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A CRASH RISK ASSESSMENT MODEL FOR ROAD CURVES

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ABSTRACT

A comprehensive model to assess crash risks and reduce driver's exposure to risks on road curves is still unavailable. We aim to create a model that can assist a driver to negotiate road curves safely. The overall model uses situation awareness, ubiquitous data mining and driver behaviour modelling concepts to assess crash risks on road curves. However, only the risk assessment model, which is part of the overall model, is presented in the paper. Crash risks are assessed using the predictions and a risk assessment scale that is created based on driver behaviours on road curves. This paper identifies the contributing factors from which we assess crash risk level. Five risk levels are defined and the contributing factors for each crash risk level are used to determine risk. The contributing factors are identified from a set of insurance crash records using link analysis. The factors will be compared with the actual factors of the driving context in order to determine the risk level.

INTRODUCTION

The crash rates in road curves are about 1.5 to 4 times higher than in straight roads (Zegeer, Stewart, F. M. Council, Reinfurt, & Hamilton, 1992). Moreover, the crash severity for curve related crashes is higher than those occurring in straight roads (Glennon, Neuman, & Leisch, 1985). Hence, studies had been carried out to assess the crash risk. Crash risk assessments are conducted to determine future possible crash risks. There are different methods to assess risk on curves. Most of them are based on the number of fatalities or crash severity on curved roads. Another way to assess risk is to discover the contributing factors of a crash and determine the effect of each factor on risk. The contributing factors are related to vehicle, driver, and environment.

Related Studies

Risk can be also subjectively assessed. An interview based study by Higgins and Besinger, (Higgins, & Beesing, 2006) identified the "riskiest" driver behaviour as cell phone use and other "multi-tasking" while driving, aggressive driving behaviours such as speeding, running red lights, and failing to yield right-of-way to other vehicles. The following sub-sections discuss related objective risk studies grouped by vehicle, driver and environment.

Vehicle Related Studies Speed is the major contributing factor for road, including curve related crashes. Speeding had contributed 16% of the fatal crashes in Queensland, and is ranked as the fifth highest contributing factor to fatal crashes in 2003 (Queensland, 2005). Kloeden *et al.* (Kloeden, Ponte, & McLean, 1997) has shown that a small increase in speed lead to a rapid increase in crash risk. This is based on the fact that most drivers underestimate the required stopping distance. The crash and injury severity increases as the speed increases. Hence, several researchers have investigated the contributing factors and the way to estimate risk. The conservative way to estimate risk is to calculate the speed, stopping distance and impact speeds (Kloeden, Ponte, & McLean, 1997; RTA,2006). Impact speed is included in the calculation as studies have shown that as the impact speed increases, the likelihood to suffer fatal injury increases (Ashton, & Mackay, 1979). This estimation leads Koleden *et al*. (Kloeden, Ponte, & McLean, 1997) to show that the crash risk doubles with every 5km/h increase in a 60km/h limit zone. Furthermore, the risk of speeding in an urban area has equivalent risk to driving with illegal blood alcohol concentration.

Besides speeding, the age of a vehicle is another risk factor. Older vehicles have higher crash risk as they do not have advanced safety features. They also have safety defects such as faulty brakes, and worn out tyres. Blows et al. (Blows et al, 2003) has shown that crash injury risk increases as the age of the vehicle increases. Results have shown that vehicles manufactured before 1984 have three times the crash risk compared to those manufactured from 1994 onwards (Blows et al, 2003).

Driver Related Studies Inexperienced drivers are exposed to higher crash risk compared to other drivers. They have poor visual and perceptual skills, judgement, control, are unable to respond to risks, and unable to cope with distractions while driving (Government, 2005). This is based on the high crash rates inexperienced drivers have in the first six months of driving alone since they failed to recognize risk and have poor hazard perception. Furthermore, they do not handle the complex task of driving well (Government, 2005). Therefore, the crash risk increases when an inexperienced driver is driving on a curved road, as it requires more experience and skill to handle such situations.

Driver intoxication with alcohol is another risk related factor. Drinking can influence the ability to control the vehicle and perform tasks such as braking and steering. Additionally, alcohol impairs drivers' decision making, such as when they are not able to make judgements of the road geometry and condition to adjust the vehicle's dynamics accordingly (NHTSA, 2006). This increases the driver's exposure to crash risk when they negotiate a road curve. Thus, drink driving is one of the causes of crashes in road curves. In 2003, Queensland recorded 284 fatal crashes and 38% of the crashes were caused by alcohol or drugs (Queensland, 2005).

