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Level Crossing Modelling Using Petri Nets Approach and Π–Tool

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Abstract: This paper presents a holistic approach in level crossing safety modelling through the use of Petri nets. A Petri net is capable of dealing with multiple sequences which involve hardware, software and human failures in complex systems. This paper begins with the motivation towards the new modelling approach assessing safety risks in a level crossing. Researches around the world related with level crossing safety risks were first reviewed and highlighted. The paper then presented the research methods, safety modelling and analysis used in the study. Π–tool, which is based on the Petri nets approach, was used to build the model. The model was tested at ten critical level crossing locations in South Australia. The first model was developed using the signal failure as the accident mechanism. Results show that the rate of potential accident occurrence at selected locations is very close to the actual rate of accidents. The Π–tool appears to be a suitable tool for assessing safety and performance at level crossings.

Keywords: *Petri Nets, Level Crossing Safety, Level Crossing Risk*, *Π–tool*

1. INTRODUCTION

Level crossings are considered as unique intersections in the transport system. This is the only case of crossing that presents two different infrastructures—road and rail, which is controlled by different sectors and which have obviously different performances during their normal operation. Level crossings have been identified to be weak points in the road infrastructure. Injuries resulting from any accidents at level crossings are often severe, which include deaths and serious injuries to thousands of road users and railway passengers. Moreover, these accidents place a heavy financial burden on the resources of the government and railway authorities. These accidents also involve extensive media coverage, both nationally and internationally.

Due to differences in level crossing environments, traffic and train characteristics, level crossing types and driver behaviours, most countries have developed their own strategies, requirements and operational procedures to develop a safe system. The Rail Safety and Standard Board (2007) in the UK reviewed level crossing techniques and approaches used in many countries. They categorised 23 approaches from 12 countries according to the main types of algorithm used, such as parameter gate, simple weighted factor, complex weighted factor and statistically driven approaches. Some of the fully developed approaches are widely applied in countries such as Great Britain, USA, Ireland and Australia. However, these models are undergoing further refinement in the USA, Canada, New Zealand, Spain and Australia to improve their model performance.

In Australia, models such as Risk Base Scoring Systems (RBSS), Australian Level Crossing Assessment Model (ALCAM) and RAAILc (Risk Assessment of Accident and Incident at Level crossings) were developed. The ALCAM model supplants the RBSS and is essentially an improved and extended version of the same model. The ALCAM is capable of modelling risk at all types of road vehicle and pedestrian user crossing in Australia. In 2004, a Level Crossing Management system (LXM) was established. The LXM database was developed to store and maintain data and run assessments in Microsoft Access format. In 2005, a pedestrian level crossing matrix was added to the modelling package and was incorporated into the LXM system. The ALCAM model is designed to apply for both active and passive level crossings, whereas the RAAILc model can be used for predicting accidents at passive level crossings only. The number of factors considered in ALCAM are quite complex. The Rail Safety and Standard Board (2007) in UK has categorised ALCAM under a simple weighted factor, and RAAILc as a statistically driven approach. Currently, ALCAM models have been adopted nationally and implemented across Australia. However, the model is still undergoing further development (Spicer, 2007).

Recently, the Coordination Action for the Sixth Framework Program has formed a Safer European Level Crossing Appraisal Technology (SELCAT) consortium, led by the Institute for Traffic Safety and Automation Engineering of the Technical University of Braunschweig, Germany. This project integrates 25 partners from 14 countries in Europe, Asia and Africa. The aims of SELCAT are for knowledge collection, exchange and identification of best practices for future design of European level crossings. SELCAT highlighted the importance of dependability, safety, reliability and availability in level crossing safety studies. SELCAT has endorsed a study by Slovak, *et al*. (2007) as work example in modelling the functionality and dependability aspect of the level crossing systems by using Petri nets approach in real application for their future design of European level crossings.

