procedure starts from a solution and in each iteration selects the best solution in a local context in a probabilistic way, reducing the variance of the probability with the iterations. The tabu search procedure in each iteration chooses the next best solution, discarding the solutions chosen in the last iterations. Hybrid methods combine several methods described.

A comparison of the results obtained with the various methods in the case of NDP is described in [26]: the application of the procedures in real transport networks has led to a reduction in travel time for users up to a maximum of 20% and depending on the real system considered.

In terms of the accurateness of finding the best solution, the best methods are genetic algorithms, simulated annealing and tabu search and the worst methods is hill climbing with single step. It is important to consider that the convergence parameters adopted for the genetic algorithms and the simulated annealing influence the convergence, therefore bad values give results similar to hill climbing.

In terms of convergence speed, the number of solutions evaluated influences the processing time: the best methods are tabu search, genetic algorithms and hill climbing with single step; the worst methods are simulated annealing and hill climbing with double steps.

By combining multiple methods the results improve considering that the benefits of both methods are obtained, but the processing times increase. In addition, methods that use populations of solutions, such as the genetic algorithm, have the advantage of being able to include in the initial population also solutions proposed by policy makers and the population, allowing initial schemes from different actors to be considered and evolved.

The description provided cannot be considered exhaustive and for further information, please refer to the numerous specialist publications in this research area, some of them cited in the references. Furthermore, the best results were obtained by applying genetic algorithms, tabu search or a combination of the two methods.

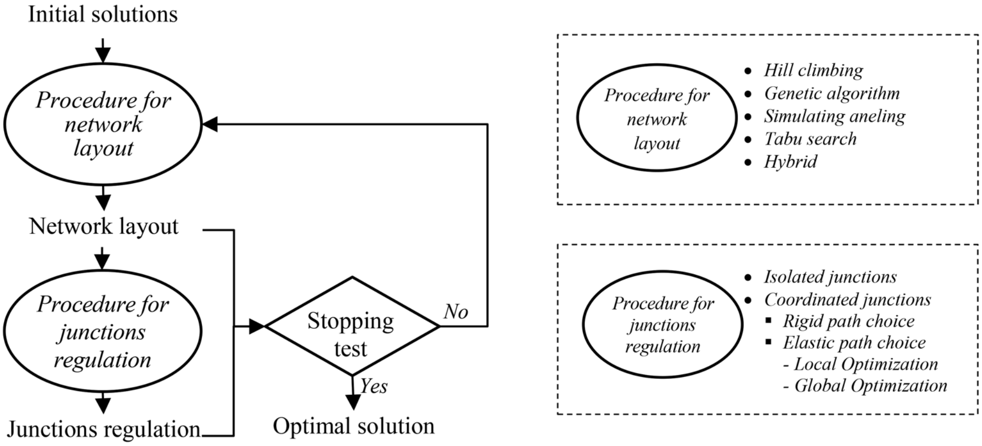

Figure 4: Decision support system: heuristic procedure.

4.2 Junctions regulation

The design of the regulation at the intersections is applied in the second level of the procedure for each topological network solution generated with the procedures used in the first level.

Considering that the system is in emergency conditions, as described above, the regulation design is part of the procedures for the dynamic assignment of demand to the transport network.

The design methods of traffic light regulation can be applied with regulation strategies considering isolated or coordinated intersections (if it is assumed that the platoons created in the previous intersection continue in the planned intersection).

In the methods for coordinated intersections, rigid or elastic (and the choice is influenced by the regulation parameters) route choice can be considered.

In the methods for coordinated junctions with elastic path choice, it is possible to apply optimization algorithms of local optimum (assignment and regulation are resolved iteratively in separate procedures) or global optimum (assignment and regulation are solved in a single procedure).

In emergency conditions it is preferable to adopt local or global optimal methods (with elastic route choice and coordinated junctions).

5 CONCLUSIONS

In this paper the problem of the design of the transport supply system in the presence of dangerous events is reported. The problem is studied in the context of risk theory by considering the occurrence and vulnerability components as fixed. This hypothesis is valid in the presence of events that have occurred and the effects are delayed over time allowing the evacuation of the population of the risk areas. With these hypotheses, the design problem is formulated considering the minimization of user exposure (objective function).

In this scenario, the minimization of the exposure takes place through the design of the optimal configuration of the supply system in terms of travel directions of the links and regulation of the junctions (control variables).

The formulation of the problem requires the definition of technical, regulatory and behavioural constraints (constraints).

The behavioural constraint simulates the choices of users who generally follow an approach of minimizing the travel time taken to reach the safe place. This choice occurs in a congested and evolving system over time.

The paper formulates the overall problem in terms of architecture, models and indications on the solution procedures. The purpose of the paper does not concern the complete specification of each aspect. The paper deals with the different aspects in an overall logic and the articles cited and the bibliography contained in them can be consulted for further information.

There are several aspects to consider in the future for the development of research. The models shown are generally used for modelling the system under ordinary conditions. The same models must be specified-calibrated-validated in emergency conditions. In addition, decision support systems should be tested in real cases to verify limits and development prospects. In this context, it is also necessary to evaluate how the various actors involved (system managers, operators, users, citizens) can receive real benefits from the use of these DSSs.

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