The methodology development of railway level crossing safety systems – South Australia case study

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Abstract

Railway level crossing accident is one of the major contributing factors of railway related fatalities in many countries. Even though railway level crossing accidents can be considered as a rare event, the impact is often severe. In Australia, safety issues at railway level crossing are not very serious relative to those of developing countries. However, railway level crossing accidents have continuously become a concern in railway industries in especially when it involved fatalities.

This paper presents a methodological development proposed for railway level crossing safety systems and South Australia's situation is used as a testing case. Due to the complex nature of railway level crossing safety systems; Petri Nets approach will be applied in assisting the development of a meaningful evaluation model. The components of basic concept of safety engineering; engineering infrastructure, level crossing surrounding environment and human factors will also be considered in the model.
Keywords: railway level crossing; safety engineering; petri nets.

1 Introduction

Railway Level Crossing (RLC) accident is one of the most serious safety issues faced by the rail system in Australia. Even though the occurrence of accidents at RLC has fewer fatalities compared to other countries such as New Zealand, United States and Finland, it continues to be the largest single cause of fatalities from rail activity. The lost due to RLC accidents is very significant and giving a huge negative impact on Australian economy [1].

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RLC accidents are amongst the most complex issues in rail operations, due to its multi reactions dealing with at least two modes of transport and surrounding environment. The function and characteristics of those components and their corresponding elements contribute to the risk at RLC locations. In most cases, the contributing factors can be difficult to identify. In overcoming such difficulties, researches have attempted numerous efforts in developing methodologies and countermeasures to RLC safety problems.

Intuitively, RLC accidents are perceived to be a result of a single factor or a combination of a few others. In rail safety engineering, factors associated with RLC accidents are human errors (both rail and others), engineering infrastructure and RLC surrounding environment.

The reasons associated with human errors (vehicle driver) related to the familiarity to the crossings [2], trying to beat the train [3], slowing down vehicles on the approach of crossing [4, 5] and other factors such as long wait times may lead drivers to engage in riskier behavior at crossings [6].

Several studies have revealed that engineering factors such as highway and railway elements at RLCs also contributing to the fatalities. Saccomanno *et al.* [7] discussed factors such as traffic volume, number of highway lanes, number of railway tracks and the speed of vehicles and train, that increased the possibility of collisions at RLCs. In addition, the other factors such as drivers' visibility that usually decreased as traffic increased at RLCs. Gau *et al.* [8] cited the works of Coghlan (1997), who found that sight distance and warning time when approaching to the crossing are amongst other factors affecting the safety level at RLCs. Inadequate sight distance and warning time can result in a perilous situation especially for long and heavy vehicles where most of the time the drivers have limited control. The concerns related to surrounding environment was due to visibility problems [9], weather and sun reflection caused by sunrise and sunset, time of the day especially during weekdays and rush hours [10].

A literature review revealed that various RLC accidents prediction equations and risk indexes have been developed to enhance the understanding of accidents occurrence at RLCs [11, 12]. The classical approach requires the accumulated past RLC accident data for a statistical model. However, there were several problems encountered by using the classical approach. The use of a linear regression model [12, 13] has led to the adoption of Poisson Regression, Negative Binomial and Zero inflated models. However, the problem of 'excess' zeros leads to dispersion. The dispersion resulted from low exposure (train frequency and/train volumes), high heterogeneity in crashes, observation periods relatively small or under reporting of near-crashes. Another problem not often observed with crash data is underdispearsion. Underdispearsion is a phenomenon which has been less convenient to model directly than overdispearsion mainly because it is less common observed. Winkelmann's gamma probability count model offers an approach for modeling underdispearsion (or overdispearsed) count data. However, past data is vital for analysis purposes. The lack of data in some countries [14] is a drawback of the classical approaches and leads to leave the RLC problems untreated.

This paper aims at the methodology development of a RLC safety assessment model. A new approach in RLC safety modeling techniques is proposed as an improved method in dealing with safety at RLC, in particular for South Australia cases.

1.1 Research background

There are two types of RLC categories exist in Australia: active and passive. Active RLCs have signals and/or boom gates which operate automatically when a train is approaching, whereas passive RLCs have signs and/or pavement markings only. This research covers active types of RLC in South Australia only. The understanding of the overall operation for the active type of RLC situations will help the passive cases as well. The operation of active RLCs is based on the Australian Standard: *Manual of Uniform Traffic Control Devices, Part 7: Railway Crossing (AS 1742.7- 2007).*

In Australia, the efforts in improving RLC safety have led to the establishment of an Australian Level Crossing Assessment Model (ALCAM). This model is a risk evaluation tool, which consistently assesses the characteristics of each element at RLCs locations; to effectively determine priorities when addressing safety risks at sites for both roads and pedestrians. The ALCAM process considers all elements outlined in the *Australian and New Zealand Standard; AS/NZS 4360:2004* and replaces the 1990's *VicRoads Railway Level Crossing Prioritisation Model.* ALCAM is widely used based on all data gathered from the Level Crossing Management Systems (LXM).

