

# THE DEVELOPMENT OF RAILWAY LEVEL CROSSING SAFETY ASSESSMENT MODEL: A RESEARCH FRAMEWORK

*Siti Zaharah, I.*

*Transport Systems Centre, School of Natural & Built Environment,  
University of South Australia, Adelaide, Australia*

*E-mail : Siti.Ishak@postgrads.unisa.edu.au*

---

## ABSTRACT

This paper presents a research framework on the development of Railway Level Crossing (RLC) safety assessment model. Even though RLC accidents can be considered as a rare event, the impact is often severe. Since RLC safety systems are complex and dealing with at least two transport modes; Petri Nets approach will be applied in assisting the development of meaningful model. South Australia's situation is used as a case study for the purpose of this research. The components of basic concept of safety engineering; engineering infrastructure, level crossing surrounding environment and human factors will be also considered in the model.

**Key words:** Railway Level Crossing; Petri Nets; Safety Engineering

---

## 1. INTRODUCTION

Railway level crossing (RLC) accidents is one of the major contributing factors of railway related fatality problems in many countries. In Australia, safety issues at RLC are not very serious relative to those of developing countries. However, RLC accidents have continuously become a problem in railway industries in especially when it involved fatalities.

RLC is considered as a unique intersection. The systems are complex and dealing with at least two mode of transport. Therefore collision between motor vehicles and trains is likely to happen at RLC and cause catastrophic consequences (Chartier, 2000). The same element has been well discussed by Tustin (1986). Safety and the operational problems at RLC can be further classified into highway and railway. The highway component comprises drivers, pedestrians, vehicles and roadway segments, whereas the train component is classified into train and track at crossing locations. The functions and characteristics of the two components and their corresponding elements represent the risk at RLC locations. Various studies have been conducted in many countries, based on a range of issues associated with safety level at RLC.

Accident at RLC may be caused by a single factor or by the combination of many other factors. There is a growing realization of the need to consider contributory factors involved in accidents at RLC. Caird (2002) has recommended that emphasis need to be focused on the multiple contributors to accident at RLC rather than looking at a single factor only. As in basic safety engineering studies; there are at least three basic contributing factors need to be considered. There are engineering infrastructure, level crossing surrounding environment and human factors.

To address these issues, Caird (2002) discussed the angle and visibility aspects at RLC while other researchers studied factors associated with RLC due to familiarity, misjudgement and distraction(Caird, 2002, Wigglesworth, 1978). Additionally, the works of Caird (2002), and Harwood (1989) also argued the technical contributing factors related to the configuration and design of RLCs.

Various accident prediction equations and risk indexes were developed in order to cater for the problems at RLC. Study conducted by Saccomanno (2003) revealed two basic perspectives of model developed in the United States during 1950 to 1970. These were absolute model and the relative risk model. The absolute models denote the expected number of collision at a given crossing for a given period of time as developed by Coleman – Stewart (1976) and the US Department of Transportation (USDOT; Farr, 1987). Meanwhile the hazard index yield the relative risk of one crossing compared to another. Several relative risk indices have been developed; the Mississippi Formula (1970), the New Hampshire Formula (1971), the Ohio Method (1959), the Wisconsin Method(1974), Contra Costa Country Method (1969), the Oregon Method (1956), The North Dakota Rating System(1965), The Idaho Formula(1964), the Utah Formula (1971) and the City of Detroit Formula (1971). The US DOT model was generally recognized as the industry standard.

The analysis methods used range from Multiple Linear Regressions to techniques including special statistical distributions such as the Poisson and Negative Binomial distribution (Carson, 2001). However, past data is vital for analysis purposes. The lack of data in some countries (Gitelman, 1997) is a drawback of traditional approaches and leads to leave the problem of RLC untreated.

In this paper, a research framework on the development of RLC safety systems is presented. Firstly, the research highlights the issue related with RLC safety. The development of various models using traditional approach is highlighted. Secondly, the past research reviewed the factors contributing to RLC accidents. The transition of potential accident modelling from traditional approach to a more current approach in reliability and safety studies is presented. Finally, an improved methodological framework for the development of risk index in accessing the risk at RLC location is proposed. The Petri Nets approach will be applied in assisting the development of meaningful model. The components of basic concept of safety engineering; engineering infrastructure, level crossing surrounding environment and human factors will be also considered in the model.

## **2. LITERATURE REVIEW**

### **2.1 Factors contributing to accidents at RLC**

Most of the time, road user tends to be blamed in consequences of accidents at RLC. It is due to the verity that road user is likely to have defied traffic control devices, rules and traffic laws when crossing. Therefore engineers of highway and railway should also take into consideration the road user factors in order to plan and to design control devices or making any improvements at RLC. They should be aware of road user characteristics, capabilities, requirements, needs and obligations of road users. It is believed that they will help road user needs through proper engineering design of crossing installations and improvements (Tustin, 1986).

