A Decision Support System for Risk Evaluation of HAZMAT Transportation in Motorways

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Abstract: The transportation of hazardous materials (HAZMAT) on congested motorways and accident management are areas of increasing interest for public safety and environmental awareness. This paper proposes the structure of a Decision Support System (DSS) for monitoring HAZMAT vehicles, aiming at solving two problems: assessing the risk induced on the population by HAZMAT vehicles travelling in the motorways and selecting the optimal routes and restoration procedures for the heavy vehicles. Two main modules of the DSS are specified: the Risk Assessment Component and the simulation module. In order to model and simulate the traffic network, a Coloured Timed Petri Net model is employed and a DSS prototype is described and applied to a stretch of a motorway in the North-East of Italy. The proposed DSS allows estimating in real time the risk of HAZMAT transportation, by taking into account the type of transported hazardous material, the traffic and the density of population living close to the motorway.

Keywords: Decision Support System, Coloured Petri Nets, Hazardous material transportation, Simulation

1. INTRODUCTION

Traffic accidents are unpredictable events that occur randomly in roadway networks. In particular, transportation of hazardous materials (HAZMAT) on road implies potentially high risks depending upon the nature of the HAZMAT carried by trucks, the physiochemical events associated with these materials, the localization and the density of the affected subjects, the characteristics and state of the roads, the density of the traffic, and the environmental conditions. It is necessary to dispose of a real time risk evaluating system in order to prevent these risks (Seyedhosseini and Mahmoudabadi 2010). Hence, an accident management system can be provided by Decision Support Systems (DSSs) that contribute to improve the efficiency and effectiveness of the decision makers (Zografos et al. 2002).

This paper proposes the structure of a DSS for monitoring HAZMAT vehicles and solving two problems: assessing the risk induced on the population by HAZMAT vehicles travelling in the motorways and selecting the optimal restoring procedures and routes of the heavy vehicles after an accident. The proposed DSS consists of three components: the Data Component, the model base component and the user interface. We specify two basic modules of the model base: the Risk Assessment Component (RAC) and the simulation module. In particular, the RAC assesses the risk of transporting hazardous materials with a path evaluation function (Erkut and Ingolfsson 2005, Centrone et al. 2009). Moreover, the simulation module is based on a modular Coloured Timed Petri Net (CTPN) model validated in a previous contribution (Centrone et al. 2011). In this paper we model in the CPTN framework the accident and the restoration procedure after the accident. The model and the simulation module are updated in real time on the basis of the events detected on the real system by using the ICT tools. Moreover, the DSS allows analysing the risk of HAZMAT transportation and forecasting the motorway stretches where the risk is high. Hence, the DSS can be used off line to suggest to HAZMAT transporters the safest route and to estimate the best accident restoration policies. Moreover, the DSS can be employed in real time to face the accident consequences and to organize the rescue operations.

In order to show the effectiveness and the applicability of the DSS, we show a DSS prototype implementation devoted to evaluate the risk related to the transit of HAZMAT in a stretch of the A4 motorway in the North-East of Italy.

2. THE DECISION SUPPORT SYSTEM ARCHITECTURE

In this section we describe the structure of the DSS devoted to evaluate in real time the risk related to the transit of HAZMAT on the motorway network and to take decisions about the traffic flow. Typically, a DSS consists of three components: the Data Component, the Model Base Component and the user interface.

The Data component stores all information needed for the DSS to operate. The user interface allows the effective interaction of the user with the system by the Information and Communication System that is based on the modern Information and Communication Technology (ICT) tools. Moreover, the model base contains all models, algorithms, rules and knowledge needed to provide decision support for the user. In the presented DSS, the model base consists of four modules: the Risk Assessment Component (RAC), the simulation module, the restoration and decision module.

