Modeling of Railway Risk Inter-Relation based on the study of Accident Context

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ABSTRACT

In order to detect and control the critical potential risk source of railway more scientifically, more reasonably and more accurately in complex accident context, a knowledge modeling method of risk inter-relation is proposed based on ontology modeling of accident context. First, the mechanism of accident causation is summarized based on the accident case analysis. Then, the knowledge model of accident cause is built based on ontology theory, including the ontology model of two context instances. Last but not least, the risk inter-relation rules with different dimensions of inter-relation patterns are inferred based on the instantiation of ontology model. The two context instances are used to illustrate the identification process of risk inter-relation. The results prove the rationality of the method, which can provide a reference for the precise railway risk prevention.

Keywords

Railway risk source, accident context, ontology modeling, risk inter-relation.

INTRODUCTION

In the domain of railway risk detection and prevention, the general researching method is to analyze existing accident reports, build accident tree and find out the risk sources which led these accidents. When the similar risk sources occur, the risk management system will send a warning. However, the current railway traffic risk prediction rate is low; early warning response cannot be multi sectoral linkage, often a single sector response to a single risk warning. Why is the risk forecast low? Why respond to a single department? To begin with, the analysis and simulation of accident did not consider complex context, which does not take the heterogeneous knowledge into account, e.g. environment and human behavior. Besides, accident analysis is a kind of after-event analysis method; the risk source can be detected only after the accident; the potential risk sources which may lead to future accident cannot be found by this kind of after-event analysis. Finally, railway risk management is a complex risk linkage system, but the potential inter-relation of risk sources is often ignored.

Speaking about context, (Moray 1994) proposed that all behavior and performance takes place in a setting or a context, and ergonomics/human factors must understand and account for this context, which increasingly is that of complex socio-technical or even social systems. What is useful for analysis of complex systems, parent-child or sibling systems is some form of systematic representation which shows where and how system boundaries operate and how each can provide context for others. (Rasmussen 2000; Rasmussen 1997) well known risk management framework for instance has been used by several authors to explain the layers of complex systems, e.g. (Waterson 2009). As for as context is concerned, this is critical for the railway.

Early risk management theory treats the occurrence of an accident as an independent event, which means that one risk source corresponds to one accident, and less attention is paid to the inter-relation of the cause of accident. Under this circumstance, only the risk source of the accident that had already happened can be effectively controlled, but the potential risk source and the risk inter-relation cannot be identified. However, in reality, there is much more inter-relation between risk factors. The occurrence of accidents is often due to the integration of multiple risk factors. The risk factors interact with each other in different places, at different times and by different sequences, covering the whole process of the occurrence of accident. Furthermore, any stages of the risk management process may create new risk sources. For example, in the stage of emergency response, the emergency staff do not treat the risk event in time, then it becomes a new risk source that eventually leads to the escalation of accident level. Consequently, risk factors may also lead to a chain of accidents; accident chain means one event is closely related to another event, and the end of the chain is the accidents and losses.

The development trend of modern risk management has transformed passive risk control into initiative risk prevention, while mining the potential risk inter-relation is the key to detect the potential risk sources, and then achieve the precise risk prevention. However, the existing accident case analysis will be helpful for discovering the potential risk sources, the analysis of each risk chain and accident chain is needed to identify the inter-relation of accident cause. Through the careful accident case analysis, if the risk inter-relation is identified, then the most critical potential risk source is detected.

In recent years, (Aitken et al. 2010; Fang et al. 2012; Fang and Marle 2012; Song and Cai 2012) have carried out the research on the correlation between risk sources. (Marle and Bocquet 2013) build the interactions-based risk model for project management by using RSM (Risk Structure Matrix) method and confirm the strength of interactions between different risks with AHP (Analytic Hierarchy Process). (Yang and Zou 2014) build a social network model considering the interactions of project risks and determine the optimal strategy set of risk response to deal with the interactions of different risks. (Cao et al. 2015) conclude the concept of risk chain and use the non-subjective method to analyze the evaluation information of the interrelationship among schedule risk factors that are given by the expert group. To summarize, these research works mainly focus on using mathematics method to identify some simple relation patterns. Knowledge modeling is not involved in the domain of railway risk inter-relation identification. The problem of potential risk source detection in complex accident chain context is still not be effectively solved.

In conclusion, in order to detect and control the critical potential risk source of railway more scientifically, more reasonably and more accurately in complex accident context. This paper proposes a knowledge modeling method based on ontology modeling of accident chain context, which can be briefly illustrated as follows:

- To begin with, the accident causation mechanism is summarized by the analysis of the context elements from accident cases in section 3 and section 4.
- Besides, the knowledge model of accident cause is constructed based on ontology theory in section 5.
- Finally, the risk inter-relation rules with different dimensions of inter-relation patterns are inferred based on the instantiation of ontology model. Two context instances are used to prove the rationality of the method in section 6.

RELATED WORKS

All the articles in related works are selected in Web of Science by key words “railway”, “risk”, and “context” and published from 2013-2017. After manual selection, 54 articles are narrowed down to 25 articles. (Wernstedt and Murray-Tuite 2015) reports how the accident appears to have changed over time the tradeoffs among safety, speed, frequency of service, cost, and reliability that the transit users stated they were willing to make in the post-accident period. According to those articles, risk management could be summarized as three phases: analysis, model, and assessment (post-accident period).