This paper will discuss the holistic approach of using Petri nets with the help of real data from South Australia. This model used the ALCAM database—LXM forming a basic guideline in identifying the best parameter. The flexibility of Stochastic Petri nets (SPN) and Petri nets tool Π–tool in dealing with qualitative and quantitative data makes it possible to use this approach in the real application of level crossing safety systems for South Australia.

The paper first explains the motivation towards Petri nets modelling approach. The remainder of this paper is organized as follows: Section 2 briefly introduces the Petri nets and Section 3 describes the modelling methodology used in this paper. The Petri nets modelling language is discussed in Section 4. Section 5 presents the safety modelling and analysis, and Section 6 presents the conclusions and future research recommendations.

2. PETRI NETS OVERVIEW

Petri nets were invented by Carl Adam Petri in 1962. It is a mathematical modelling tool that allows setting up state equations, algebraic equations and other mathematical models leading to an understanding of the system behaviours. Through its graphical representations, Petri nets can be used as a visual communication aid similar to flow charts, block diagrams and networks. It contains a set of places or transitions net. Petri nets are a capable tool for specification and analysis of concurrent, asynchronous, distributed, parallel, nondeterministic and stochastic processes.

Although the original model of Petri nets is often sufficient to model real systems, it is increasingly felt that more extensions are needed to model complex systems of the real world.

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. Due to its versatility with large calculation capabilities and abilities, the Petri nets approach is becoming popular in railway engineering and widely studied.

Numerous studies using the Petri nets approach in railway safety have been conducted by examining various factors. For example, several studies have looked into the application of CPN to investigate the functional correctness and performance of the railway networks systems (Fanti, *et al*., 2006; Janczura, 1998 and Jansen, *et al.,* 1998), the consistency and safety of operational and technical devices at level crossing (Einer, *et al.,* 2000), communication based train control (CBTC) system to increase track utilisation and safety (Xu and Tang, 2007), and track maintenance systems (Quiroga, 2008).

Petri nets and their stochastic timed extensions have been proven to be a useful formalism for real-time systems. They are considered to be a concise and appropriate way in describing the event systems (Zimmermann and Hommel, 2003). Therefore, the use of SPN and stochastic timed extension methods have become a great interest to a group of researchers from Germany. The motivation towards the establishment of a model called ProFUND model, aims at harmonizing different safety cultures and obtaining cross acceptance in the railway domain of Europe. The ProFUND methodical design concept is based on Process, FUNCtional and Dependability modelling. The approach is used in order to describe the railway control process, the function of the railway control system and the system's function dependability (Slovak, *et al.,* 2003). From the basic ProFUND model, other factors such as human behaviour at level crossings by using Extended Deterministic and Stochastic Petri nets (EDSPN) are also studied (Slovak, *et al.,* 2007).

3. METHODOLOGICAL CONCEPT

3.1 Research Methods

The methodological framework in assessing the level of risk at level crossing locations is described in Figure 1. The structure and purpose of the framework forms the foundation of the research design steps in assessing this level of risk.

Two types of level crossing categories exist in Australia—active and passive. Active level crossings have signals and or boom gates which operate automatically when a train is approaching, whereas passive level crossings have signs and or pavement markings. This research covers the active types of level crossing in South Australia only.

The modelling process involved four different stages. The first stage required an understanding on the level crossing operation, current practices, and tools available for analysis. The operation of active level crossings in Australia is based on the Australian Standard: *Manual of Uniform Traffic Control Devices, Part 7: Railway Crossing (AS 1742.7-2007).* Further categorization is made from the existing ALCAM database—LXM. A suitable tool was identified in order to achieve the desired research outcome.

In the model development stage, suitable Petri nets tool, Π–tool was selected. Π–tool is suitable for the creation of complex models and for analysing their deterministic and stochastic temporal behaviour. Proper classification of states and transitions were made and presented in tabular form. All parameters considered were built into the Petri nets model structure.