There are 3 main factors contributing to accidents at RLC in basic safety engineering studies,

- Human factor
- Engineering factor
- Environment factor

#### **Human factor (driver behaviour)**

Caird (2002) reported that many studies related with human factors contributing to accidents at RLC were conducted by many researchers mainly from Australia ( Wigglesworth, 2001); Sweden ( Aberg, 1988); Israel (Shinar, 1982) and the US (Klein 1994; Lerner 1990). Others include researchers from Netherlands (Tenkink, 1990) and UK (Ward, 1996).

Familiarity with crossings was one of the reasons identified as human factors. In a case study conducted by (Wigglesworth, 1978) he found that from the total of 85 fatal accidents occurred in

Victoria, Australia (1973 to 1977), 87 percent of accidents were due to road user familiarity of the RLC near their location especially if it was close to their residence or place of employment. The finding also shows that 68 percent from 87 percent, due to road user get through the RLC at least 4 times per week and another 19 percent used between 2 to 4 times per week.

Witte (2000) studied on the driving behaviour of 891 randomly selected residents in Michigan, USA. Approximately 10 to 20 percent from the total number of respondents tried to beat the train and it was considered as a risky behaviour. Most of the respondents involved were males who love to have a new experience and challenge themselves, engaged in such behaviour. However, the results suggest that due to their high sensation to beat a train can cause disappointment and misinterpretation on the crossing judgement.

Driver's behaviour such as slowing down vehicles on the approach of crossing remains as another contributing factor to accidents at RLC (Moon, 2003, Ward, 1996). A slower adopted speed applied at the same time of visual search present more time to deliberate over response options and thus extend exposure to a hazard. Other factors such as long wait times may lead drivers to engage in riskier behavior at crossings (Berg, 1982).

Caird (2002) cites the work of Lerner (1990) and NSTB (1998) in reviewing the driver behaviour at passive RLC. NSTB (1998) investigated that out of 60 accident cases, 49 cases were due to driver error. From 49 cases, 29 cases include driver disregard for the stop sign and failure to look for a train. The remaining cases related to roadway and track conditions and affecting the ability of the driver to realize the passive crossing ahead and the attendance of approaching train. It was due to reason that no element of this type of passive crossing changes to give warning an oncoming train. Drivers disobeying train-activated warning devices are one among the many causes of accidents at active RLC. Behaviors such as driving around a lowered crossing gate arm or ignoring the flashing lights are among the other deliberate decisions by drivers at active level crossing.

Several attempts have been made to compare the behaviour of drivers at active RLC with two different protection systems as a train approached and at flashing light only (Meeker, 1997, Aberg, 1988). Wigglesworth (1978, 2001) studied on the driver behaviour at both active and passive RLC in Australia.

## **Engineering factor**

Several studies have revealed that engineering factors includes highway and railway characteristics are the contributing factors to accidents at RLC.

Qureshi (2005) reported that there are nine important and significant variables in determining the blackspot location based on seven models which were most commonly used in United States. There are Annual Daily Traffic (ADT), Number of Passenger Trains, Stopping sight Distance Vs Recommended Sight Distance, Approached Sight Distance vs Recommended Sight Distance, Speed of Train, Total Numbers of Train, Speed of Highway Traffic, Number of Quadrants Sight is Restricted from and the Clearance Time.

Studied by Saccomanno (2003) showed that there is an unambiguous relationship between traffic volume on the road and the number of collisions at RLC. The number of collision rises as the number of traffic volume rises on the road. Others factors associated with RLC safety is the surface width of the road. Surface width affects vehicle-train collisions as well as among the vehicle collisions. Width can be used to reflect the number of lanes. An increase in the number of traffic lanes render into higher traffic volume on the road and produce greater chances for collisions at RLC. In addition, driver visibility usually decreases as traffic at highway-rail grade crossing increases.

Gau (2003) cites the works of Coghlan (1997), who found that sight lines and warning time approaches to crossing amongst the other factors affecting the safety level at RLC. Inadequate sight lines and warning times can generate perilous situation especially for long and heavy vehicles where most of the time the drivers have no control.