In analysis phase, one task is to find **modeling factors** which is the inputs of next phase. Human factor is the most important part. (Grote 2014) argued that in order to change this situation human factors/ergonomics based system design needs to be positioned as a strategic task within a conceptual framework that incorporates both business and design concerns. (Tey et al. 2014) compares driver behavior towards two novel warning devices with tow conventional warning devices at railway level crossing using microsimulation modelling. (Ghomi et al. 2016) identifies the main factors associated with injury severity of vulnerable road users involved in accidents at highway railroad grade crossings using ordered probit model, association rules, and classification and regression tree algorithms to accident database (user view, not worker view). (Saat et al. 2014) talked about environment factor. It describes a quantitative, environmental risk analysis of rail transportation of a group of light, non-aqueous-phase liquid chemicals commonly transported by rail in North America. (Liu et al. 2014) developed an analytical model to address the tradeoffs of broken rails among various factors related to rail defect inspection frequency, so as to maximize railroad safety and efficiency. Another task is the **analysis method**. (Peng et al. 2016) presents an analysis technique called timed fault tree which extends traditional fault tree analysis with temporal events and fault characteristics (assessment). (Castillo et al. 2016) provides a new Markovian-Bayesian network model to evaluate the probability of accident associated with circulation of trains along a given high speed or conventional railway line with special consideration to human error. This method is better than fault tree to break the limitation of variables' dependency. (Azad, Hassini, and Verma 2016) propose an optimization-based methodology for recovery from random disruptions in service legs and train services in a railroad network. This model is solved for each service leg to evaluate a number of what-if scenarios.

In the model phase, most work used mathematics model. (Fan et al. 2016) proposed a combinational method of analytic hierarchy process and fuzzy comprehensive evaluation to assess hazards in a complex maglev bogie system associated with multiple subsystems' failures. (Wu et al. 2014) developed a methodology to model the passenger flow stochastic assignment in urban railway network with the considerations of risk attitude. (Ghazel and El-Koursi 2014) conduct a risk assessment comparative study involving two main types of automatic protection systems, the first using a pair of half-barriers and the second with four half-barriers. (An et al. 2016) presents a modified fuzzy analytical hierarchy process that employs fuzzy multiplicative consistency method for the establishment of pairwise comparison matrices in risk decision making analysis. (Adjetey-Bahun et al. 2016) proposed a simulation-based model for quantifying resilience in mass railway transportation systems by quantifying passenger delay and passenger load as the system's performance indicator (resilience). (Guo et al. 2016) presents a comprehensive risk evaluation method based on a fuzzy Petri net model for long-distance oil and gas transportation pipelines. (Haleem 2016) identifies the significant predictors (e.g., temporal crashes characteristics, geometry, railroad, traffic, vehicle, and environment) of traffic casualties and no injury. The method applies both the mixed logit and binary logit models. (Vaidogas, Kisezauskiene, and Girniene 2016) assesses individual segments of road and railway network by estimating risks posed by potential fires and explosions on road and rail.

For the assessment phase, (An et al. 2016; Zhang et al. 2016; Guo et al. 2016; Zhao, Stow, and Harrison 2016; Chen et al. 2016; Peng et al. 2016; Vaidogas, Kisezauskiene, and Girniene 2016; Ghazel and El-Koursi 2014) used analysis method and modeling method to achieve risk assessment goal. From tool or implementation angle, (Lira et al. 2014) used a data analytics workflow to compile an incident risk index that processes information about incidents along railway lines and display it on a geographical map. (W.Y. Chen, Wang, and Fu 2014) developed terrain drop compensation technique, linear regression technique and calculating local maximum Y-coordinate object points to detect the risk area of a railway crossing. (Zhang et al. 2016) presented an adaptable metro operation incident database for containing details of all incidents that have occurred in metro operation. (Figueres-Esteban, Hughes, and van Gulijk 2016) focuses on visual text analysis techniques of Close Call records to extract safety lessons more quickly and efficiently.

To summarize, two problems remain to be solved:

- Modeling factors are not structured as a system. Modeling factors of context should be organized by concept-relations.
- Modeling method are mathematics method, knowledge base is not involved in this domain. But as a complex system, knowledge modeling is needed, especially for the potential risk inter-relation mining.

ACCIDENT CONTEXT ANALYSIS

In 1994, Schilit and Theimer proposed the concept of context-aware for the first time, it was described as, "the location, identity and change information of people and objects in the surrounding environment". Then the concept of context had been largely considered in research, but the more accurate mentions that "the context is any information that can be used to identify entities such as people, places or objects et al. and the information that is related to the interactions of users and computing system" (Abowd and Dey, 1999). Modern knowledge theory holds that context is a typical implicit information. Because of the existence of the context, there is a correlation between knowledge, knowledge itself makes sense (Li et al., 2014).

Context information is rich in content, including computing context (network connection, communication cost, communication bandwidth, peripheral resources), user context (user profile, location, social status), physical context (light, noise, traffic conditions, temperature), time context (time, week, month, season) and other types (Chen and Kotz, 2000). The description of the types and characteristics of the accident context will vary slightly from one industry to another and there is no uniform description of the criteria. In the field of railway safety management, the existing context description of large-scale accident or small-scale security incident mainly consists of seven elements, and they are analyzed in detail as follows:

- *Time*: It describes the time when the accident or security incident happen.

- *Place*: It describes the place where the accident or security incident happen.
- *Risk factor*: It is described as the potential cause of accident. From the point of view of system theory, the risk factors of railway are divided into four categories as follows, the detailed index system is illustrated in Figure 1:
  - *People* is the subject of the railway safety management system.
  - *Equipment* is the general term for all objects that are controlled by people.
  - *Environment* is the specific working conditions of people and equipment.
  - *Management* is the means to coordinate people, equipment and environment.

