The role of ITS in evacuation route optimization for emergency vehicles

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Abstract

In this paper the application of ITS (Intelligent Transportation Systems) in road evacuation in the case of route optimization for emergency vehicles is reported. The ITS are usually used in transport to analyse the data and improve the system performances. In road evacuation, the ITS can be used at three levels: survey and transmission, control and user information. This structure allows managing an evacuation starting from the network monitoring and defining the optimal strategies to apply to speed up the evacuation procedure.
Keywords: vehicle routing; link cost functions; network monitoring.

1   Introduction

The road evacuation researches involve different fields of study, concerning demand analysis [1–5], demand-supply interaction [6], route design [7] and planning [8–12]. For a study in depth, see [13].

ITS (Intelligent Transportation Systems) are a set of hardware and software systems who allows collecting, processing and distributing some information to improve the travel of people and freight [14].

In many countries a national architecture for ITS system is implemented, to improve the transport systems (i.e. in Italy is named ARTIST). The emergency vehicles management is provided in the national architectures (i.e. the emergency management system in Italy or the emergency management in U.S.). The ITS assume a core role in road evacuation, because they allow to manage the information in real time and hence to address the evacuees. Using real-time information allows defining a travel plan for users to reduce the total evacuation time [15].

In the following (Figure 1), three main classes of ITS are considered: ITS for survey and data transmission, ITS for control and ITS for user information.

The first class (survey and transmission) allows surveying the data (i.e. flow) and transmitting it. The second class (control) allows to processing the data and, using appropriate tools, to establish the strategies to optimize the objectives. The third class (user information) allows sending the strategies at the users (private users and rescue vehicles). The paper is structured so that explicates these three
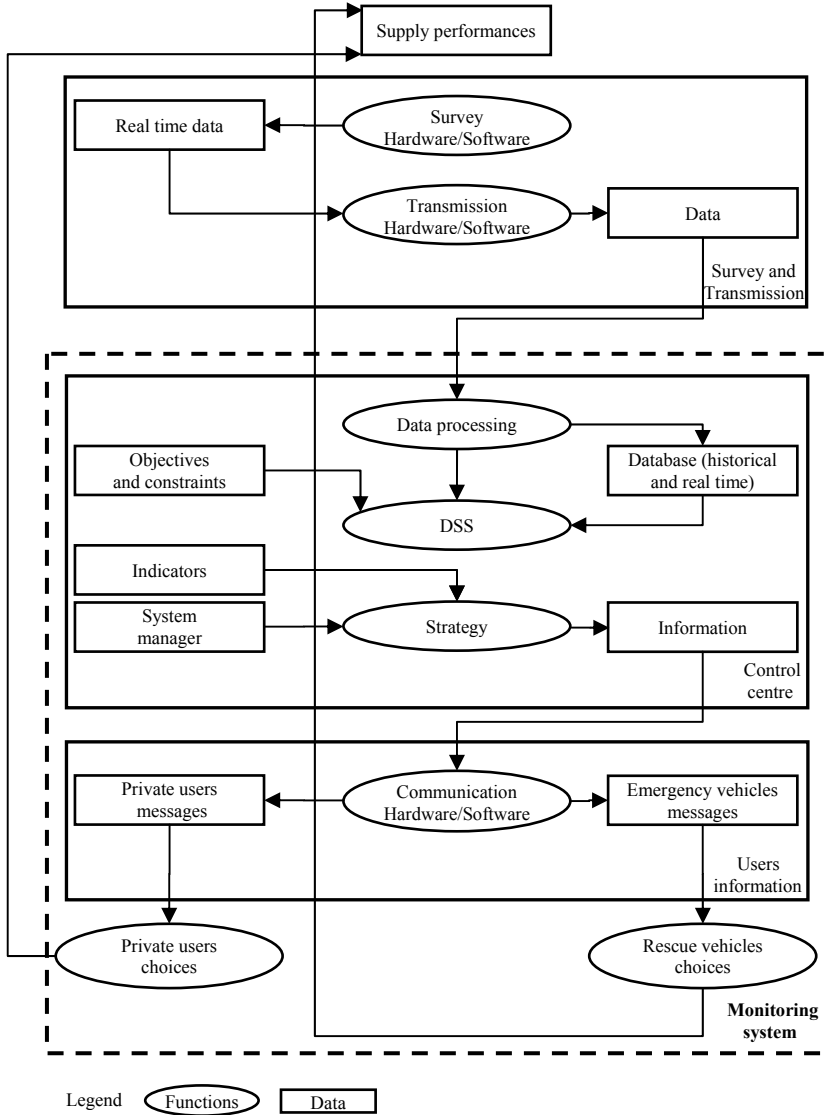

Figure 1:   ITS for monitoring and management.

classes in relation to route optimization. Section 2 deepens the data survey and transmission; Section 3 analyses the control system; Section 4 reports the methodologies to send the messages at the users. Finally, in Section 5 some conclusions are reported.