Even though the ALCAM model is widely applied throughout Australia, it is still under development to its full capacity. In this study, the use of Petri Nets as a new approach in RLC safety evaluation, is believed to better represent the accident potential at a level crossing. The factors considered are: engineering infrastructure, level crossing surrounding environment and human factors.

2 Methodological concept

2.1 The proposed methodological framework

This section describes the methodological framework in assessing the level of risk at RLC locations. The structure and purpose of the framework forming the foundation of the research design steps are presented in Figure 1. The design phases and the modeling steps are illustrated by stages according to the nature of the considered elements.

The modeling process includes three phases, namely conceptual creation, performance validation and model development. The conceptual creation phase requires an understanding on the RLC operation, current practices and tools available for analysis. The performance validation phase involves computation of the design model and model refinement and a validation process. A refinement of the model is necessary to ensure the model would be functioning effectively based on Stochastic Petri Nets (SPN) specification requirements. This process will be repeated until the performance measure is satisfied. Based on the framework, the model needs to be implemented and evaluated; therefore real life cases could be used to calibrate the model.

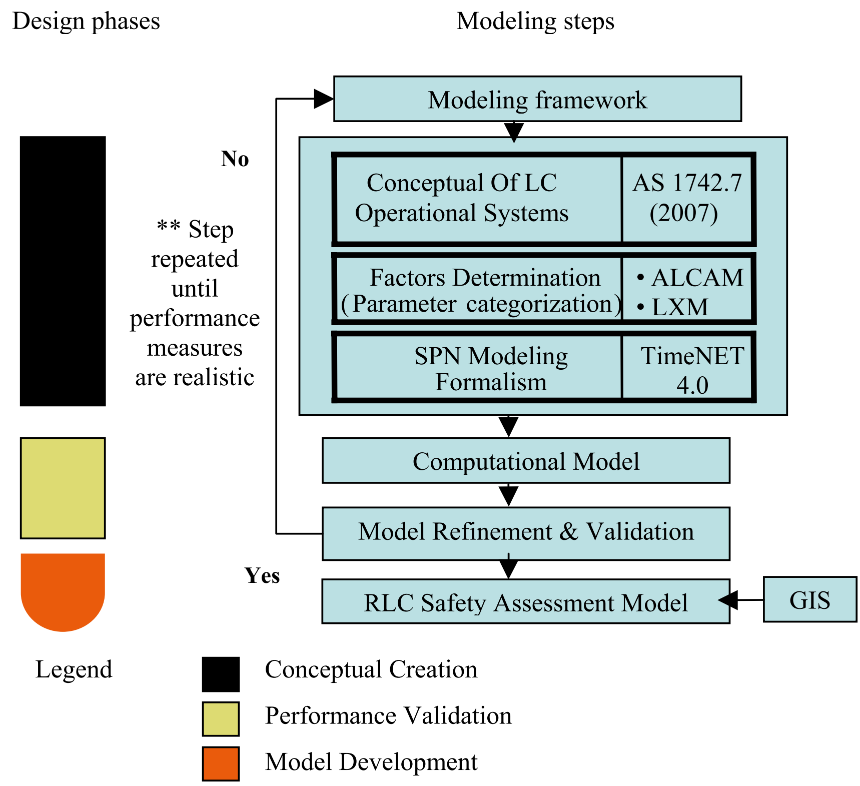

Figure 1: An improved methodology development framework.

The third phase, model development applies Geographic Information System (GIS) to support the RLC safety assessment model, considering land use and population characteristics near the RLCs.

2.2 Parameter characterisation

All obtained data from LXM will be further classified and categorised according to the elements included in the model. The basic elements of RLC are signal control, roadway characteristics and railway characteristics.

In general, RLC experiences three phases of independent operation; train approaching to RLC, opening the gate to train and stopping of traffic at RLC. The concurrent operation of tasks is needed to ensure that train passes through RLC safely. These scenarios can be categorised as the desired event and focussing on the top level event. However, since there have been issues of focus on top level events applied in reliability studies is seen as limiting the understanding of the causes of incidents and its foundation. Therefore in this model development stages, further classification and extension of parameter will be made in order to ascertain the sub contributing factors (sub event) that can cause potential accidents at RLCs. The sub factors to be considered in this research are focussing on three major factors; engineering infrastructure, level crossing surrounding environment and human factors. These three factors have been discussed broadly in past literature.