Model verification and validation is the third stage in the methodological framework. The verification process involved the process of proving all parts in the model specified. The process involved checking if the model is equivalent to the real operation and the technical behaviour of the level crossing systems. The validation is a proof of the model against reality. The system measured through this simulation and automatic model calibration by using Π–tool allowed automatic verification for steady state and Monte Carlo simulation. If the expected measure is not achieved, the input parameters need to be modified and if the output is equivalent to the real operation, the system complies. Sensitivity analysis will be conducted to measure parameter effects to the model.

The desired outcome will be based on the mechanism chosen during the modelling steps. The comprehensive modelling stage steps are described in Figure 2. The output will be the basis for the development of the level crossing risk index for South Australia. This development will be supported by the application of Geographic Information System (GIS). Other factors considered in the risk index assessment process are land use and population characteristics near the level crossings.

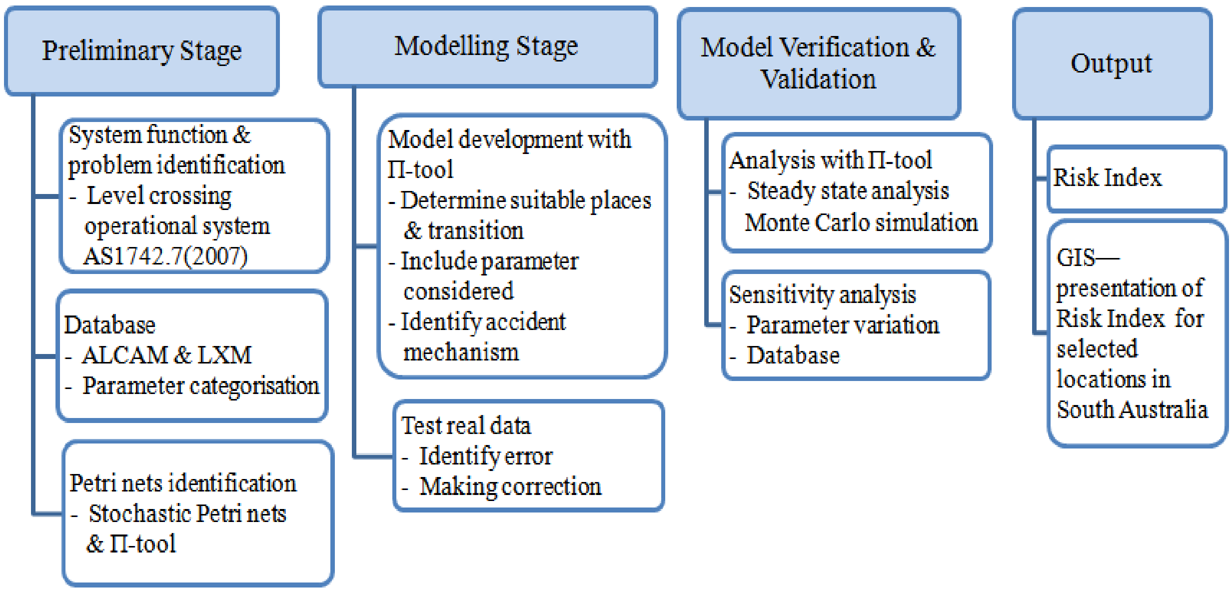


Figure 1. Methodological framework

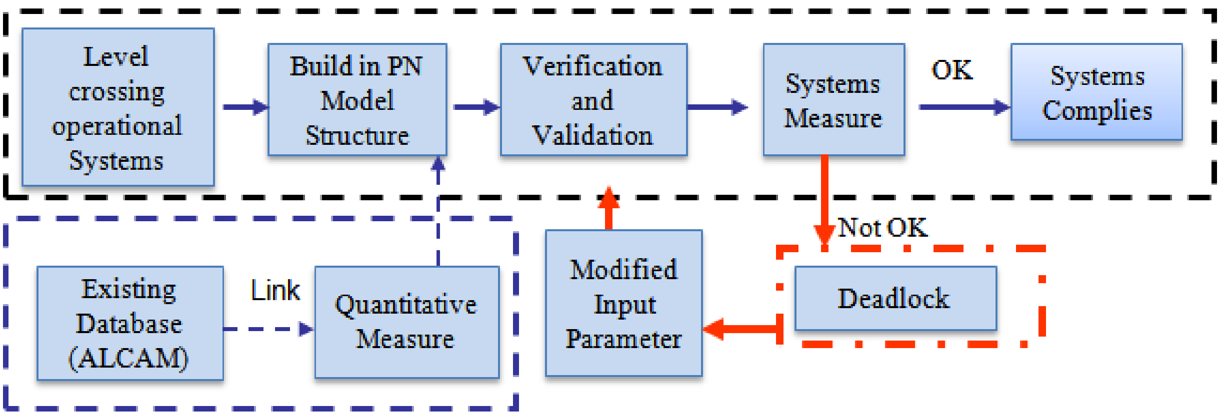


Figure 2. Petri nets modelling stage steps