A driver raises his crash risk when he is fatigue (VicRoads, 2006). Fatigue can cause slow reaction, reduced concentration ability, and drivers take a longer interpretation time to understand the traffic situation. Drivers also have trouble to keep the vehicle within the lane, drifting off the road, change of speed and not reacting in time to avoid hazard situations. This leads to a high number of single vehicle crashes, run-off-road and hit roadside objects, and severe head-on collisions (Authority, 2005).

Fatigue is as unsafe as drink driving as research has shown that the driving ability of a fatigue driver who goes without sleep for 24 hours has the same driving ability of a driver with Blood Alcohol Concentration (BAC) of 0.1(VicRoads, 2006).

Environment Related Studies Environmental factors such as wet or slippery road surfaces, poor lighting, narrow shoulder width, slide resistance, and unprotected roadside environment, contribute to crashes in road curves. The crash risk in road curves is also influenced by the road design such as the degree of curve, length of curve, lane width, surface and side friction, sight distance, and super elevation. The following paragraphs discuss a few of the factors mentioned previously that influence crash risk.

Research has shown that a decrease in curve radii will increase the related risk rate. Blair (Turner, 2005) has defined the relative risk and curve risk and is presented in Figure 1.

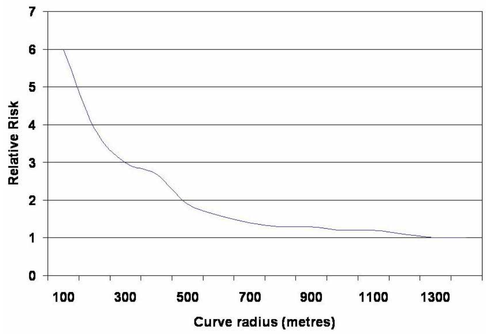

Figure 1. The relative risk for different curve radius (metres).

Sharp horizontal curves or curves with smaller radii are associated with large central angle and limited sight distance. Insufficient sight distance results in high crash rates in horizontal curve (Torbic et al., 2004) and increases the crash risk. The relative risk is approximately 1.1 when the sight distance is 2/3 of required and it increases to 1.42 when the sight distance is less than 2/3 of required (Turner, 2005).

The location of the curve is critical and will affect the crash risk level. The risk is higher when a curve is after a long straight road or after a sequence of gentle curves (Seneviratne & Islam, 1994). Other road features such as superelevation and side friction also contribute to crash rates. Superelevation will affect the travelling speed on curved road and in turn increase or decrease crash risk. Wet weather can contribute to the risk level when the superelevation is less than 2% (Dunlap, 1978).

To our knowledge, none of the existing risk assessment studies have integrated contributing factors of the situation (environment, vehicle, and driver) and past crash records. Past crash records used for our assessments are past crash claims from an insurance company. Risk is assessed based on the number of records and severity of each crash recorded. Even though FHWA had investigated crashes related to trees using the approach but there are no studies for curved roads yet.

The innovative aspect of the proposed approach is that it uses past crash records and information about the current situation that consists of environmental, vehicle dynamics and driver behaviour. Then the collected data is analysed in order to improve the accuracy of the real time risk assessment in a vehicle.

The rest of the paper is structured in the following manner. The overview of our conceptual framework is presented, followed by a description of the risk assessment methodology. Results of the crash history review is presented and discussed. Then we conclude with a summary of the findings and recommendations for future work.

CONCEPTUAL FRAMEWORK

Figure 2 illustrates the overall framework of our approach. Details are discussed in previous work (Chen et al, 2006). In summary, the framework consists of a training phase which involved crash history review, and simulation to study driving behaviour in curved roads. Then the review and simulation results are obtained and used to train a driver behaviour model. This is later used to assess crash risk in real-time. The risk assessment model is called Ubiquitous Situation Awareness Risk Prediction Model for Road Safety (UbiSARPS), which is designed to assess and determine crash risk on curved roads.

The focus of the paper is on the risk assessment model that is on the right side of Figure 3, and an overview of the analysis processes, that includes the grey out area, is also illustrated. Crash risk assessment of curved roads could help to determine future crash risks. Risk assessment involves the consideration of several factors that are related to road curves.