<table>
<tr><td>MODEL 1</td><td colspan="3">Basic operation
Signal control + traffic/road characteristics + train/ railway characteristics.</td></tr>
<tr><td>MODEL 2</td><td colspan="3">MODEL 1 + traffic/road characteristics.</td></tr>
<tr><td>Factor</td><td>Engineering infrastructure
- Geometric design & road characteristics
- Traffic characteristics</td><td>Level crossing surrounding
- Visibility problems
- Weather
- Land use
- Etc.</td><td>Human
- Familiarity with crossing
- Beat the train
- Slowing down vehicle approaching. RLC, etc.</td></tr>
<tr><td>MODEL 3</td><td colspan="3">MODEL 1 + train/ railway characteristic</td></tr>
<tr><td>Factor</td><td>Engineering infrastructure
- Geometric Design & crossing characteristics.
- Train characteristics.</td><td>Level crossing surrounding
- Visibility problems
- Weather
- Land use
- Etc.</td><td>Human
- Fatigue
- Etc.</td></tr>
<tr><td>MODEL 4</td><td colspan="3">MODEL 2 + MODEL 3
= RLC Safety Assessment Model</td></tr>
</table>

Figure 2: RLC safety assessment modeling stages.

Figure 2 indicates the RLC safety assessment modeling stages. The structure for the model development process will be based on the separation of RLC characteristics. Firstly, Model 1 considers the basic operations involving signal control, railway and highway elements. Secondly, Model 2 combines of Model 1 and traffic/ road characteristics. Thirdly, Model 3 combines of Model 1 and railway /train characteristics. All elements considered will be further categorised by different factors; engineering infrastructure, level crossing surrounding environment and human factors.

Finally, Model 4 will be the combination of Models 2 and 3. It represents the possible events 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 high level Petri Nets; Stochastic Petri Nets and its extension will be applied.

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

3 Analysis method

3.1 Stochastic Petri Nets

Petri Nets is a set of places or transition net or a graphical and also a mathematical modeling tool which was invented by Carl Adam Petri in 1962. Petri Nets is a capable tool for specification and analysis of concurrent, asynchronous, distributed, parallel, nondeterministic and stochastic processes. Through graphical representations, Petri Nets can be used as a visual communication aid similar to flow charts, block diagrams and networks. As a mathematical tool, the Petri Nets is allowed to set up state equations, algebraic equations and other mathematical models leading to an understanding of the system behavior.

Although the original model of Petri Nets is often sufficient compared to model real systems, it has rapidly appeared that various extensions are necessary to what is needed to model the average systems. Several extensions have been suggested which are directed at expressiveness of repeated similar situations, time information, probability and structuring. Therefore, various extensions such as Coloured Petri Nets (CPN), Timed Petri Nets (TPNs), Stochastic Petri Nets (SPN), Generalised Stochastic Petri Nets (GSPN) have been developed.

Several reasons of using Stochastic Petri Nets as an appropriate analysis technique in this research are due to the advantages of their graphical format for system design and specification and its facility to describe synchronisation in concurrent events. Meanwhile, the possibility and existing rich theory for functional analysis offered by using Petri Nets and its natural way in which time can be added to determine quantitative properties of the specified systems are the other benefits of using Stochastic Petri Nets [15].

The specialities of Stochastic Petri Nets in dealing with qualitative and quantitative type of analysis allows for proving functional, performance and safety properties of the system describe by net. The qualitative analysis allows state space investigations and can be used for validation of developed models. Meanwhile the quantitative analysis offered safety and performance evaluation. This allows predictive calculations of state probabilities or event occurrence rates in reference to a particular point in time or in the steady state of the modelled systems behaviour. The inherent mathematical background of Petri Nets offers the application of several analytic and simulation based evaluation methods [16].

In a simple example, Petri Nets used for the description of discrete events systems in a causal and temporal view. Places can be best interpreted as local systems states (conditions for events) in systems behaviour and transitions representing events which take place on the systems. The occurrence of an event is modelled by firing of a transition, which is enabled if its input places are marked where the local states are satisfied that allow the event occurrence. When a transition fires, a mark is removed from each input place and a mark is inserted in each output place, leading the systems into a new state. The set of all marked places, considered at any time during the system's lifetimes represents the global state of modelled system. The Petri Nets model represents a static structure as well as the dynamic behaviour of the modelled systems

3.2 TimeNets

Modeling and evaluation of complex systems and real time systems are only feasible with the support of appropriate software tools. The latest version of TimeNET 4.0 will be used in this study. 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 modeling Stochastic Petri Nets (SPNs) and Stochastic Coloured Petri Nets (SCPNs) [17]. SPNs and SCPNs will be considered as the modeling techniques in these studies.