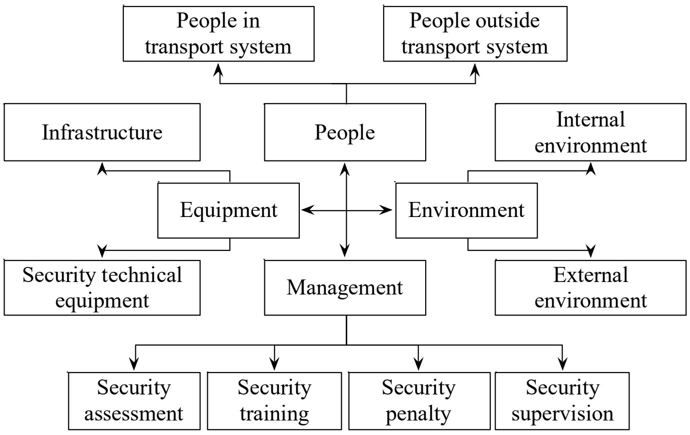

Figure 1. Risk Factor Index System of Railway

- *Accident*: The American Society of Safety Engineers defines accidents as, "An accident is a contingency that occurs abruptly, forcing a person's purpose of action to be temporarily or permanently interrupted, and sometimes resulting in personal injury or social damage".
- *Accident level*: The classification of the accident level is generally closely related to national laws and regulations. According to the "*Regulations on emergency rescue and investigation and handling of railway traffic accidents"* (The State Council of the PRC bulletin, 2007), on the basis of different situations of casualties and economic losses, accident is divided into four categories: extraordinarily serious accident, serious accident, major accident and general accident. Besides, according to the level of accident loss from the maximum to the minimum, general accident is divided into A-level accident, B-level accident, C-level accident and D-level accident (see Figure 2).

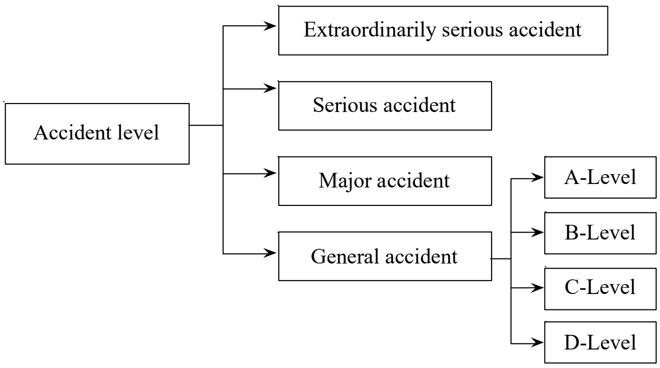

Figure 2. The Classification of Accident Level

- *Accident unit level:* It describes which unit of the whole organization will take responsible for the accident. To a certain extent, the level of the unit illustrates the sphere of influence and severity of the accident. Take the organizational structure of a railway company as an example, it represents the division of the responsibility unit level of accident in the company (see Figure 3).

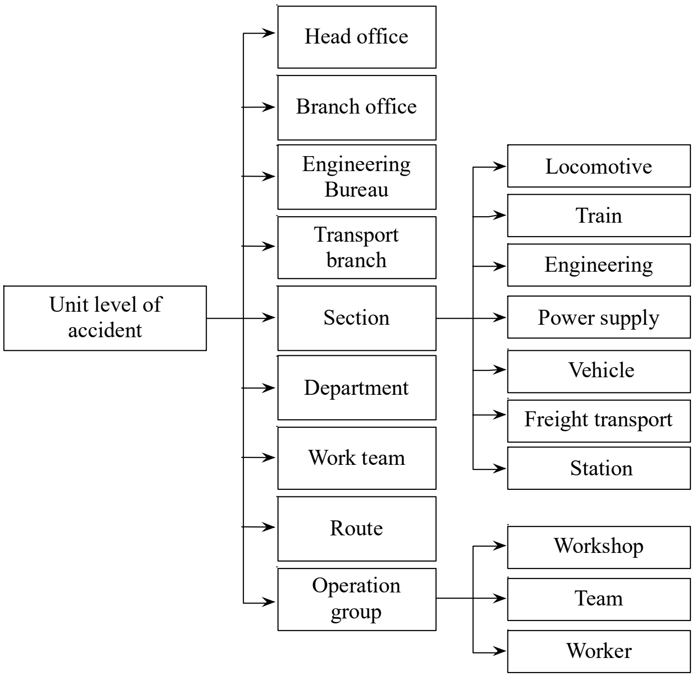

Figure 3. The Responsibility Unit Level of accident in a Railway Company

- *Emergency performance*: It describes the context of emergency treatment after accidents. It is worth mentioning that new risk sources may be created if the emergency is not handled properly.

ACCIDENT CASE ANALYSIS

In railway traffic area, the causes of accidents are manifold and complex, and at the same time there are rules to follow. Accident case management is one of the important contents of railway safety work. There are a large number of accident chain cases stored in the accident case database, which provides a base of knowledge acquisition for the analysis of the causes of railway accidents in complex contexts. The accident chain case provides many important accident context information such as time, weather, location, participant, accident level and so on for digging out the cause of the accident and the potential risk sources.

In reality, the accident may be caused by one risk source, may be caused by the simultaneity of two risk sources, and may be caused by the succession of multiple risk sources. Through the accident case analysis, it can be found how the risk sources are created, how the risk factors interact with each other and what the mechanism of accident cause is. What's more, it is also essential to analyze and decompose the risk chain and the accident chain of each accident case in detail. As the most important part of chains to be found, the most crucial potential risk sources can be controlled or eliminated.

There are 101 case reports of railway accidents from 2002 to 2012 provided by a railway company. The case reports include a short description of the accident, the process of the accident, emergency actions, the main cause of the accident and the responsibility unit or personnel. They will be thoroughly analyzed for the mechanism of accident cause based on the previous analysis of seven context elements. The accident context information and the process of accident case analysis are organized and recorded for a pattern as illustrated in Table 1.

Table 1. The Record Pattern of Accident Case Analysis

Number	Time	Location	Risk Factor	Accident	Accident Level	Unit Level	Emergency Performance
......	......	......	......	......	......	......	......

The following three patterns of accident cause can be summarized after accident case analysis, and an instance of every pattern will be illustrated as follows:

- Pattern A: Single risk factor leads to an accident.
  This kind of accidents are small-scale security incidents in general with less loss. The instance of pattern A (see Table 2) refers to an accident case of electricity major, about which a personnel on-duty operated

illegally against the security operation systems and thus led to the turnout error. Due to the timely repair after the accident, there was no risk accumulation to cause the other accident.