The factors involved in the traffic composition on road also have been discussed by Tardiff (2001). It was reported that the percentage of heavy vehicles involved in the accident at RLC was increased approximately 4% from 1990 to 2000 even though the number of accident originally has dropped by half from 1983 to 2000 in Canada. A similar situation had also accounted in US as highlighted by Harwood (1990). From 11 percent of road accident involving heavy vehicle in US, 20% occurred at RLC. Earlier studies by Tustin (1986), shows the statistics that the number of trucks in term of accident per million vehicle miles has contributed the highest relative hazard when compared to the other type of vehicles. However, motorcycles have a higher fatality rate. Perhaps it was due to the lack of operator protection provided by the motorcycle. Amongst other factors associated with railway characteristics that affect risk at highway-rail grade crossings include number of tracks, track angles, train speeds and number of trains per day.

Meanwhile, study conducted by Saccomanno (2003) showed that there are an adverse impact of train speed to the number of collision at RLC especially at sign crossings and flashing light crossings. The number of collisions at those location increases as the train speed increases. It is different at RLC that are equipped with gates. It was shown that numbers of tracks have an effect on collisions at RLC equipped with gates. With the increased number of trains daily, the number of collisions at RLC is expected to increase.

### **Environmental factors**

Earlier studies conducted by Meeker (1989) reported that in US, over 57 accidents occurred at RLC which activated by flasher, 56 cases involved visibility problems. It was due to the severe thunderstorm at location during the observation. Related work by Gau (2003) cites the work of Caird (2002) who reported that weather as another important factor of accidents occurred at passive RLC. Amongst the environmental factors affecting the visibility problems are snow, heavy rain, fog or blowing snow. The sun also can blind the drivers due to sun reflection caused by sunrise and sunset when drivers try to check the approaching train at RLC. The visibility problems also can occur as a result of sun reflecting windshields.

Caird (2002) has also investigated that 40% of the accident occurrence is between 9.30 a.m to 3.30 p.m during weekdays, normally during rush hours. January and December were the months with the highest accident occurrence whereas the lowest month was April.

## **2.2 Reliability in safety engineering studies**

Safety engineering and system engineering are linked. Both deal with complex systems and concerns with the accident occurrence within the system and can be best related to dependability studies. Dependability encompasses reliability, availability and safety. The term of system safety engineering involves a determination of safety hazards and assists with procedures to mitigate the problem condition. The application of scientific management and engineering principle is essential to control the hazard and optimize safety level through out the system stages. The risk management tool is important in reviewing the safety. Failure in identifying the risk and controlling the risk can result in detrimental effects for both human and economic factors.

Therefore, involvements of various professional disciplines are needed in dealing with accident prevention or safety engineering, in particular for RLCs. Safety engineers take an early design of a system, analyse it to find its faults and propose changes to make the system safer. Reliability must be designed into the system. Therefore incorporating reliability in safety is essential in order to ensure that the system work properly.

Reliability engineering techniques have been applied in safety studies related with RLC. Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) have been recommended as techniques for RLC safety assessment in the Asia Region (Transport and Tourism Division, 2000)

Vernez (2003) reviewed previous accidents models and analysis methods used in safety studies. Several types of analyses apply in reliability studies have been developed such as

Quantitative Risk Analysis (QRA) methods which includes Linear Chain of Events, Branched Event Chain; to a Multilinear Events Sequence, Catastrophic Theory, Hazard and Operability study, Fault Tree Analysis(FTA) and Event Tree Analysis(ETA). The Multilinear Event Sequences (MES) model introduced by Hendrick and Benneer in 1986 was postured as a powerful tool in accidents investigations at that time. Sequential Timed Events Plotting (STEP) method was used as an application of the MES model to accidents reconstruction within the transportation sector.

However, there are several limitations of FTA and ETA used in quantitative techniques in reliability engineering. The result always need to be relapsed to past safety performance statistics. Several other factors associated with RLC problems such as signal conspicuity, train speeds, human behaviour characteristics and sighting still questioned by practitioners. The limitations of STEP or FTA in the prospective analysis create uncontrolled number of possible accident paths. The limitation encountered has been overcome by a new computer tool developed such as Markov Chain and Petri Nets (Haile, 2006). The same things were reported by Nivolianitau (2004) , previously system engineers used ETA and FTA as their usual tools when dealing with safety and risk analyses. However, the use of Petri Nets is more convincing.

## 2.3 The application of Petri Nets

A Petri Net (PN) is known as a set of places, a set of transition net or P/T net is one of graphical and mathematical modeling tool invented by Carl Adam Petri in 1962. Petri Nets are a capable tool for specification and analysis of concurrent, asynchronous, distributed, parallel, nondeterministic and stochastic. Through graphical representations, Petri Nets can be used as visual communication aids similar to flow charts, block diagrams and networks. As a mathematical tool, the Petri Nets allow to set up state equations, algebraic equations and other mathematical models leading to an understanding on the behaviour of the system. The application areas of Petri Nets can be seen in the software design, workflow management, data analysis, concurrent programming, reliability engineering, etc.