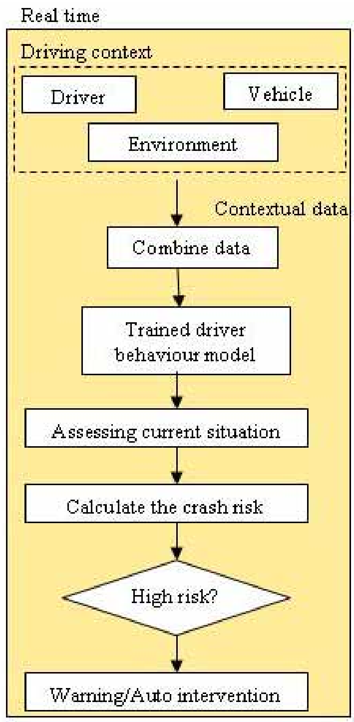

Figure 2. An overview of UbiSARPS.

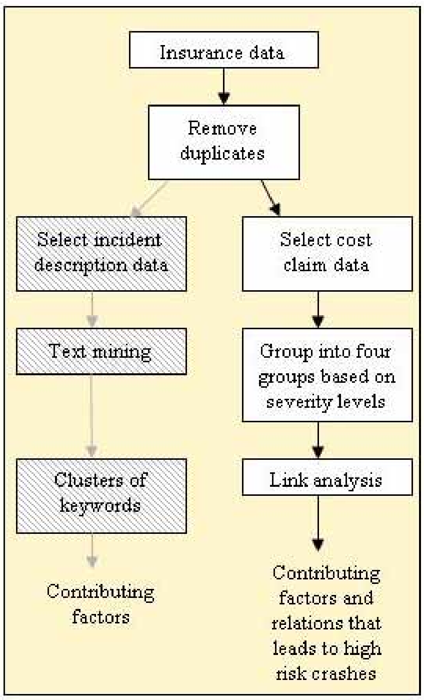

Figure 3. Overview of the crash review process which is part of the training phase.

The next section is a description of the review methodology.

CRASH REVIEW METHODOLOGY

Analysing past crash records is a critical step in assessing crash risk on curved roads. Crash risks are determined from contributing factors, crash severity, hazard locations, and patterns of crashes.

We mined a large amount of crash records from an insurance company in order to extract knowledge about contributing factors to crashes on curves. The records consist of 8035 insurance claims, related to property damage occurred in Queensland urban areas between the years 2003 and 2005 inclusive. Each record contains information about the crash such as the location of the crash, time, age of driver, years of experience, severity, and whether the driver was under the influence of alcohol. The records contain crash claims that cost more than AUD$2500.

In this paper, we classify the data into different vehicle damage severity groups and define a risk scale with five levels. Groups are classified based on the claim amount of each crash and corresponds to the risk scale level that we will define. The data are 'cleaned' before using for the analysis processes. The 'cleaning' process consists of removing duplicate records and replacing invalid or empty fields. The next section describes the risk scale levels.

Risk Scale Levels

A five-level risk scale is defined for assessing crash risk on road curves. A risk with level one indicates a low crash risk and the risk increases until level five which is an indication of high crash risk. Crash risk level is determined by assessing the contributing factors. A set of contributing factors are defined in each level and are used to determine the risk level of the current situation. The initial step to determine risk level is to use a set of selected contributing factors and compare with the defined contributing factors in each level. A close match to the defined contributing factors indicates the crash risk level.

With the insurance crash records, the five risk levels are based on the claim amount for curve related crashes. The records are divided into five groups and the first group is the records that cost less than AUD$2500. A previous (Chen, 2006) has presented the findings of the contribution factors on curved roads based on the claim descriptions. The remaining records are divided into quartiles which results in four equal groups of the records. The minimum claim amount to divide into quartiles is AUD$2502 and the maximum amount is AUD$63,314, and consists of 1041 records. Table 1 presents the distribution of the cost across different risk levels.

Table 1.
The cost distribution for each crash risk levels.

Level	Claim amount in AUD$
5	$9734-63,314
4	$5477-9733
3	$3479-5476
2	$2500-3748
1	Less than $2500

After defining the five levels, the next step is to define related contributing factors for each level. The contributing factors will be identified with the link analysis approach which is discussed in the Crash Records Analysis Process section.

The following section describes the preliminary analysis process on the crash records. A preliminary analysis was conducted to provide a background of the crash records used for the analysis process. Then the next step is to discover the contributing factors for each severity group.

Preliminary analysis

The aim of preliminary analysis is to determine the distribution of the contributing factors from the insurance crash records. This distribution provides an overview of the characteristics of the records used.

The initial step for the preliminary analysis is to determine and select the variables to observe. Selected variables are based on the contributing factors with the highest number of crashes that are identified by the Queensland Transport crash report. They are: *alcohol, inattention, inexperience, age, and wet roads*. The corresponding contributing factors from the insurance records are: *wet roads, inattention, inexperience, young drivers, and alcohol*.