Table 2. An Instance of Pattern A

Time	Location	Risk Factor	Accident	Accident Level	Unit Level	Emergency Performance
1/24/2005	North station	People	Turnout error	D	Station	Timely repair

- Pattern B: An accumulation of multiple risk factors lead to an accident.
  The instance of pattern B (see Table 3) refers to an accident case of power supply major, about which different kinds of risk factors have emerged one after another, a number of risk factors accumulated without timely detection and control, eventually which lead to an accident.

Table 3. An Instance of Pattern B

Time	Location	Initial Risk	First Accumulation	Second Accumulation	Third Accumulation
10/14/2011	Substation	Equipment	People	Environment	Management

The Fourth Accumulation	Accident	Accident Level	Unit Level	Emergency Performance
People	Circuit breaker tripping	D	Section	Error treatment scheme

- Pattern C: Multiple risk factors lead to a number of accidents, resulting in an accident escalation.
  The instance of pattern C (see Table 4) refers to an accident case about which a small sub-accident occurred due to the negligence of the staff at the beginning. Then the second sub-accident occurred because of the management problem after one risk accumulation. But all the risks and incidents emerged were not timely and promptly controlled. Eventually, three risk accumulation and two small incidents lead to an accident escalation.

Table 4. An Instance of Pattern C

Time	Location	Initial Risk	First Sub-Accident	First Accumulation	Second Sub-Accident
5/10/2013	North station	People	Bad shunting	Management	Cancel shunting route

Third Accumulation	Accident Escalation	Accident Level	Unit Level	Emergency Performance
People	Two cars collided	C	Branch office	Without timely controlled

ONTOLOGY MODELING OF ACCIDENT CAUSE

Ontology model can provide clear consistent semantic description for context information from different sources. It can also support automatic reasoning for abstract higher-level contexts from underlying information that is full of uncertainty, imprecision and dynamic change feature (Bettini et al., 2010). Protégé (Horridge et al., 2004) is widely used to create, populate, update and visualize ontology. In this paper, it will be used to create the ontology model of accident cause. OWL (Bechhofer et al., 2004), which has a unified grammatical format and explicit semantics, it will be adopted as the formal description language of the ontology model.

In order to further search for the inter-relation of risk factors, a number of accident cases with complex accident cause and high accident level will be selected to collect and analyze the context information. The ontology model of accident cause (see Figure 4) is constructed by the process of the definition of core concepts and relationships, the construction of ontology architecture, the addition of instances and the evolution of ontology model. Owing to spatial confined, the relevant properties of concepts and instances are omitted from the model. The ontology model reflects the accident cause mechanism; the core concepts and relationships of the model are illustrated as follows:

- *Accident*: It describes the accidental damage or destruction in the process of railway traffic driving.

Generally, the occurrence of accidents is the result of the combined effects of many risk factors.

- *Risk source*: It describes the root cause of the railway traffic accident. The categories of risk source include the class of people, equipment, environment and management. Through the analysis of the real railway accident cases, it is found that the concept of risk source itself has the accumulation relationship, that is, accident is caused by the accumulation of multiple risk sources.
- *Sub-accident*: It describes an accident in the accident chain, and the combination of multiple sub-accidents constitutes a terminal accident. It is generally a lower level of security risk incidents. However, it is found that the occurrence of sub-accident represents the accident cause has a more complex pattern in the process of accident case analysis. To be more specific, this kind of pattern of accident cause is that risk source leads to sub-accident, the terminal accident of high level is caused by the accumulation of multiple risk factors and the escalation of multiple sub-accidents. Therefore, the concept of sub-accident itself has the escalation relationship.

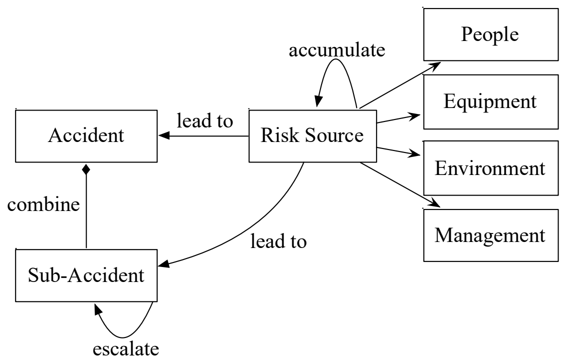

Figure 4. The Ontology Model of Accident Cause

In the ontology model of accident cause, the classification of risk source and the relationship between risk sources are the most complex part. The concept of risk sources of people is selected as an example, and the concept system of people in ontology model is illustrated in Figure 5. The risk source of people is divided into behavior risk and characteristic risk. According to the accident case analysis results, behavior risk includes some personal behavior risk such as duty neglect and non-standard operation, as well as group behavior risk such as construction and group work. Besides, security consciousness and working condition of characteristics risk are the most common cause of the accident.

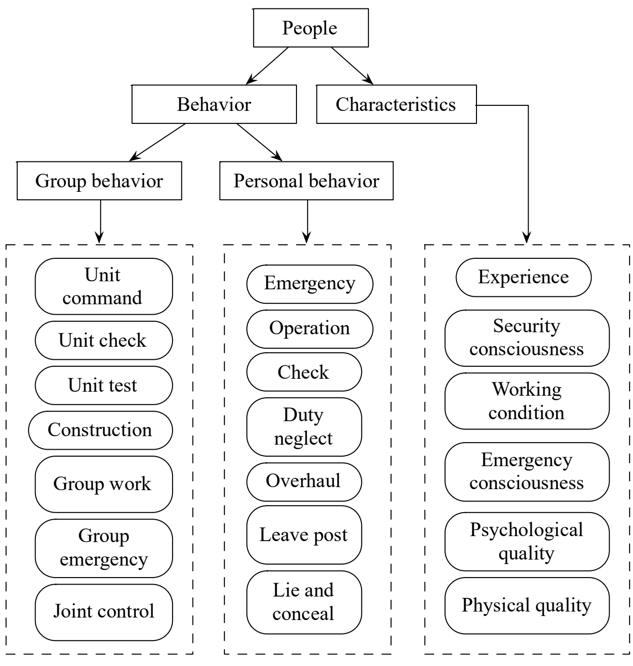

Figure 5. The Concept System of People in Ontology Model

The instance of pattern B (see Table 3) and the instance of pattern C (see Table 4) that given by the previous section are selected as the examples to construct the ontology model of instances (see Figure 6 and Figure 7), which is named instance B and instance C.