Recently, the application of Petri Nets in the field of risk analysis and modelling has become the utmost interest in safety studies. It was due to Petri Nets large calculation capabilities and abilities overcomes the rigorous time and combinatory limitations problems encountered through the process in modelling (Vernez, 2003) . The recent exercises and applications of Petri Nets in risk analysis and accident modelling fields by several authors as indicated in *Table 1*. The advancement in Petri Nets such as Hierarchical nets, Stochastic Petri Nets (SPN) and Coloured Petri Nets (CPNs) are the greatest interest in safety related application.

Therefore, various studies of using Petri Nets approach in railway safety have been conducted by many researchers in looking into various factors. CPN applied to investigate the functional correctness and performance of the railway networks systems (Janczura, 1998, Jansen, 1998, Fanti, 2006), consistency and safety of operational & technical devices at RLC (Einer, 2000) and in communication based train control (CBTC) system to increase track utilisation and safety (Xu, 2007).

Most of the work that used a Petri Nets approach in the area of train control systems deals with qualitative aspects like validation of correctness and absence of forbidden safety-critical states. Yet in real-time systems likes a distributed communication-based train control systems, critical safety questions can only be answered when quantitative aspects are considered and evaluated. Failures and other external influences on the model require stochastic model values, but fixed values for deadlines or known processing times are equally important. Modelling and evaluation techniques need to support both to be applicable in this area.

Petri Nets and their stochastic timed extensions have proven to be a useful formalism for real-time systems. They are considered to describe event systems in concise and appropriate way (Zimmermann, 2003). Therefore, the use of SPN and stochastic timed extension methods also have been continuously become an interest of a group of researches from Germany. The motivation towards the establishment of model called ProFUND model; aims to the harmonization of different safety cultures and obtains cross acceptance in the Railway Domain

in Europe. The ProFUND methodical design concept is based on Process, FUNCTIONal and Dependability modelling. The approach used in order to describe the railway control process, the function of the railway control systems and the system's function dependability (Slovak, 2003). From the basic ProFUND model, there are also other factors included in the model such as human behaviour at level crossings by using Extended Deterministic and Stochastic Petri Nets (EDSPN) (Slovak, 2007).

However, previous studies looking into the main events or scenarios that lead to accidents at RLC (top level event) and it is seen as limiting the understanding of the causes of incidents and precursors. Therefore in order to fill in the gap, an improved methodology proposed in this paper is more into the understanding not only the top level event but also the contributing events which lead to the main event. All events and sub events will be further categorized into various factors including engineering infrastructure, level crossing surrounding environment and human factors.

**Table 1** The use of Petri Nets tools in the field of safety

Reference	Modelled	Petri Nets	Results
El Koursi, 1992	State of Space	PN	Safety Data
Brummer et.al., 1994	State of Space	PN	Safety Data
Malhotra and Trivedi, 1995	Events and Logical Gates	GSPN-SRN	Failure Data
Balakrishnan and Trivedi, 1996	State of Space	SRN	Reliability Data and Critical Paths
Katsumata et.al., 1996	State of Space	PN	Failure Diagnosis
Sziics et al., 1996	Objects, Modes and Failure Modes	CPN	Critical Pathways
Cordier et.al., 1997	State of Space	SPN	Reliability Data
Dutuit et.al., 1997	State of Space with stochastic transitions	SPN	Reliability Data
Ereau et.al., 1997	State of Space with stochastic transitions	Timed PN	Reliability Data
Liu and Chiou, 1997	Events and Logical Gates	PN	Failure Data
Marier et.al., 1997	State of Space with stochastic transitions	GSPN	Reliability Data
Rochdi et.al., 1999	Events and Logical Gates	PN	Failure Data
Rudas and Horvath, 1997	Objects and Modes	PN	Dynamic Behaviour Data
Yoshikawa et.al., 1997	State of Space	CPN	Safety Data
Srinivasan and Venkata	State of Space	PN	Safety Data
Wang and Wu, 1998	Objects and Modes	CPN	Dynamic Behaviour
Yang and Liu, 1998	Events and Logical Gates	PN	Failure Data
Vernez, 1999a, 1999b	Accident Events Sequences	CPN	Safety Data, critical
Kontogiannis et.al., 2000	State of Space	PN	Reliability Data and Critical Paths

Source: from Vernez (2003)