2 Data survey and transmission

The road network survey can be crucial in many cases, from capturing the network actual status to capturing the network modifications. The collected data can be used to operate in real time (i.e. disseminating the information to the users) or to forecast the network response due the external events (i.e. to individuate possible critical points). The needs are related to monitoring in real time the traffic conditions evaluating (flow, velocity, travel time). In Table 1 the user needs and the possible functions able to satisfy them are reported.

Table 1:   Data survey and transmission: user needs and functions.

Needs	Functions
Survey and transmission	• Collect traffic data • Monitor network vehicle occupation • Detect incidents • Infrastructure monitor

The data survey can be made manually or automatically [17, 18]. In the first case, operators on the road survey some flow characteristics (i.e. number of vehicles, vehicle type, velocity) who can be analysed at a later stage. This method can be lack related to operator necessity. Conversely, the automated means allows surveying the flow characteristics in conditions not favourable for human operators. For example, during a road evacuation, an automated approach can be used to survey specific data related to situation (damaged roads, congested links and so on).

The data survey is based on a hardware/software system: the hardware is a sensor or a network sensor (i.e. a camera, radar, infrared systems, GPS) that monitor the traffic, the software decode the signal sent by the sensors and save the data. According to [17], can be distinguish *tripwire* sensors, who operate in a road section (like a camera), and *tracking* sensors, who are able monitoring an area or track vehicles trajectories. An example of vehicle tracking is reported in [19], in which this system is used to optimize a bus line. In some cases, probe vehicles can be used to measure the network characteristics [20]. Other approaches [21] consider sensors for short duration survey and sensors for permanent survey for collecting traffic load data.

Also the transmission system is composed by hardware/software tools able to manage the data transmission. Two ways are possible: transmission on-line and transmission off-line. In first case, the data are sent to the command centre using some technologies, as GSM, internet, wireless and so on. In second case, the data are stored in a fixed support (connected to the sensors) that must be carried by an operator to the control centre.

In literature, some works investigate this field. In [22] some technologies to survey a road network to measure the travel time are reported. Marzolf *et al*. [23] propose an object-oriented approach to survey the system using a probe vehicle equipped with a GPS. The aim is allowing at the vehicle to visit all links. A network sensor location problem is solved in [24] to identify subsets of links in which locate the sensors to survey flow data. An approach using some cameras to survey the network is reported in [25]. ITS technology was also used post a sudden event happening to analyse the damage incurred in the network [26]. In [27] an emergency management information system is reported; this system allows the data communication between the control centre and the operators involved in the emergency. Also in routing problem the data survey in real time play a fundamental role, in freight transport in [28] and [29] real time information on link travel time are provided by a probe vehicle equipped with a personal digital assistant and GPS antenna and used to improve vehicle routes. Considering rescue vehicles, the vehicle management is indicated with Computer Aided Dispatching (CAD). In [30] an integrated system for ambulances management is described, a part of this system is a GSM modem able to transmit the vehicle position (and eventually vocal messages) at the control centre. In Figure 2 a schematic representation of means related to data survey and transmission is reported, summarizing the considerations reported in this section. Some means able to collect traffic data are considered. Considering the automatic survey, in the tripwire sensors can be considered loop sensors, video sensors, optical or acoustic sensors. In some cases, these instruments can be used joint to refine the collected data. About the transmission, the off-line and on-line possibilities are considered; in the first case an operator is need to retrieve data, in the second case the data are sent automatically.
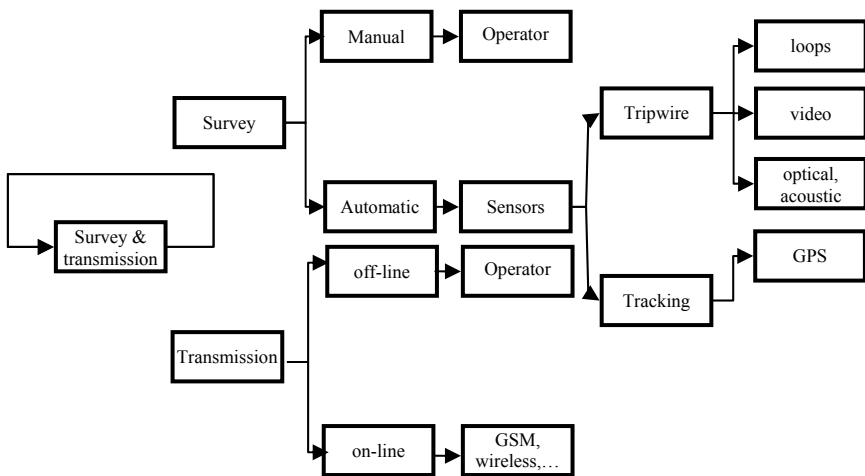

Figure 2:   ITS for monitoring and management.