By means of the ICT tools belonging to the ICS, the DSS monitors the network, detects the events occurring in the system and sends the related information to the data component. The RAC can evaluate in real time the risk of the zones where there are vehicles transporting HAZMAT by considering the interaction among the transportation network (in this case the motorway), the vehicles (the traveling risk source), and the impact area. On the basis of the risk assessment, the decision module can modify and tune the rules for the network management. Moreover, in consequence of the detected events and the model state knowledge, the decision module may decide to trigger the simulation and to apply different restoration procedures. The reasons that can determine the start of the simulation are the unpredictable event occurrences as well as the model state that can exhibit queues, blockages, breaks and all those occurrences that interact with the flow and management of materials and transporters. The simulation applies and evaluates the possible solutions proposed by the restoring component. Hence, the RAC uses the outputs of the simulation to evaluate the risk and the consequences of the occurrence of possible scenarios. On the basis of the simulation results and the RAC assessment, the decision module chooses the routing and dispatching rules to manage the network. Moreover, the routing and dispatching rules and the restoration choices can be determined by distributed software optimization modules as well as by teams of expert practitioners that specify the decision strategies. On the basis of the choices proposed by the DSS, the user interface transmits the commands to the ICS that sends the corresponding messages to the network system. This paper focuses on the specification of the two main modules of the model base: the RAC and the simulation module. Furthermore, a simple decision rule is proposed for the restoration module.

3. THE RISK ASSESSMENT COMPONENT

In this section we specify the module devoted to calculating in real time the risk related to the transit of HAZMAT in a motorway network. We recall that there is a cause-effect chain which can be associated to a vehicle transporting HAZMAT: the vehicle may be subject to a road accident, and the accident may cause the release of transported material; the release may cause a series of events that can harm people in the accident zone surroundings. The characterization of the risk in transporting HAZMAT is determined by evaluating the frequency of the occurrence of an accident involving HAZMAT in a given scenario (Erkut and Ingolfsson, 2005).

In this paper we denote by $H=\{h : h=0, 1,\ldots,\mathrm{H}\}$ the set of possible H hazardous materials that can be transported by a heavy vehicle. The element h=0 means that no hazardous material is transported by the vehicle. Table 1 reports H=7 HAZMAT that are more frequent in an Italian motorway. In particular, the first column reports the name of the hazardous material and the associated value h in parenthesis, the second column shows the average lethal radius r_h that represents the distance within which the release of material h can be lethal, and the third column reports the probability that a vehicle transporting HAZMAT is carrying material h.

The freeway system is split in a set $L=\{L_i \mid i=1,\ldots,\mathrm{L}\}$ of L links where each link represents a motorway stretch between two successive tollbooths and may include several lanes. In addition, the set of links is partitioned in $L=L_H\cup L_{in}\cup L_{out}$ where L_H collects highway links, L_{in} collects input links that represent the tollbooth to enter the motorway, and L_{out} is the set of the output links trough which vehicles exit the motorway. In order to characterize and evaluate the HAZMAT transportation risk in a motorway, the following parameters are defined (Erkut and Ingolfsson 2005): $f_i(h,\tau)$ [*events/vehicles*] is the frequency of the accident occurrence in a motorway link $L_i\in L_H$ involving the HAZMAT h, at a given time τ; λ_i [*events/vehicles*] is the accident rate per truck in a motorway link $L_i\in L_H$ (Harwood et al. 1993); $p_{rel}(h)$ is the probability of releasing HAZMAT h as a consequence of the accident; $p_a(h,\tau)$ is the probability that HAZMAT h determines an accident at time τ.

Table 1. The Considered HAZMAT

Materials (h)	r_h [km]	p_h
Petrol (1)	0.25	0.21
Diesel (2)	0.25	0.15
Hydrocarbon (3)	0.5	0.10
Hot transported substance (4)	1	0.10
Liquid oxigen (5)	0.25	0.07
Liquid nitrogen (6)	0.13	0.04
Other (7)	0.4	0.33

The most common function (R_i) to evaluate the risk of HAZMAT transportation for a link $L_i\in L_H$ at time τ is defined as follows (Seyedhosseini and Mahmoudabadi 2010, Leonelli et al. 2000):

$$R_i(h,\tau)= N_{HV}(i,h,\tau)\, f_i(h,\tau) \qquad (1)$$

where $N_{HV}(i,h,\tau)$ is the number of vehicles carrying the dangerous substance h transiting in link $L_i\in L_H$ at time τ. Moreover, function $f_i(h,\tau)$ is determined as follows (Leonelli et al. 2000):

$$f_i(h,\tau)= \lambda_i\cdot p_{rel}(h)\, p_a(h,\tau). \qquad (2)$$

Function (1) points out that to evaluate the risk $R_i(h,\tau)$ it is necessary to know the number of vehicles carrying HAZMAT and the DAC can obtain the value of $N_{HV}(i,h,\tau)$ by the ICS. Alternatively, in order to assess the risk in different scenarios or to forecast the risk of HAZMAT transportation,