### 3. THE PROPOSED RESEARCH DESIGN

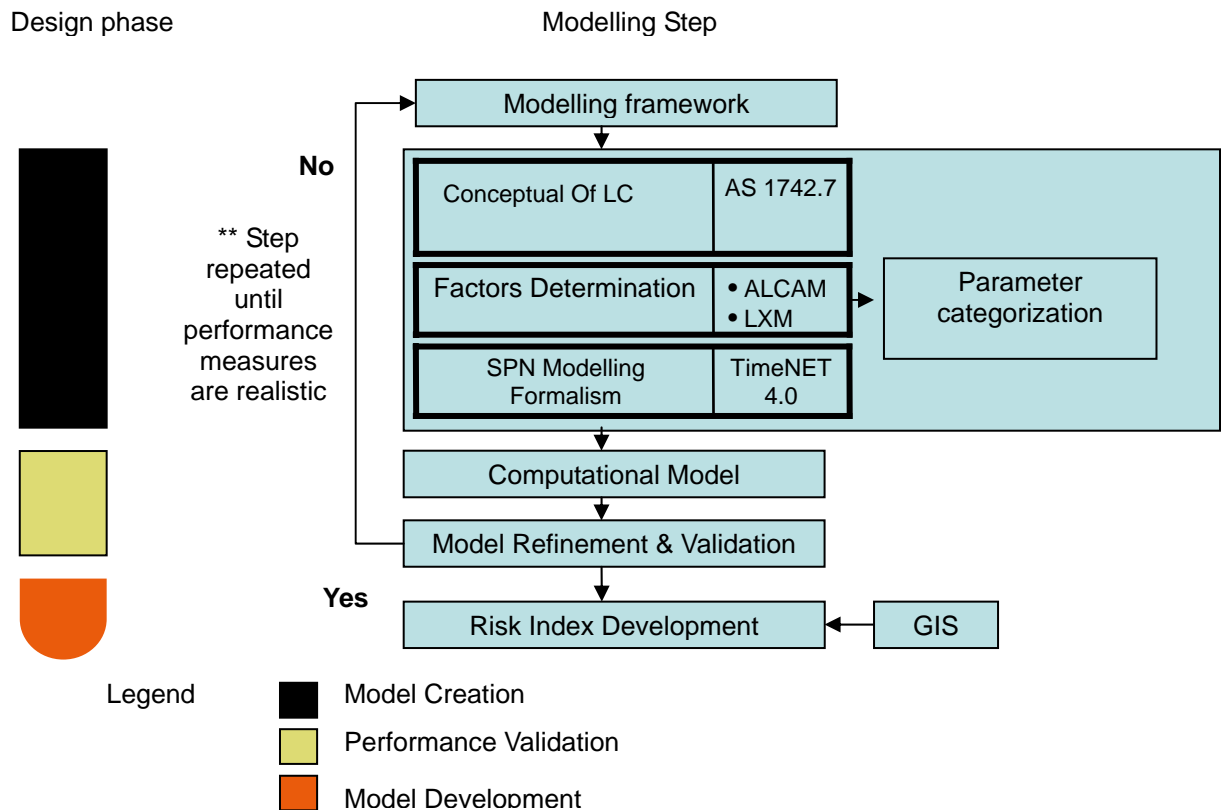
In this section, the framework for the methodology development in assessing the level of risk at RLC locations is described in *Figure 1*. The purpose of the framework is to form the foundation of

the research design steps for further discussion. The design phases and the modelling steps are illustrated by stages.

There are three phases involved in this modelling process. Firstly, model creation phase requires an understanding on the RLC operation, current practise and tools available for analysis.

The case study of this research will cover active types of RLC in South Australia. Therefore, the understanding of the overall concept of active types of RLC operations is needed. The basis of understanding of RLC operation obtained from the Australian Standard; Manual of Uniform Traffic Control Devices, Part 7: Railway Crossing (AS 1742.7- 2007).

ALCAM is widely used in Australia and all data gathered in the Level Crossing Management Systems (LXM). Permission will be obtained from the ALCAM committee in order to use their data in the studies. All data will be categorised according to category as illustrated in *Figure 3*. There are few studies using SPN and its extension dealing with safety study at RLC. By referring to the research gap, an improvement will be made in terms of the parameter consideration and categorisation. The engineering infrastructure, level crossing surrounding environment and human factors will be the factors considered.