The records used are cleaned and consist of all types of road crashes. The selected and cleaned records from the insurance company are imported into SPSS for analysis. A frequency count on the number of records is performed for each selected contributing factors and are consolidated and converted into a percentage. The consolidated results are used to discover the distribution of the contributing factors from the insurance company records. The contributing factors are arranged in a descending order in terms of the number of crashes and are presented in a chart. Figure 4 illustrates the distribution of the contributing factors from the insurance company crash records.

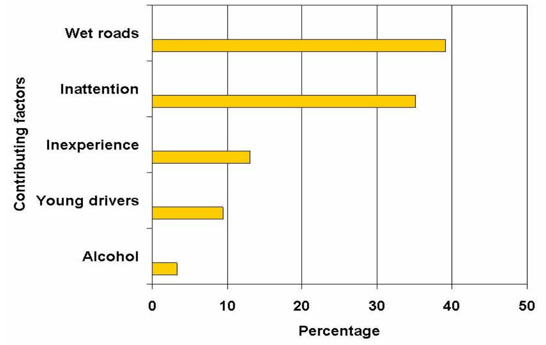

Figure 4. The distribution of the contributing factors from the insurance crash records.

The most significant contributing factor in the crash records is wet roads, followed by lose of control, inexperience, young drivers and alcohol.

These findings are different from Queensland Transport database which rank contributing factors as follows in Figure 5.

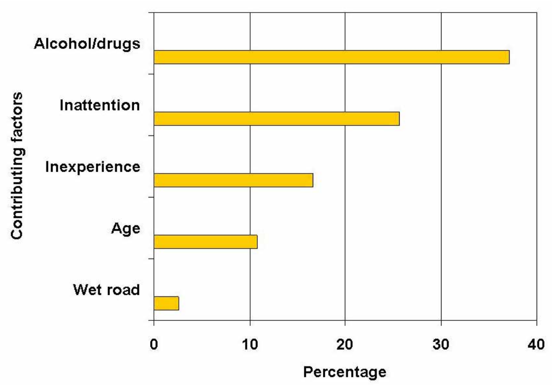

Figure 5. The distribution of the contributing factors defined in the Queensland Transport crash report (Queensland, 2005).

Crash Records Analysis Process

The aim of the analysis process is to determine the contributing factors for each crash of the five risk groups. The identified contributing factors will be exploited to define a risk scale.

Crash records are filtered and only curve-related crashes are analysed. Then the records are categorised into four groups based on the claimed amount. Each of the four categorized groups is examined using the link analysis method to identify the contributing factors in each group. Link analysis is a process to find the relationship between selected variables using nodes and links. A node represents a field attribute and a link represents an association between nodes where the variables from one node to another occurred together. For example, male drivers are involved with more tree related crashes than female drivers. This is concluded based on the number of links between the male node, and tree crash node. Figure 6 illustrates the nodes, links and relationships.

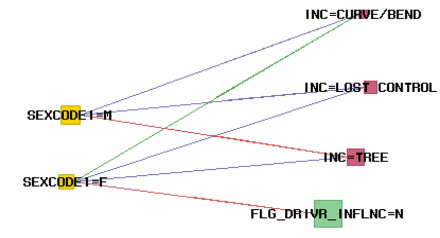

Figure 6. An example of nodes, links and their relationship.

The linkages are presented graphically; the size of the node indicates the number of records and different colours of the link indicates the number of related records. As seen in Figure 6, red lines have the most number of links compared to blue and followed by green lines. Therefore, an increase in size or change of colours signifies that nodes are highly associated with each other. This interpretation aids our analysis in identifying the significant contributing factors among the crash records. Then the identified contributing factors are listed and arranged in a chart format for each of the four groups.

Apparatus

In the preliminary analysis, a statistical tool called SPSS is used to remove duplicate records and to analyse the distribution of the contributing factors in insurance crash records. Later in the data analysis process, SPSS is used again to group the records into four groups that correspond to the vehicle damage severity levels. Then SAS is used to perform the link analysis process in order to identify contributing factors in the crash records.

CRASH RISK LEVELS AND RELATED CONTRIBUTING FACTORS

The expected result from the crash records analysis process is to obtain a different set of contributing factors for each crash risk level.

Risk Level One

The contributing factors for Level One are presented in previous work (Chen, 2006). hence, this paper presents the results from Level two to five.