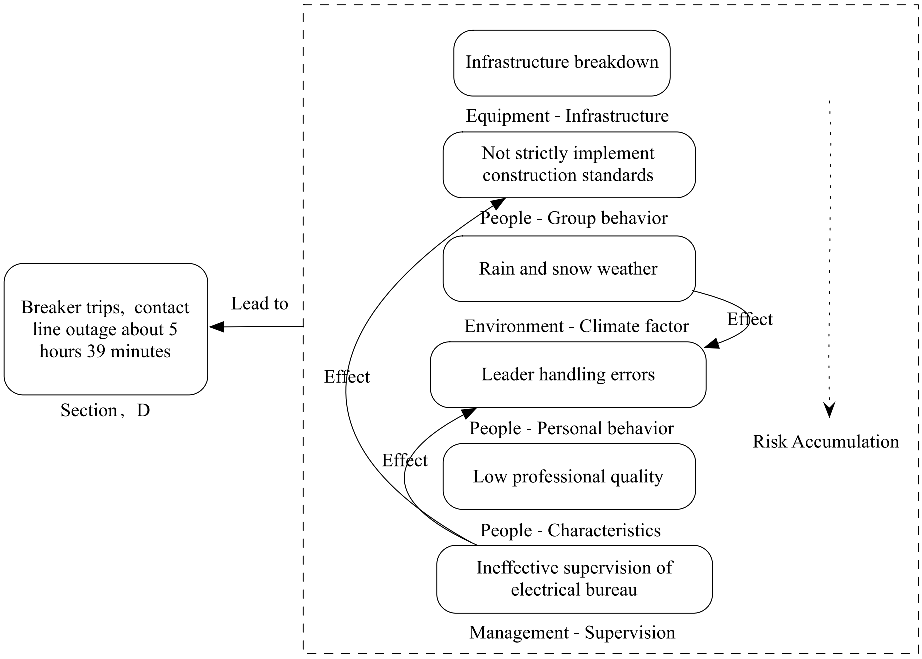

Figure 6. The Ontology Model of Context Instance B

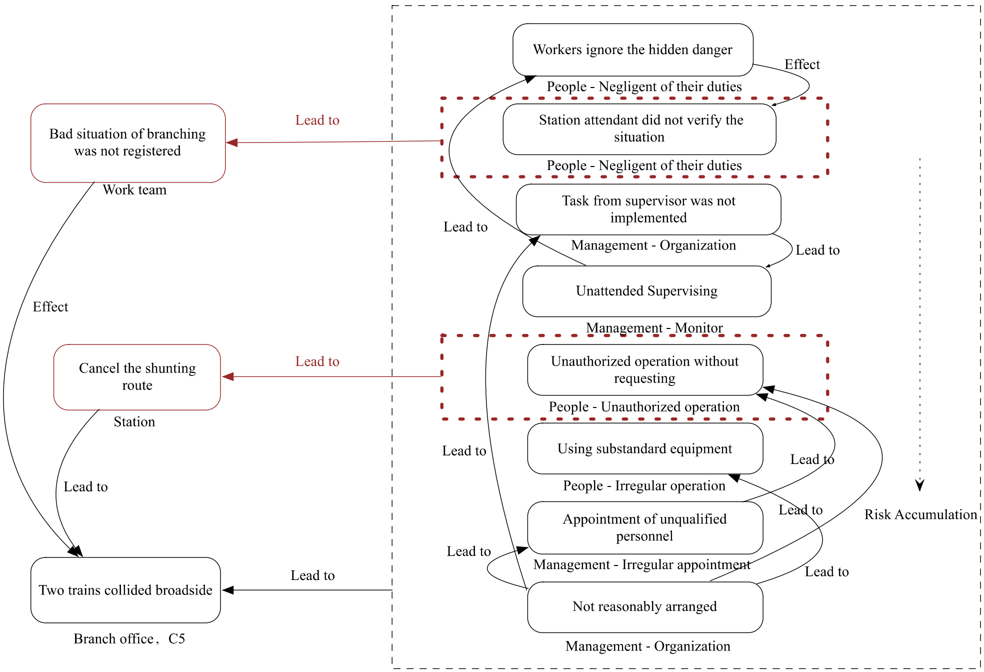

Figure 7. The Ontology Model of Context Instance C

IDENTIFICATION OF RISK INTER-RELATION PATTERNS

The two accident context instances in the last section show that risk source as the root cause of accident does not exist independently. The occurrence of accident is due to the integrated effect between multiple risk factors. Consequently, the identification and mining of all these inter-relation patterns is the focal point of risk prevention. As illustrated in Figure 8, if the potential inter-relation between two pairs of risk factors is identified, then just controlling one inter-relation point can solve two risk sources, so the repetitive control of risk sources can be avoided, the potential risk source can be controlled more accurately. What's more, since ontology provides a nice expression mechanism for context information and supports semantic reasoning, a balance can be established between context description and context reasoning. Accordingly, the rules of risk inter-relation pattern can be summarized through the ontology model when the potential risk sources are identified. The knowledge base formed by the ontology model makes the intelligent risk prevention possible.