**Figure 1:** An improved methodology development framework

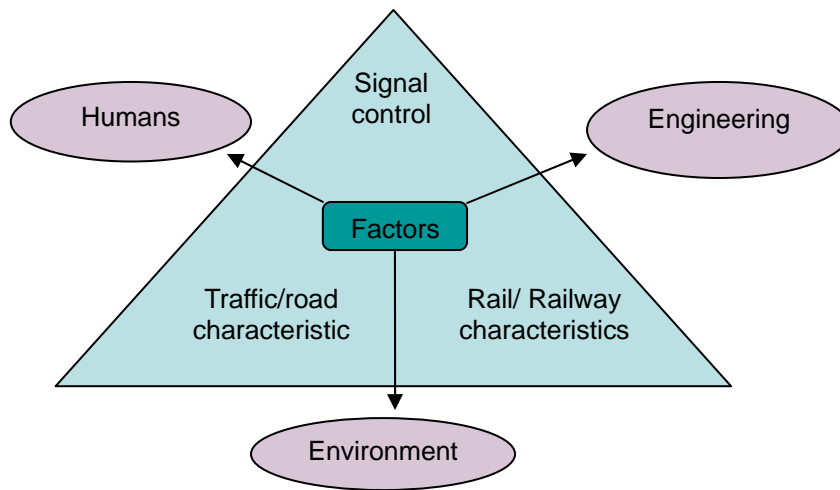
The latest version of TimeNET 4.0 will be used in the studies. It is a graphical and interactive toolkit which has been developed at the Real-Time Systems and Robotics group of Technische Universität Berlin, Germany (<http://pdv.cs.tu-berlin.de/>). TimeNET was designed for modelling Stochastic Petri Nets (SPNs) and Stochastic Coloured Petri Nets (SCPNS) (Zimmermann, 2007). SPNs and SCPNs will be considered as the modelling techniques in these studies.

Secondly, the performance validation phase involves computational of the model design and the model refinement and validation process. Refinement of a model is necessary to ensure the model works properly based on SPN specification requirements. The process will be repeated until the performance measure is realistic. Based on the framework discussed above, the model needs to be implemented and evaluated; therefore real life cases will be used to calibrate the model.

Lastly, Geographic Information System (GIS) will be applied to support the Risk Index development process. GIS offers a spatial representation of risk and location of RLC in the cases study area. GIS will provide the function of aggregate land use and physical environment around the RLCs.

### 3.1 Estimation of Parameter

The parameter considered will be categorized according to various factors. There are engineering infrastructure, level crossing surrounding environment and human factors as in *Figure 2*.



*Figure 2: The categorization of parameter*

All data obtained from LXM will be further classified and categorised into factors considered in the model. The basic elements of RLC are signal control, roadway characteristics and railway characteristics. There has been issues of the focus on top level event applied in reliability studies is seen as limiting the understanding of the causes of incidents and its foundation. Therefore, in this study further classification will be made in order to ascertain the sub contributing factors that can cause accidents at RLCs.

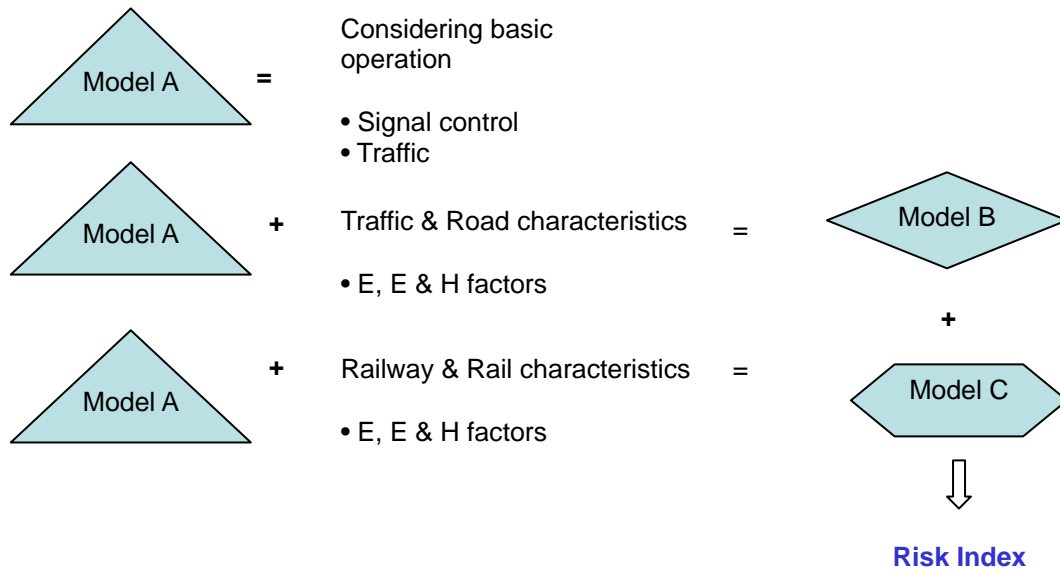


Figure 3: RLC risk index modelling stages

Figure 3 indicates the risk index modelling stages. The structure for the risk index development process will be based on the separation of RLC characteristics. Firstly, model A will be considering the basic operation involving signal control, railway and highway elements. Secondly, model B will be the combination of model A and traffic/ road characteristics. Thirdly, model C will be the combination of model A and railway and rail characteristics which have been further categorised by different factors; Engineering, Environment and Human factors.