3   Data processing

In literature, the use of various Decision Support Systems (DSSs) to simulate an evacuation and to optimize the best strategies to apply in an evacuation is proposed. An inventory of these DSSs is reported in [31]; an example in the use of these DSSs is reported in [32]. When the data are transmitted at the command centre, a control procedure is needed to elaborate the data and define the strategies to apply to face the situation. In a first stage, the data can be filtered to eliminate implausible records and given as input to a DSS who allows to define the optimal strategies (in respect to objectives and constraints) to put in action. The DSS can be use also historical data in the strategies definition. In Table 2 the user needs and the possible related function are reported. General considerations on DSS use in disaster management are reported in [33].

Table 2:   Data processing: user needs and functions.

Needs	Functions
Data processing	• Evaluate Trip • Implement Trip Plan • Manage Traffic Data • Provide Traffic Control • Provide Traffic Forecasts and Strategies • Provide Traffic Management

The DSS can be specific for a single aspect of the problem (in this case several DSS can be used to solve the whole problem), or general to consider simultaneously all the aspects of the problem. In first case, for example, can be consider a DSS to evaluate the network performances and a DSS to optimize the paths. In second case, the DSS is able to analyse the system and define the strategies to apply [34]. Further considerations can be made considering that, in some cases, using historical data, is possible a pre-processing procedure, for example to allocate resource on the network [35] to speed up the operations during the evacuation. In the field of route optimization, many DSS can be considered to optimize (or re- optimize) the routes for emergency vehicles. In this case, the output is a route (or a set of route) to assign at the rescue vehicles minimizing an objective (minimize evacuation time). In [36] a tool to manage in real time an evacuation plan is proposed. This tool, given the evacuation area, allows optimizing the evacuation paths for the users using a heuristic procedure. Tufekci [37] proposes a modular DSS to hurricane evacuation management. The modules composing the DSS have a specific function, like prediction and tracking, planning, emergency management, coordination; moreover a GIS module is implemented to furnish graphical information. In [38] a DSS named Group Analytic Network Process (GANP) is proposed. This is a DSS allowing decision-makers to compare some alternatives in a multi-criteria approach. In [39] an open DSS (EPLAN) able to integrate data from different sources, to perform data analysis and model computation is provided. In Figure 3 a schematic representation of data processing in reported, considering DSS able to

solve a specific part of the problem and DSS able to solve the whole problem. In first case, a DSS can be used to get, for example, the network performances (network optimization) and another can be used for route optimization. In second case, an only DSS can be used for solving simultaneously network and route optimization.
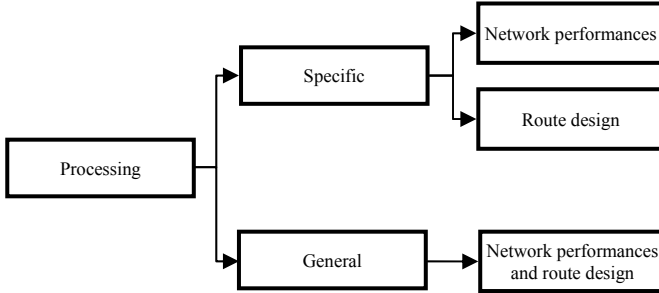

Figure 3:   ITS for monitoring and management.

4   User information

Once acquired and processed by the DSS, the data must be sent to the users. Two cases can distinguish, considering if the users are the rescue operators or the people who evacuate. In first case, command centre use information to coordinate the rescue operations. In second case, the information are sent directly to the population suggesting or imposing the actions to follow.

An efficient method need to send the information as soon as possible also in emergency conditions. Various communication systems can be used (radio, telephone, mobile, internet, SMS, GSM, wifi and so on). The sending of information to the users is investigate in some papers, for example, in [25] and [40] an analysis on the effects related to the data sending with variable message panels is proposed; in [41] an analysis to determine *what* data to send and *how* send it is reported; in [42] user behaviour by sending travel information is analysed. In most case, these communication systems are indicated as Advanced Traveler Information System (ATIS [43]). The information sent, in general, change the user behaviour, like in term of path choice [44, 45] and consequently change in traffic assignment [46]. In Table 3 the user needs and the possible related function for data communication are reported.

Table 3:   Data communication: user needs and functions

Needs	Functions
Data communication	• Plan trip • Propose trip alternatives • Support trip • Inform and guide traveller • Assess perturbations

The network monitoring systems provides real-time traffic conditions and, consequently, the information can be address the users towards other paths. In fact, the travel information modifies the user's behaviour, also according to how information is sent [47]. The evacuation managers, to clearing the path for rescue vehicles can be using this method [48]. In [36], a system to address the user in the networks is proposed; this system is based on light signals located at nodes to indicate at the users the path to follow.

