An Approach to the Real-Time Risk Analysis for Hazardous Material Transportation

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Abstract. Real-time risk analysis is the critical point of monitoring, warning and re-routing HazardousMaterial Transportation (HMT). In this paper, we propose a real-time risk analysis approach based on Internet of Things (IoT), which dynamically evaluates the risk at discrete time pointsduring the whole transportation process.Probabilities of accidents are determined by both statistic accident data and real-time monitoring data collected by IoT techniques. To determine the potential consequences of accidents, Areal Location of Hazardous Atmospheres (ALOHA) is used to simulate the accident scenarios and estimate the influence areas. The population exposed can be calculated with the interface of Intelligent Traffic System (ITS). Furthermore, our approach provides a more accurate way to dynamically evaluate the risk of HMT.

1 Introduction

Hazardous materials, the properties of which are toxic, corrosive, explosive and flammable, often do harm to human beings, facilities and the environment. Particularly, the transportation of them is a risky activity, as explosions, side-rolling crashes and collisions usually happen during the transportation processes. Once this kind of accidents happens, it would cause deaths and environment pollutions, so the damage is inestimable.

According to the statistics of the U.S. Department of Transportation, there were 13,682 accidents relevant to hazardous materials transportation (HMT) happened in 2011, 85.5% of which occurred on the road [1]. China is one of the most productive nations of hazardous materials. To the end of 2010, there have been 22,000 enterprises that produce hazardous materials, and about 28,600 companies run relative businesses in China [2]. As the total transport amount rising year by year, the situation of supervising HMT becomes more serious.

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Real-time risk analysis is the basis of monitoring and warning HMT, which can be used to plan a less risky route and reduce the potential harm of accidents [3]. The Internet of Things (IoT) is an innovating technology integrating with RFID, Wireless Sensor Networks (WSN), GPS, etc.It has the ability of real-time sensing, data transporting and processing [4]. IoT has been widely used in intelligent transportation, smart grid, agriculture and supply chains, as it provides a real-time, precise and intelligent management tool [5-8]. Nowadays, the supporting techniques of IoT have becoming matured, and the infrastructure of it has been consummated day by day, which provides a new opportunity for real-time risk analysis of HMT.

In this paper, we proposed an IoT-based approach to the real-time risk analysis forHMT.The remaining part of the paper is organized as follows. In the 2^{nd} section, the state of the art of the risk analysis in the hazardous material area is reviewed. In section 3, the real-time risk analysis framework is illustrated. Finally, we conclude this paper in section 4.

2 Literature Review

Hazardous materials can be transported by road, water and air. Due to their distinct characteristics, the methods of risk analysis under different transport modes differ a lot. Erkut etal. [9] reviewed existing risk analysis models.They thought that a comprehensively accepted model does not exist, and meanwhile the least risky routes derived from different risk analysis models may not be the same, or even vary a lot.

Bi Jun and Wang Huadong [10] proposed a risk evaluation method based on the concept of “basic routes” and used it in route planning of hazardous wastes transportation in Shenyang. Guo Xiaolin and Li Jun [11] introduced the accident gradation into the risk measurement model to improve the original model. Fabiano etal. [12] considered both the individual and societal risks, and presented a risk assessment model that is sensitive to route features and population exposed. Wu Zongzhi etal. [13] developed a quantitative risk-assessing model, and introduced the modifying factors of the possibility of hazardous accidents.

Because there are various factors that influence the transportation risk of hazardous materials, it’s very difficult to calculate the transportation risk. Although many researchers have focused on this issue, available methods still have some defects. Jiang Xuepeng etal. [14] surveyed the development of researches on risk assessment of HMT both at home and abroad. They assumed that accident rate is consistent, and transportation process is continuous, which are not rational. Fabiano etal. believed that the existing methods just focused on the inherent factors such as hazardous materials, vehicles, drivers, and neglected the weather, traffic flow, conditions and other external factors [15].

In recent years, researchers introduced sensors, GPS, GIS and other technologies to improve the analysis of risk in HMT. Verter took polygon to represent the population exposed, took polyline to represent the road links, and proposed a GIS-based risk analysis method[16]. Wei Hang considered the varied population density around the HMT route, and proposed a population-estimation-based risk analysis model[17]. Zhang Jianghua used information-diffusing theory to evaluate the dangerous chemicals transportation accident rate, and analyzed the result of accident with GIS simulation technology[18]. Tomasoni used ALOHA to simulate the dispersion of hazardous materials, and proposed a consequence-based risk evaluation method[19].

Besides the above mentioned researches, some researchers use qualitative methods to study the risk analysis problem of HMT. Arslan applied the SWOT analysis approach to formulate the safe carriage of bulk liquid chemicals in maritime tankers[20]. Milazzo considered the potential terrorist attacks during HMT, and proposed a dynamic scenario-analysis-based risk management approach[21].

By analyzing these researches, we find that current researches have the following two drawbacks when dealing with monitoring and warning HMT:

(1) Current researches mostly evaluate the risk of the whole route before transportation.Nevertheless, the risk may vary a lot when travelling at different time points or in different parts of the route.

(2) The calculation of accident rate and result are often based on the static and historical data, which can not reveal the current transportation scenario and real-time context changes.

The proposed IoT-based approach to the real-time risk analysis for HMT in this research will overcome these drawbacks.