The combination of models B and C will represent the possible event and scenarios. In this regard, two possible scenarios will be identified; desired events and undesired events. The scenarios themselves will be represented by possible marking of the corresponding Petri Nets places and transition process.

The application of the modelling process is possible only if suitable software tools, allowing the construction and subsequent analysis of the model are available. For the purpose of this modelling process, the latest version of TimeNET version 4 will be used as a tool in this research.

#### 4. DISCUSSION & CONCLUSION

In Australia, RLC accidents are still continuing and become the great concern in railway industries in especially when it involved fatalities. This paper describes a research framework in developing RLC safety systems specifically for South Australia's as a case study. The proposed research design in developing a risk index is outlined. The parameter considered will be justified during the model development stages. Since RLC safety systems is complex, the used of PN approach in reliability safety engineering studies will be applied in order to have better understanding on the behaviour of the systems. The components such as engineering infrastructure, level crossing surrounding environment and human factors considered in the model can help in selecting a sound alternative for selected location for further improvements.

#### ACKNOWLEDGEMENTS

The authors would like to thank Mr. Derek Henekar (Manager), Mr. Peter Furnell (Information Manager) from Rail Safety Department and Mr Graham Cook (Chief Project Officer) from Level Crossing Unit, Department for Transport , Energy and Infrastructure, South Australia for allowing us to access and utilise the database for the purpose of this research. We would also like to

acknowledge Mr. Matthew Hart, Delivery Manager SA/WA – Asset Management from ARTC for his valuable information in railway operation.

## REFERENCES

- ABERG, L. (1988) Driver Behavior at Flashing-Light, Rail-Highway Crossings. *Accident Analysis & Prevention*, 20, 59-65.
- BERG, W. D., KNOBLAUCH, K AND HUCKE, W (1982) Causal Factors in Railroad-Highway Grade Crossing Accidents. *Transportation Research Record*, p.47-54.
- CAIRD, J. K., CRESER, J.I., EDWARDS, C.J., DEWAR, R.E. (2002) A Human Factors Analysis of Highway-Railway Grade Crossing Accidents in Canada. *Fourth Workshop on Highway-Railway Grade Crossing Research* Montreal, Quebec, Transportation Development Centre, Publication Distribution Services.
- CARSON, J., MANNERING, F. (2001) The Effect of Ice Warning Signs on Ice-Accident Frequencies and Severities. *Accident Analysis & Prevention*, vol.33, p.99-109.
- CHARTIER, P. (2000) Level Crossing Safety in Countries of the Asia-Pacific Region. 22 *ASEAN Railway General Managers' Conference*. Yangon, Myanmar.
- EINER, S., SLOVAK, R., SCHNIEDER, E. (2000) Modelling Train Control Systems with Petri Nets - An Operational Specification, *IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC'2000)*. Nashville, TN.
- FANTI, M. P., GIUA, A., SEATZU, C. (2006) Monitor Design for Colored Petri Nets: An Application to Deadlock Prevention in Railway Networks. *Control Engineering Practice*, vol.14, p.1231-1247.
- GITELMAN, V., HAKKERT, A. S. (1997) The Evaluation of Road- Rail Crossing Safety with Limited Accident Statistics. *Accident Analysis & Prevention*, vol.29, p.171-179.
- GOU, M., BELLAVIGNA-LADOUX, O. , DUMONT-MACKAY, E. (2003) Impact of Heavy Vehicles on Crossing Safety-Development of an Adapted Design Tool. Transportation Development Centre (TDC), Montreal, Quebec.
- HAILE, J., HESS, T. (2006) The Event Window - Modelling Risk at Level Crossings, *Conference of Railway Engineering*. Melbourne.
- HARWOOD, D. W., GLAUZ, W D & MASON, J M (1989) Stopping Sight Distance Design for Large Trucks, *Transportation Research Record*, 1208.
- JANCZURA, C. W. (1998) Modelling and Analysis of Railway Network Control Logic using Coloured Petri-nets. *The School of Mathematics*. Adelaide, University of South Australia.
- JANSEN, L., MEYER ZU HORSTE, M., SCHNIEDER, E (1998) Technical Issues in Modelling the European Train Control System(ETCS) using Coloured Petri Nets and the Design/CPN Tools, IN K. JENSEN, E., WORKSHOP ON PRACTICAL USE OF COLOURED PETRI NETS AND DESIGN/CPN (Ed.) *DAIMI PB - 532*. Denmark, Department of Computer Science, University of Aarhus
- MEEKER, F., FOX, D., WEBER, C. (1997) A Comparison of Driver Behavior at Railroad Grade Crossings with Two Different Protection Systems, *Accident Analysis & Prevention*, 29, 11-16.
- MEEKER, F. L., BARR, R. A. (1989) An Observational Study of Driver Behavior at a Protected Railroad Grade Crossing as Trains Approach, *Accident Analysis & Prevention*, 21, 255-262.
- MOON, Y. J., COLEMAN, I. I. I. F. (2003) Dynamic Dilemma Zone Based on Driver Behavior and Car-Following Model at Highway-Rail Intersections, *Transportation Research Part B: Methodological*, vol.37, p.323-344.
- NIVOLIANITOU, Z. S., LEOPOULOS, V. N., KONSTANTINIDOU, M. (2004) Comparison of Techniques for Accident Scenario Analysis in Hazardous Systems, *Journal of Loss Prevention in the Process Industries*, 17, 467-475.
- QURESHI, M., AVALOKITA, S., YATHAPU, N. (2005) A Framework for Assessing Models that Rank Highway-Rail Grade Crossings for Improvement. *Journal of Transportation Engineering*, 131, 352-357.
- SACCOMANNO, F., FU, L., REN, C., MIRANDA, L. (2003) Identifying Highway-Rail Grade Crossing Black Spots in Canada; Phase 1 *TP 14168E*. Montreal Quebec, Transportation Development Centre, Transport Canada