A module of the system proposed in [37] is reserved to the communications (satellite connection), able to operate in emergency conditions when the normal communication channels can fail.

In logistic field, to optimize the vehicles route and the vehicle allocation, CVRS (Computerised Vehicle Routing and Scheduling) systems can be used, this system can give information at the vehicles (i.e. users' position). In emergency field, the vehicle dispatching, starting from data available (i.e. user position, user condition, …) can be managed using CAD systems able, among other things, to send radio messages at the vehicle (ambulances, fire trucks) [49]. In [30] GSM network communication is used to send messages to the ambulances, these messages are related to the user position, path to following. Furthermore, the ambulance can be equipped with a monitor to display the path calculate by the control centre. In the MAGES (Mature Applications of Galileo for Emergency Scenario) project [50] the support to operations for the management of various emergency types was expected. In [50] an example of MAGES application is explained: it is possible to communicate the target and the path to reach him, integrating traffic information.

Figure 4 summarize, in a schematic way, the sending of information at the users, using some possible communication systems. The information provided are related to the netwok conditions (i.e. closing links), paths to follow, users positions (i.e. to communicate in real time new users to rescue).

During an emergency, the communication systems can be fail for various reasons (i.e. damage to the physical elements of the system, system overload,
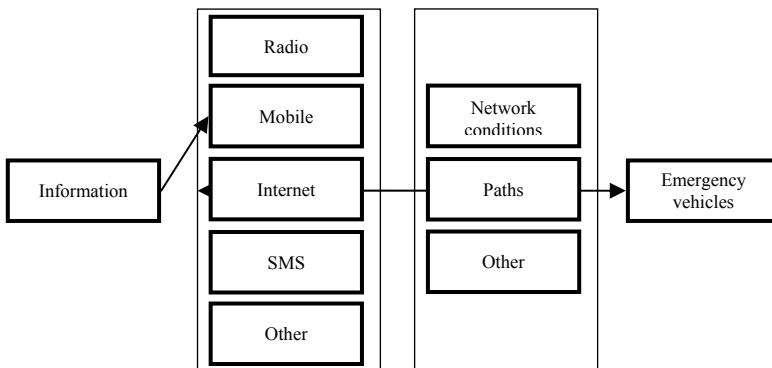

Figure 4:   Sending information at the emergency vehicles.

Table 4:   Data communication: user needs and functions.

ITS	Reliability
radio	medium
telephone	low
mobile	medium
internet	medium
SMS	medium
wifi	low
satellite	high

and so on). It is necessary to evaluate the reliability of the available communication systems. In Table 4 a qualitative reliability analysis is reported.

5   Experimentation

A prototype of a system to collect data from a real network is designed. In this prototype, the data are collected using an hardware/software system able to record some travel information. According to the definition given in the previous sections, the survey system is automatic with a tracking sensor while the transmission system is off-line, managed by an operator.

The real case application is designed to detect the paths and stops of a rescue vehicle. The ITS used is PDA equipped with GPS sensor and a software able to save the position at fixed instant. The operators can be to interact intuitively with the system to save additional positions (i.e. for rescue vehicles, the positions in which they intervene) and additional information (i.e. if the rescue vehicle is an ambulance, the number of users rescued). The analyst can obtain more information (travel time, duration of the stops) during the data analysis. In Table 5 some possible data obtainable with the experimentation are reported.

Table 5:   Data communication: user needs and functions.

ID	UTC	Latitude		Longitude		Cause[*]	Duration (sec.)	Number of users	Notes
1	70248	37.92070	N	15.78355	E	A	348	2	-
2	81281	37.92134	N	15.77176	E	B	512	-	Medical supplies
3	86147	37.92131	N	15.77851	E	C	155	-	Technical stop
..	..	..	..	..	..	..	..	..	..

* A: users rescue, B: supplies delivery, C: other.

Starting from the available data collected by the survey systems, the operative centre elaborate its (also using historical data) and can simulate a sudden event that forces an evacuation. In this way it is possible to optimize in advance the paths for users and rescue vehicles, and for example establish the means to furnish information to deviate the demand flow. Moreover, it is possible to establish contraflow strategies to reduce evacuation time and design alternative paths.

6   Conclusions

In this paper a discussion on use of ITS in road evacuation is conducted. Three main classes of ITS are examined: ITS for survey and transmission, control and user information. For each class, the main use of ITS is analysed.

The data survey and transmission is analysed considering the possible means to collect the data and send it at a control centre. The aim of the control is the data analysis to elaborate the strategies to apply during an evacuation. The strategies need to be sent at the user: the communication system is analysed considering the possible means.

Finally, a short experimentation is reported.

Acknowledgement

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