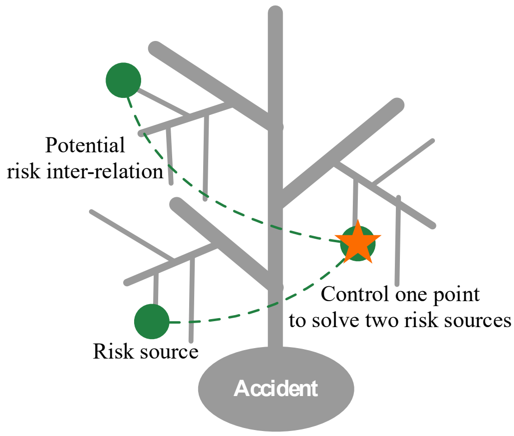

Figure 8. The Risk Prevention in Pattern of Risk Inter-Relation

The instantiation of knowledge has a unified structure and form that makes knowledge sharing, reuse and operation very convenient. The risk inter-relation analysis will be carried out by using the instantiation knowledge in the accident cause ontology. The inter-relation rules with different dimensions of inter-relation patterns can be inferred based on the instantiation of ontology model. The basic definition of risk inter-relation reasoning rules is described as follows:

i. Risk source set is R, R=(Risk(R_1), Risk(R_2), Risk(R_3) ... Risk(R_n)), n is the number of risk source.
ii. Occur() is the state function of risk source set R. Occur(R)=1 represents that the risk sources of set R occur in sequence by input order.
iii. RelationRisk() is the inter-relation function of risk source set R. RelationRisk(R)=1 represents that there is an inter-relation between risk sources of set R.

Four patterns of risk inter-relation are selected as the examples, which are illustrated as follows:

- Pattern A: The risk sources occur in the same time.
- Pattern B: The risk sources occur in the same location.
- Pattern C: Two risk sources occur in pairs.
- Pattern D: Three or more risk sources occur with combination.

Rule (1) ~ Rule (8) are the inter-relation rules for the four patterns of risk inter-relation inferred by risk inter-relation analysis. They are illustrated as follows:

- Rule (1) describes the inter-relation rules for Pattern A that two risk sources occur in the same time. If R_1 and R_2 occur in the same time, then R_1 and R_2 have the inter-relation.

$$\begin{aligned}&\text{If OccurTime}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\\&\rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{aligned} \tag{1}$$

- Rule (2) describes the inter-relation rules for Pattern B that two risk sources occur in the same location. If R_1 and R_2 occur in the same location, then R_1 and R_2 have the inter-relation.

$$\begin{aligned}&\text{If OccurLocation}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\\&\rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{aligned} \tag{2}$$

- Rule (3) and Rule (4) describes the inter-relation rules for Pattern C that two risk sources occur in pairs. Rule (3) illustrates if R_1 and R_2 occur repeatedly by the same sequence, then R_1 and R_2 have the inter-relation; Rule (4) illustrates if R_1 and R_2 occur repeatedly by the exchanged sequence, then R_1 and R_2 have the inter-relation.

$$\begin{aligned}&\text{If Occur}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1 \wedge \text{Occur}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\\&\rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{aligned} \tag{3}$$

$$\begin{aligned}&\text{If Occur}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1 \wedge \text{Occur}(\text{Risk}(R_2),\text{Risk}(R_1)) == 1\\&\rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{aligned} \tag{4}$$

- Rule (5) ~ Rule (8) describes the inter-relation rules for Pattern D that three or more risk sources occur with combination. Rule (5) illustrates if R_1, R_2 and R_3 occur repeatedly by the same sequence, then R_1, R_2 and R_3 have the inter-relation; Rule (6) illustrates if R_1, R_2 and R_3 occur repeatedly by the exchanged sequence, then R_1, R_2 and R_3 have the inter-relation.

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \\ &\qquad \rightarrow \text{RelationRisk(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1\end{aligned} \tag{5}$$

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_2\text{),Risk(R}_3\text{),Risk(R}_1\text{))} == 1 \\ &\qquad \rightarrow \text{RelationRisk(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1\end{aligned} \tag{6}$$

- Rule (7) illustrates if R_1 and R_2 which are in the combination of R_1, R_2 and R_3 and the combination of R_1, R_2 and R_4 occur repeatedly by the same sequence, then R_3 and R_4 have the inter-relation; Rule (8) illustrates if R_1 and R_2 which are in the combination of R_1, R_2 and R_3 and the combination of R_2, R_1 and R_4 occur repeatedly by the exchanged sequence, then R_3 and R_4 have the inter-relation.

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_4\text{))} == 1 \\ &\qquad \rightarrow \text{RelationRisk(Risk(R}_3\text{),Risk(R}_4\text{))} == 1\end{aligned} \tag{7}$$

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_2\text{),Risk(R}_1\text{),Risk(R}_4\text{))} == 1 \\ &\qquad \rightarrow \text{RelationRisk(Risk(R}_3\text{),Risk(R}_4\text{))} == 1\end{aligned} \tag{8}$$

The above-mentioned risk inter-relation rules are used for the accident context instance B and the accident context instance C as the examples. The running results are illustrated in Figure 9 and Figure 10. Figure 9 indicates the condition in which two risk sources occur by the same sequence and lead to accident. The inter-relation of two risk sources is identified by Rule (3), however the two risk sources derive from different instances but the same class that is people and management. Likewise, Figure 10 indicates the condition in which two risk sources occur by the exchanged sequence, then lead to accident. The inter-relation of two risk sources of people and equipment is identified by Rule (4).