3.2 Model Verification and Validation

The verification of the model was stimulated based on two cases; 1) level crossing safe operation and 2) Type I hazard. Automatic simulations provided by the Π–tool allow for an easier model verification process. The output was obtained after the steady state and Monte Carlo simulation were executed.

3.3 Safety State Process

Figure 3 shows the safety state in the modelling processes. The three states identified were desired state, hazard state and undesired state.

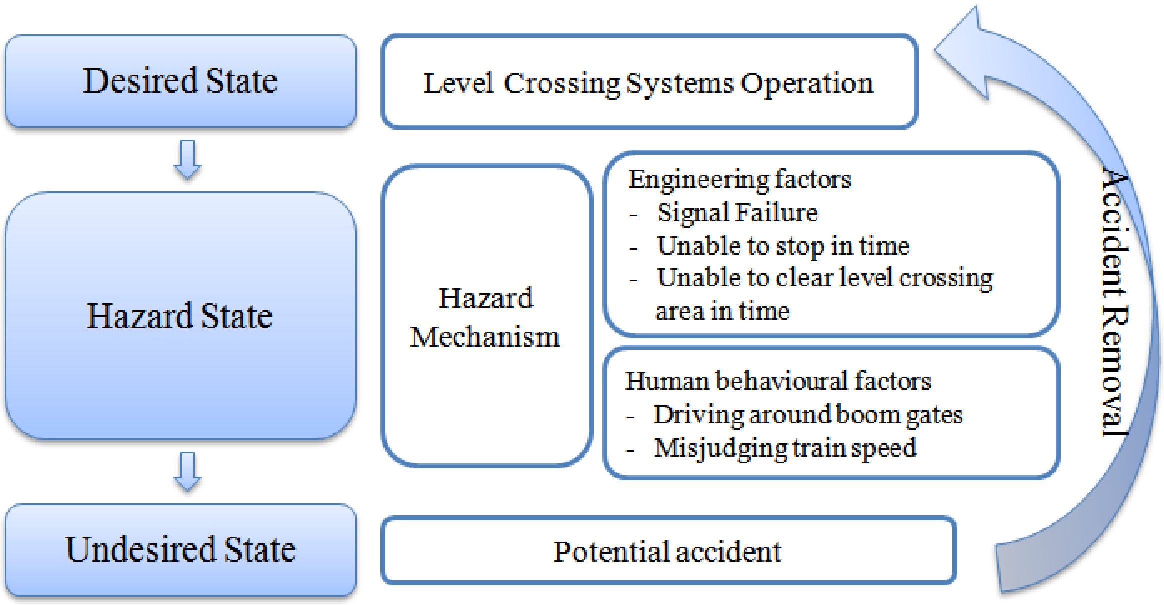


Figure 3. Safety state processes for risk modelling

3.3.1 Desired State

The safe operation of level crossing is the first priority in safety systems. The safe interaction between train, signal control and traffic is desired. In normal operation, when the train approaches the track circuit, the signal detects the oncoming train. The signal lights then start flashing and the bell rings. Meanwhile, traffic is alerted with advance warning signs. In normal conditions, road users are always alert at signalized level crossings. When the bell starts ringing, vehicle traffic stops before the stop line and waits for the barrier to close. Until the train clears the crossing, the bell continues to ring. After the train passes, the barrier opens to traffic and the bell stops ringing. Traffic then passes through the interaction area to continue its journey safely.