Risk Level Two

Figure 7 illustrates the significant contributing factors for Level Two risk (claim cost = AUD$2500-3748). Significant factors are factors which are associated with a high number of crashes. The factors are expressed as the percentage of the total number of crashes for the first quartile group of records (n=261).

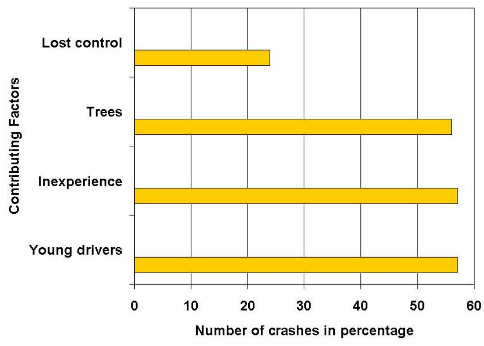

Figure 7. The list of contributing factors for Risk Level Two.

Figure 7 shows that young drivers of 22 years of age and drivers who have 9 years of driving experience are the significant factors in the list. The maximum age of drivers for this level risk is 43 years of age. Both genders are equally involved in the crashes, even though males have 8% more number of crashes than females. However, this is not a major issue. Hence, both genders face the same risk.

The next factor is trees where trees can be the roadside objects that the vehicle hit when it go off the road in order to avoid animals or through loss of control. Possible reasons for loss of driver control are: speeding, inattention, fatigue, inexperience, and misjudgement on curves. Hence, a driver will be assessed as Level Two risk if he or she is between 22 to 43 years of age, or with 9 years or less of driving experience or when there are trees or a curved road in the environment.

Risk Level Three

The total number of crash records used for Level Three analysis is 260. The claim cost is between AUD$3479 and AUD$5476. The list of contributing factors is expressed in percentage according to the total number of crashes and is illustrated in Figure 8. The contributing factors are similar to Risk Level Two, however, the detailed information of each factor are different.

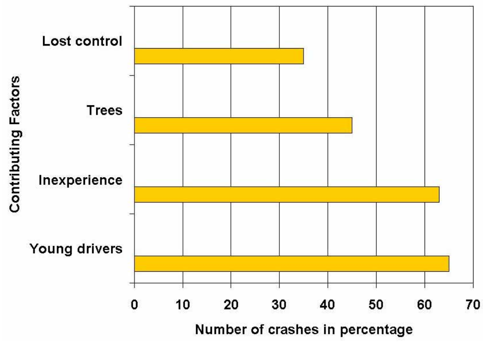

Figure 8. The list of contributing factors for Risk Level Three.

In Level Three, young drivers of 23 years of age or with 10 years or less of driving experience drivers are the leading contributing factors. This may be due to lack of skill to handle risk and the perception of risk is not well developed yet. This applies to underdeveloped both male and female drivers, as male drivers have 5% more number of crashes in comparison to female drivers. The maximum age is 43 years of age for level Three too. The remaining factors are trees, lost of control and curves. The tree factor is not significant compared to Level Two. However, the number of lost control crashes increase. A possible reason is due to speed as most drivers are over-confident and will drive more recklessly. Therefore, Level Three risk is identified when a driver with age ranges from 23 to 43 of age or with 10 or less years of driving experience and if he or she speeds.

Risk Level Four

This level of risk is considered moderately high and more contributing factors are identified. A total of 260 crash records and with claim cost between AUD$5477 and AUD$9733 are used for the analysis process. Figure 9 presents the list of factors.

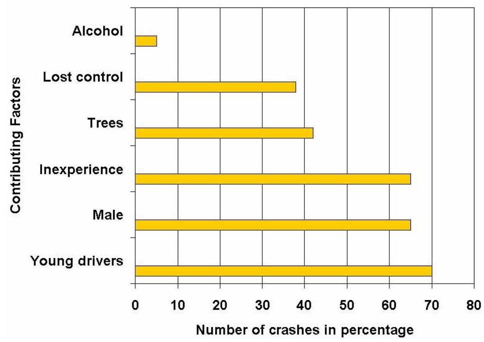

Figure 9. The list of contributing factors for Level Four.

The group of young drivers involved in Level Four of risk are 21 years of age with more male drivers are involved in the crashes. The maximum age is 41 years for this level. Another factor is the driving experience, where 9 or less years of driving increases the number of crashes. The remaining factors such as trees, lost of control and curves are similar factors to Level Two and Three. However, alcohol is an additional factor in Level Four. Alcohol can affect control and judgment when driving on the road. Risk increases when the driver drives in a curved road. Hence, when a male driver is between the age 21 and 41 and is alcohol intoxicated, the crash risk increases to level four.