- SLOVAK, R., WEGELE, S., SCHNIEDER, E. (2007) Holistic Modelling And Safety Analysis Of Railway Systems By Example Of A Level Crossing Protection. *Proceedings of the 15th Symposium of the EURENEX ZEL*.
- SLOVAK, R. M., J.; SCHNIEDER, E.: (2003) Profund Modelling for Holistic Risk and Availability Analysis by Means of Stochastic Petri Nets Applied to a Level Crossing Control System, Formal Methods for Railway Operation and Control Systems, *Symposium FORMS 2003*. Budapest, 2003.
- TARDIF, L. P. (2001) Grade Crossing Contraventions and Motor Carrier Safety Assessment Transportation Development Centre (TDC), Montreal, Quebec.
- TENKINK, E., VAN DER HORST, R. (1990) Car Driver Behavior at Flashing Light Railroad Grade Crossings. *Accident Analysis & Prevention*, vol.22, p.229-239.
- TRANSPORT AND TOURISM DIVISION (2000) Evaluation of Cost Effective Systems for RLC Protection.
- TUSTIN, B. H., RICHARDS, H., MCGEE, H., PATTERSON, R. (1986) Railroad- Highway Grade Crossing Handbook. *FHWA-TS-86-215*. Federal Highway Administration.
- VERNEZ, D., BUCHS, D., PIERREHUMBERT, G. (2003) Perspectives in the Use of Coloured Petri Nets for Risk Analysis and Accident Modelling. *Safety Science*, 41, 445-463.
- WARD, N. J., WILDE, G. J. S. (1996) Driver Approach Behaviour at an Unprotected Railway Crossing Before and After Enhancement of Lateral Sight Distances: An experimental Investigation of A Risk Perception And Behavioural Compensation Hypothesis. *Safety Science*, vol.22, p.63-75.
- WIGGLESWORTH, E. C. (1978) Human Factors in Level Crossing Accidents, *Accident Analysis & Prevention*, vol.10, p. 229-240.
- WITTE, K., DONOHUE, W. A. (2000) Preventing Vehicle Crashes with Trains at Grade Crossings: The Risk Seeker Challenge, *Accident Analysis & Prevention*, vol. 32, p.127-139.
- XU, T., TANG, T. (2007) The Modelling Analysis of Data Communication System (DCS) in Communication Based Train Control (CBTC) with Coloured Petri Nets. *Eight International Symposium on Autonomous Decentralized Systems (ISADS'07)*.
- ZIMMERMANN, A., HOMMEL, G (2003) A train Control Systems Case Study in Model-Based real Time System Design. *International Parallel and Distributed Processing Symposium (IPDPS'03)*
- ZIMMERMANN, A., KNOKE, M. (2007) TimeNET 4.0; A Software Tool for the Performability Evaluation with Stochastic and Coloured Petri Nets, *User Manual, Faculty of EE & CS Technical Report 2007 - 13*. Berlin, Germany, Real- Time Systems and Robotics Group, Technische Universität Berlin.