3.3.2 Hazard State

Hazard state or potential accident occurrence can be caused by various mechanisms. In this paper, the mechanism can be categorised under engineering and human factors as illustrated in Figure 3. Engineering factors include signal failure, traffic unable to stop on time at the stop line, and traffic unable to clear the interaction area (IA) on time. Human factors include driver misbehavior such as driving around boom gates, and in some cases, driver misjudgment of the train speed.

3.3.3 Undesired State
The obvious undesired state in any safety system is the presence of potential accident occurrence. The hazard state will be the indicator which leads to this undesired state. At this stage, the accident will need to be removed to ensure continued operation in accordance with the desired state.

4. MODELLING PROCEDURES

4.1 Systems Requirements

In order to carry out a qualitative analysis, a clear understanding of the technical and operational processes involved in a level crossing is needed. Because accident mechanisms need to be justified, the complete processes representing the real operation at a level crossing have to be modeled locally in a concurrent way. Using quantitative analysis, the probability of undesired states or hazardous events relating to the systems lifecycle at any time has to be evaluated. Inputs are the considered parameters determined along the process. The automatic simulation using Π–tool will help in the verification and validation process.

4.2 Petri nets Language

Suitable formal modelling language should be applied in order to support the modelling requirement using Petri nets modelling. The structure of Petri nets is visualized as a bipartial graph. The two disjunctive types of nodes are: 1) places and 2) transitions. Places are represented as circles and transitions are represented as rectangles. Transitions are active components of Petri nets, used to model various kinds of actions. In this case study, the activity or event during the operation is represented by a transition. Places can be considered as passive components and represent conditions for events or local states. For example, the transition may represent *traffic_entering_approaching_area* and places may represent *traffic_in_the_approaching area.*

Tokens in Petri nets represent volatile components and are used to model objects. In this model, the volume of traffic and volume of train are used as input tokens. The causal structure of the systems is determined by oriented arcs. The arcs will allow the change in state by transferring tokens from one place to another by firing the transition. The occurrence of the transition is related to changes in the global system's state and shows different activities or events. In this way Petri nets model represents not only the static structure but also the dynamic behaviour of the model systems. An arc, which is an input as well as an output arc, is called a test arc. A test arc reveals the causal relationship between conditions and events, but will not lead to deleting the condition after the occurrence of the events. For example, the token will still remain at the place after the transition fires. Another special arc is an inhibitor arc which inverses the condition. This means that a transition occurrence is allowed only if the place connected by an inhibitor arc is free from the token.

To meet the requirements of the method, extended stochastic and deterministic Petri nets (EDSPN) were used. The EDSPN allow four types of transitions which reflect temporal behaviour depending on the time parameter as illustrated in Figure 4.

- Immediate transition—the transition occurs immediately after conditioning without any delay. Such transition always has priority over transitions of other types.
- Deterministic transition—the transition occurs a constant numbers of times after

conditioning.

- Exponential transition—the firing time of this transition is distributed exponentially with mean time 1/λ.
- General stochastic transition—the time after meeting of input conditions until the transition occurrence is described by a probability distribution function.