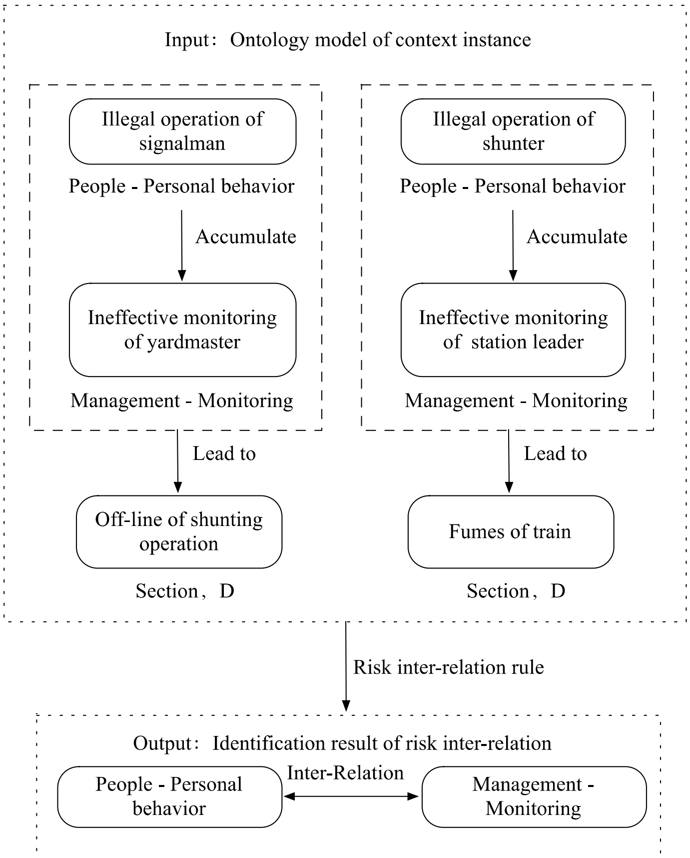

Figure 9. The Identification Process of Risk Inter-Relation in Context Instance B

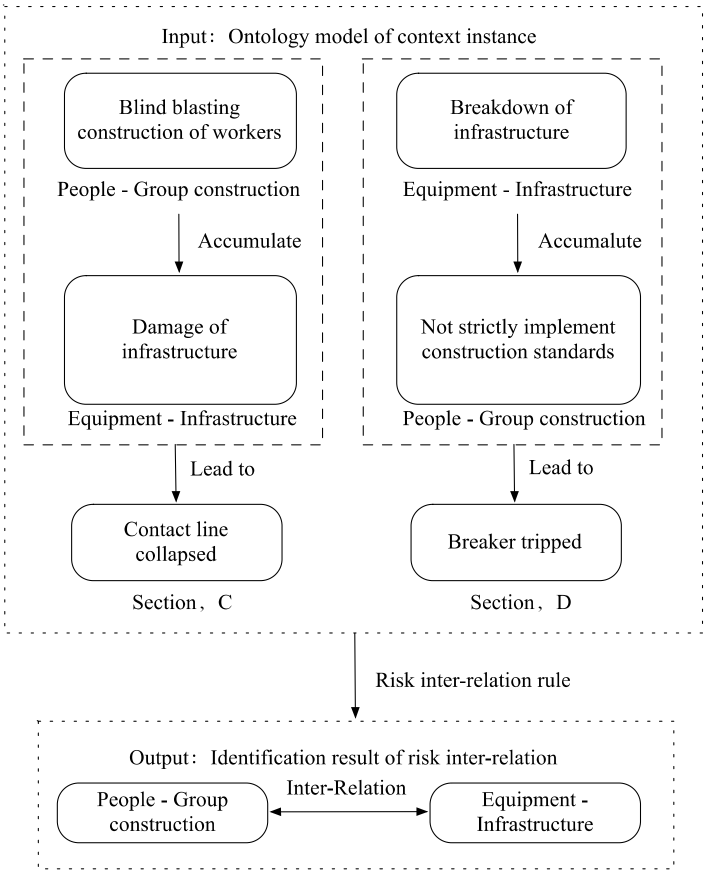

Figure 10. The Identification Process of Risk Inter-Relation in Context Instance C

CONCLUSION AND FUTURE WORK

Considering the characteristics of complex railway accident context and the difficulty of detecting potential risk source, this paper accomplished the following work to solve the problem: the description of accident context was resolved for seven context elements; the method of accident case analysis was illustrated based on the description of accident context; the mechanism of accident causation was summarized from the accident case analysis; the ontology model of accident cause was constructed to describe the mechanism of accident causation; the risk inter-relation rules were inferred based on the ontology model which described different patterns of risk inter-relation.

The future work will focus on the automatic reasoning for the inter-relation rules and construct the knowledge base of accident cause. It will aim to realize the self-learning of knowledge base by obtaining the new inter-relation rules, then knowledge base will be updating and revising for the knowledge of accident cause. The self-learning of knowledge base will provide a foundation of intelligent risk prevention and risk early warning.

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REFERENCES

An, M., Qin,Y., Jia, L.M. and Chen, Y. (2016) Aggregation of Group Fuzzy Risk Information in the Railway Risk Decision Making Process, Safety Science, 82 (February): 18–28.

Azad, N., Hassini, E. and Verma, M. (2016) Disruption Risk Management in Railroad Networks: An Optimization-Based Methodology and a Case Study, Transportation Research Part B-Methodological, 85 (March): 70–88.

Aitken, J. M., Alexander, R. and Kelly, T. (2010) A case for dynamic risk assessment in NEC systems of systems, In 2010 5th International Conference on System of Systems Engineering (pp. 1-6).

Abowd, G.D., Dey, A.K., Brown, P.J., et al. (1999) Towards A Better Understanding of Context and Context-Awareness, Handheld and Ubiquitous Computing, Springer Berlin Heidelberg, 304-307.

Bahun, A., Kpotissan, Birregah, B., et al. (2016) A Model to Quantify the Resilience of Mass Railway Transportation Systems, Reliability Engineering & System Safety, 153 (September): 1–14.

Bettini, C., Brdiczka, O., Henricksen, K., et al. (2010) A Survey of Context Modelling and Reasoning Techniques, Pervasive and Mobile Computing, 6, 2, 161-180.

Bechhofer, S., Harmelen, F.V., Hendler J, et al. (2004) OWL Web Ontology Language Reference, W3c Recommendation, 40, 8, 25–39.

Castillo, E., Calvino, A., Grande, E., et al. (2016) A Markovian-Bayesian Network for Risk Analysis of High Speed and Conventional Railway Lines Integrating Human Errors, Computer-Aided Civil and Infrastructure Engineering, 31 (3): 193–218.

Chen, R. P., P. Jiang, Ye, X.W. and Bian, X.C. (2016) Probabilistic Analytical Model for Settlement Risk Assessment of High-Speed Railway Subgrade, Journal of Performance of Constructed Facilities, 30 (3): 04015047.