3.3 GIS

The final phase of this study will incorporate the modelling output into Geographic Information Systems (GIS). GIS will offer the spatial representation of a particular RLC location of RLC in the case study area. GIS provides the function of aggregate land use and physical environment around the RLCs.

4 Conclusion

In this paper, the issue of conventional methods in dealing with RLC accidents was discussed. Even though the conventional approach has proven some solutions in reducing accidents at RLC, the fatality rate is still continuing to be the greatest concern in railway industry in Australia. Therefore, this paper describes a methodological framework in developing a RLC safety assessment model and using data from South Australia's as a testing case. The development of a RLC safety assessment model will apply Stochastic Petri Nets to assess the performance and reliability of RLC location. The model will include related elements in RLC systems such as signal control, train and traffic characteristics. To understand the factors contribute to the failures at RLCs, the components such as engineering infrastructure, level crossing surrounding, human factors and nearby land use will be examined. With the improved methods using Stochastic Petri Nets, it is believed that the model can help in selecting sound alternative in prioritising locations for improvements or upgrade. The application of GIS in spatial representation of RLC locations will link model output with visualisation of the surrounding land use environment, and further enhance the understanding of RLC accident phenomena.

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References

[1] Australian Railway Association. Rapid Government Actions on Level Crossing Safety Welcomed. In: 2007.

[2] Wigglesworth, E.C., Human factors in level crossing accidents. *Accident Analysis & Prevention*, (10), pp. 229–240, 1978.

[3] Witte, K. & Donohue, W. A., Preventing vehicle crashes with trains at grade crossings: the risk seeker challenge. *Accident Analysis & Prevention,* (32), pp.127–139, 2000.

[4] Moon, Y.J. & Coleman, I. I. I. F., Dynamic dilemma zone based on driver behavior and car-following model at highway-rail intersections. *Transportation Research Part B: Methodological,* (37), pp. 323–344, 2003.

[5] Ward, N.J. & Wilde, G. J. S., 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*, (22), pp. 63–75, 1996.

[6] Berg, W.D., Knoblauch, K. & Hucke, W., Causal factors in railroad-highway grade crossing accidents. *Transportation Research Record*, pp. 47–54, 1982.

[7] Saccomanno, F., Ren, C., Fu, L. & Miranda, L., Identifying highway-rail grade crossing black spots: phase 1. In: Transportation Development Centre (TDC), Montreal, Quebec, 2003.

[8] Gou, M., Bellavigna-ladoux, O. & Dumont-Mackay, E., Impact of heavy vehicles on crossing safety-development of an adapted design tool. In: Transportation Development Centre (TDC), Montreal, Quebec, 2003.

[9] Meeker, F.L. & Barr, R. A., An observational study of driver behavior at a protected railroad grade crossing as trains approach. *Accident Analysis & Prevention*, (21), pp. 255–262, 1989.

[10] Caird, J.K., Creaser, J.I., Edwards, C.J. & Dewar, R.E., a human factors analysis of highway-railway grade crossing accidents in Canada. In: Fourth Workshop on Highway-Railway Grade Crossing Research Montreal, Quebec, Transportation Development Centre, Publication Distribution Services, 2002.

[11] Austin, R.D. & Carson, J.L., An alternative accident prediction model for highway-rail interfaces. *Accident Analysis & Prevention*, (34), pp. 31–42, 2002.

[12] Oh, J., Washington, S. P. & Nam, D., accident prediction model for railway-highway interfaces. *Accident Analysis & Prevention*, (38), pp. 346–356, 2006.

[13] Miaou, S.P. & Lum, H., modeling vehicle accidents and highway geometric design relationships. *Accident Analysis & Prevention*, (25), pp. 689–709, 1993.

[14] Gitelman, V. & Hakkert, A. S., The evaluation of road- rail crossing safety with limited accident statistics. *Accident Analysis & Prevention*, (29), pp 171–179, 1997.

[15] Falko, B. & Pieter, S. K., Stochastic Petri Nets; an introduction to the theory. Braunschweig/Wiesbaden, Germany: Vieweg; 2002.

[16] Slovak, R. , Wegele, S. & Schnieder, E., Holistic modeling and safety analysis of railway systems by example of a level crossing protection. *Proceedings of the 15th Symposium of the EURENEX ZEL*, 2007.

[17] Zimmermann, A. & Knoke, M., TimeNET 4.0, a software tool for the performability evaluation with stochastic and coloured Petri Nets. In: User Manual, Faculty of EE & CS Technical Report 2007 - 13. Berlin, Germany: Real- Time Systems and Robotics Group, Technische Universität Berlin, 2007.