Risk Level Five

Level Five is the maximum point of the risk scale and indicates the highest risk level. The crash claims cost for Level Five ranges from AUD$9734 to AUD$63,314 and 260 crash records are used. Figure 10 is the list of contributing factors for Level Five, expressed in percentage in terms of the total number of records used (n=260).

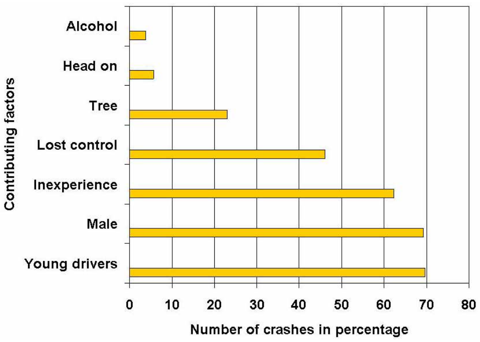

Figure 10. The list of contributing factors for Level Five.

Young drivers of 24 years of age and male drivers are the significant factor. The maximum age is 46 years of age. Drivers with 11 years of driving experience contribute to this level of risk. Then lost of control, trees, curves and alcohol are the other contributing factors. The additional factor is head-on type of crash. Head-on relates to possible causes such as lost of control, unintentional manoeuvre, fatigue, distraction, travels too fast in curves, and alcohol (NHTSA, 2006). Thus, the contributing factors to assess a driver with Level Five are when a driver is between 24 and 46 years of age or with 11 years of driving experience. Plus, other factors such as alcohol, speeding, fatigue, lost of control also increase the crash risk.

Table 2 summarizes the difference in the significant contributing factors for each risk level that was discussed in the previous sections. The comparison starts from Level Two and upwards to Level Five. Common factors are not listed in Table 2. From all the contributing factors in each level, the crash risk increases as alcohol consumption, and possible fatigue affects the driver performance in terms of alertness, reaction time, judgement and control over the vehicle.

Table 2.
Summary of the difference between the significant contributing factors for each risk levels.

Risk Levels	Contributing Factors
5	Fatigue, Speeding (Head-on related).
4	Alcohol, male drivers.
3	23 years of age drivers, 10 or less years of driving experience.
2	22 years of age drivers, 9 or less years of driving experience.
1	Presented in previous work (Chen, 2006).

CONCLUSION AND FUTURE WORK

Drivers are at risk when they start to drive their cars. The level of risk varies according to factors related to the environment, vehicle and driver. This paper analysed driver's related factors affecting crash risks.

The analysis of the insurance claim from an insurance database revealed that drivers are exposed to higher risk when they are young and/or with less than 10 years of driving experience. It also showed that crash risk decreases as young drivers obtain more driving experience (Government, 2005). Such findings are aligned with common knowledge about risk exposure of inexperienced drivers. Results also showed that drivers with 9 or less years of driving experience are exposed to a higher number of crashes on curves. A possible reason is that drivers have not developed their perception skill well and not able to handle risky situation as well as experienced drivers yet. Crash risk increases to level four or five when drivers consumed alcohol or are experiencing fatigue or driving in curve roads at high speed. The risk scale defined in this paper will be used to recommend advanced driving assistance interventions to drivers such as warnings or errors are automatically corrected by advanced mechanisms.

The records do not contain information about the curvature of the road, driver's speed at the time before the crash, driver's fatigue level or drug use. Thus, the information has to be obtained from sensors. The process of obtaining and analysing the sensor information will be carried out as part of the studies in the future.

The next step from here is to refine the risk scale with information from simulation as described in Figure 11.

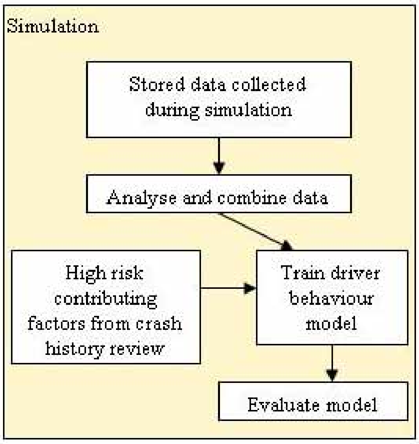

Figure 11. Overview of the simulation process.

A simulation session will be setup to collect information of driving behaviour in road curves. Then the information will be used to update and enhance the risk scale.

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