3 The Model for Real-Time Risk Analysis

Although there are many different kinds of risk analysis models, most of them are based on the simple idea that risk can be evaluated by the possibility of accidents together with their consequences. In this paper, we also use the classical form of risk analysis, which takes the summation of potential accident scenarios' expected consequences as the total risk for one route. To do this, we should decide two elements of these scenarios, their possibility as well as their consequences.

We define $R_t$as the location road of HMT truck at time t, then the transportation risk could be evaluated by equation (1).

$$\mathrm{D}_t = \sum_S f_t N_{s,t} P_s \tag{1}$$

Where D_t is the transportation risk at time t.f_t is a time-varied possibility of accidents which depends on the dynamic transportation scenarios.S is the accident scenario, which includes flaming accident, explosion, side-rolling crash, etc. $N_{s,t}$ is the population and facilities that would be affected by accident scenario S at time t, and P_s is the accident rate of scenario S. $\mathrm{N}_{s,t} \cdot P_s$ represents the consequence of accident scenario S.

3.1 The Possibility of Potential Accidents

As mentioned above, the possibility of accident is not consistent, which changes as the transportation scenarios change. According to the previous researches, there are many factors that can affect the risk of HMT. We first divide the factors into four subgroups,

Meteorological information, including fine, rain, fogs and et al.
Road characteristics, including the lanes number, bridge or not and et al.
Traffic conditions, including high density, medium density and low density.
Status of hazard materials, including pressure, temperature, humidity and et al.

The above factors can be obtained by different IoT techniques in real time. For example, the status of hazard materials is monitored by wireless sensors, and the traffic conditions can be provided by ITS interface.

With the real-time data of these factors, we can calculate f_t as indicated in formula (2).

$$f_t = \gamma_r n_t \tag{2}$$

where n_t is the vehicle amount on road R_t at time t, γ_r is related to the accident rate of each vehicle that on R_t , and it could be calculated by equation (3).

$$\gamma_r = \gamma_0 \sum_{i=0}^{|H|} \left(|H_i| \cdot h_i \right) \tag{3}$$

Here, γ_0 stands for the basic traffic accident rate of each $year^{-1} \cdot vehicle^{-1} \cdot kilometer^{-1}$. H is set to represent the data of the subgroups mentioned above, |H| is the base of set H, and H_i is the i^{th} aspect of transportation scenario sets. Take the traffic condition set $H_{traffic}$ for example, it includes the low vehicle density, the medium vehicle density, the high vehicle density, etc. h_i is the accident rate of transportation scenario i.

3.2 The Consequence of Accident Scenarios

The accident consequence is evaluated by the population, vehicles and facilities exposed to a specific accident scenario at time t . The evaluation of consequence is based on accident scenarios. We use Areal Location of Hazardous Atmospheres (ALOHA) to simulate the chemical dispersion scenarios. Figure 1 illustrates the framework of the simulation process by ALOHA.

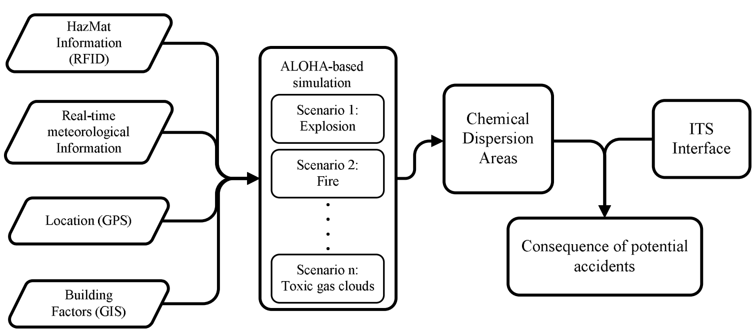

Fig. 1 The framework of the simulation process by ALOHA for accidents' consequence

Real-time input data of ALOHA is collected by techniques of IoT. The HazMat information is read from the RFID tag on the truck. The location of the truck is gotten from Global Positioning System (GPS). Building factors which will impact the dispersion of HazMat are gotten from GIS. Including the meteorological data such as wind speed and direction, ALOHA is used to estimate the HazMat dispersion areas that caused by different potential accident scenarios. By querying the carriages in the dispersion area from ITS, we can estimate the population on road.

Although wecould not get the exact population exposed in the carriages, buildings and road at specific time point using current technologies, and thus the evaluation of potential accident consequence would not accurate,however, with the development of techniques of IoT, we can almost exactly know the population exposed and thusnearly accurately evaluate the potential accident consequence.

4 Conclusions

In this paper, we proposed an IoT-based approach to the real-time risk analysis for HMT, in which the time becomes an important input variable. This approach concerns the risk at discrete time points rather than that in the whole transportation process. Techniques including RFID, WSN,and ITS are used to collect real-time data including chemical status, meteorological data, traffic conditions, etc. The probability of potential accidents is evaluated by the dynamic transportation scenarios, which can be known from the IoT monitoring data. And we used ALHOA and GIS to evaluate the consequence of a set of accident scenarios under specific transportation conditions.

Real-time risk analysis for HMT contributes to reducing the potential accident consequence and finding a transportation route with the minimized risk. Using the real-time data collected by IoT, our approach provides a more accurate way to evaluate the risk of HMT. However, IoT nowadays can't provide the exact population on roads or in buildings. Therefore, further study could focus on improving the accuracy with the techniques of IoT.

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