Chen, W.Y., Wang, M. and Fu, Z.X. (2014) Railway Crossing Risk Area Detection Using Linear Regression and Terrain Drop Compensation Techniques, Sensors, 14 (6): 10578–97.

Cao, J.M., Shen, L.F., Peng W., et al. (2015) Novel method for schedule risks assessment in construction projects from perspective of risk chain, Journal of Tongji University (Natural Science), 43, 3, 468-474.

Chen, G., Kotz, D. (2000) A survey of context-aware mobile computing research, Technical Report TR2000-381, Dept. of Computer Science, Dartmouth College.

Fan, C.X, Dou, F.S., Tong, B.M., et al. (2016) Risk Analysis Based on AHP and Fuzzy Comprehensive Evaluation for Maglev Train Bogie, Mathematical Problems in Engineering, 1718257.

Fang, C. and Marle, F. (2012) A simulation-based risk network model for decision support in project risk management, Decision Support Systems, 52, 3, 635–644.

Fang, C., Xiao, X. and Zhu, X. (2012) Accounting for risk interactions and using importance measures for risk prioritization in project management, In 2012 IEEE International Conference on Industrial Engineering and Engineering Management (pp. 1998–2002).

Grote, G. (2014) Adding a Strategic Edge to Human Factors/Ergonomics: Principles for the Management of Uncertainty as Cornerstones for System Design, Applied Ergonomics, 45 (1): 33–39. doi:10.1016/j.apergo.2013.03.020.

Ghomi, H., Bagheri, M., Fu, L.P., et al. (2016) Analyzing Injury Severity Factors at Highway Railway Grade Crossing Accidents Involving Vulnerable Road Users: A Comparative Study, Traffic Injury Prevention, 17 (8): 833–41.

Ghazel, M. and El-Koursi E.M. (2014) Two-Half-Barrier Level Crossings Versus Four-Half-Barrier Level Crossings: A Comparative Risk Analysis Study, Ieee Transactions on Intelligent Transportation Systems, 15 (3): 1123–33.

Guo, Y.B., Meng, X.L., Wang, D.G., et al. (2016) Comprehensive Risk Evaluation of Long-Distance Oil and Gas Transportation Pipelines Using a Fuzzy Petri Net Model, Journal of Natural Gas Science and Engineering, 33 (July): 18–29.

Haleem, K. (2016) Investigating Risk Factors of Traffic Casualties at Private Highway-Railroad Grade Crossings in the United States, Accident Analysis and Prevention, 95 (October): 274–83.

Horridge, M., Knublauch, H., et al. (2004) A practical guide to building OWL ontology using the protégé-OWL Plugin and CO-ODE tools, The University of Manchester 8.

Kpotissan, A.B., Birregah, B., Chatelet, E., et al. (2016) A Model to Quantify the Resilience of Mass Railway Transportation Systems, Reliability Engineering & System Safety, 153 (September): 1–14.

Liu, X., Lovett, A., Dick, T., et al. (2014) Optimization of Ultrasonic Rail-Defect Inspection for Improving Railway Transportation Safety and Efficiency, Journal of Transportation Engineering, 140 (10): 04014048.

Lira, W.P., Alves, R., Jean M. R. et al. (2014) A Visual-Analytics System for Railway Safety Management, Ieee Computer Graphics and Applications, 34 (5): 52–57.

Li, H., Xie, Q., Ding, Q.L. (2014) Proactive knowledge requirement modeling based on scenario, Computer and Digital Engineering, 42, 2, 627-631.

Miguel, F.E., Hughes, P. and Coen van Gulijk. (2016) Visual Analytics for Text-Based Railway Incident Reports, Safety Science, 89 (November): 72–76.

Marle, F., Vidal, L.A., Bocquet, J.C (2013) Interactions-based risk clustering methodologies and algorithms for complex project management, International Journal of Production Economics, 142, 2, 225-234.

Peng, Z.G, Yu, L., Miller, A., et al. (2016) Risk Assessment of Railway Transportation Systems Using Timed Fault Trees, Quality and Reliability Engineering International, 32 (1): 181–94.

Saat, M.R., Werth, C. J., Schaeffer, D., et al. (2014) Environmental Risk Analysis of Hazardous Material Rail Transportation, Journal of Hazardous Materials, 264 (January): 560–69.

Song, H. and Cai, C (2012) A Social Network Approach to Software Development Risk Correlation Analysis, In 2012 Fifth International Conference on Business Intelligence and Financial Engineering (pp. 308-312).

Schilit, B., Theimer, M. (1994) Disseminating Active Map Information to Mobile Hosts, IEEE Network, 8, 5, 22-32.

Tey, L.S., Zhu, S., Ferreira, L., et al. (2014) Microsimulation Modelling of Driver Behaviour towards Alternative Warning Devices at Railway Level Crossings, Accident Analysis and Prevention, 71 (October): 177–82.

The State Council of the PRC (2007) Regulations on emergency rescue and investigation and handling of railway traffic accidents, The State Council of the PRC bulletin, 24, 4-6.

Vaidogas, E.R., Kisezauskiene, L. and Girniene, I. (2016) The Risk to Structures Built Near Roads and Rails Used for Moving Hazardous Materials, Journal of Civil Engineering and Management, 22 (3): 442–55.

Wu, J.J, Sun H.J., Gao Z.Y., et al. (2014) Risk-Based Stochastic Equilibrium Assignment Model in Augmented Urban Railway Network, Journal of Advanced Transportation, 48 (4): 332–47.

Yang, R.J., Zou, P.X.W. (2014) Stakeholder-associated risks and their interactions in complex green building projects: a social network model, Building and Environment, 73, 3, 208-222.

Zhang, X.L., Deng, Y.L., Li, Q.M., et al. (2016) An Incident Database for Improving Metro Safety: The Case of Shanghai, Safety Science, 84 (April): 88–96.

Zhao, Y.S., Stow, J. and Harrison, C. (2016) Estimating the Frequency of Trains Approaching Red Signals: A Case Study for Improving the Understanding of SPAD Risk, Iet Intelligent Transport Systems,10 (9): 579–86.