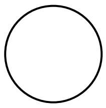
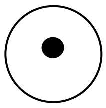
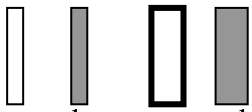
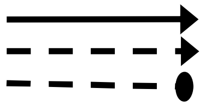
Symbol			 a b c d	a b c 
Type	Places	Places with Token	Transition a) Immediate Transition b) Deterministic Transition c) Exponential Transition d)General Stochastic Transition	Arc a) Normal arc b) Test Arc c) Inhibitor Arc

Figure 4. Basic symbols of Petri nets

The EDSPN allows qualitative and also quantitative analysis for proving performance and safety properties of the systems described by the net. Using the steady state analysis, the system state probabilities at the infinite time can be obtained. This kind of Petri nets class, as well as these analysis techniques, is supported by a software tool Π–tool, which was used to model analysis carried out to obtain the results presented in the paper.

4.3 Petri nets Tools

This research uses Π–tool. The Π–tool was developed at the Institute for Traffic Safety and Automation Engineering of Technical University of Braunschweig. This software tool is suitable for creating complex models and for analyzing deterministic and stochastic temporal behaviour. Some of its features are:

- Interactive token animation to observe the token flow as transition fires. There are manual steps animation and automatic animation with token speed controller.
- Simulation consisting of Monte Carlo Simulation which is suitable for all kinds of transitions and steady state analysis, appropriate for only immediate or exponentially distributed transitions.
- Calculation of reachability graph. The information on deadlock and the number of states can also be obtained.

4.3.1 Input Data

The meaning of places and transitions described in section 4.2 are used for further application in Π–tool. The relevant input parameters of places and transitions used are as follows:

Place

- Name —Place name must be unique
- Capacity—Maximum number of tokens that the place can allocate
- Initial marking—Initial number of tokens

Transition
The class of transition is probably the most important input parameter that needs to be chosen. The other input parameters are:

- Name—The transition name must be unique
- Distribution type—This parameter may be used as one of the following:
    - Deterministic—the transition is untimed
    - Exponential—timed stochastic transition, with exponential distribution
    - Normal—timed stochastic transition, with normal distribution
    - Uniform — timed stochastic transition, with uniform distribution

5. SAFETY MODELLING AND ANALYSIS

5.1 South Australia Case Study

Level crossing collision data for Australia from 1 January to 30 June 2008 is tabulated in Table 1, and covers the states of New South Wales, Victoria, South Australia, Queensland, Western Australia, Tasmania, and one territory of the Northern Territory. The state which experienced the highest total number of level crossing collisions is Victoria followed by Queensland and South Australia. In South Australia, there are 78 collisions involving road vehicles and 18 collisions involving pedestrians. In this paper, only collisions between trains and road vehicles are discussed.

Table 1. Australian level crossing collision data from 1 Jan 2001 to 30 Jun 2008

State	Level Crossing Collision		Total
	Road Vehicle	Pedestrian	
Queensland	141	10	151
Northern Territory	4	0	4
South Australia	78	18	96
Western Australia	28	5	33
Victoria	220	38	258
Tasmania	22	1	23
New South Wales	85	5	90
Total	578	77	655

*Source Australian Transport Safety Bureau (2009)

5.2 Level Crossing Example

About 1228 level crossing locations exist throughout South Australia, consisting of 261 passive level crossings and 697 active level crossings. For the purpose of this paper, only active type level crossings will be considered. Other considerations are:

- One-way directional vehicle traffic volume per hour.
- Two-way train volume per hour.
- Identification of several important zones:
    - Signal zone is at the track circuit point.
    - Approaching area for traffic is considered from the distance of advance sign (level crossing ahead sign) given to traffic.
    - Approaching area for train starts just immediately after the signal is activated

- Interaction Area (IA) is the point of potential interaction between train and traffic. This is considered as the dangerous point in the level crossing system.

5.3 Parameter Estimation

The input parameter and criteria used in the model is shown in Table 2. The parameters which are considered in the basic operation of level crossings are train, traffic and signal control parameters. The main input parameter is the traffic and train volume per hour. Traffic parameters considered factors such as approach speeds, percentage of heavy vehicles and Level of Services (LOS). Train parameters considered factors such as speeds of the approaching trains and their lengths. The various criteria for traffic and train parameters are used as input data and are considered as the main variables in the model.

Table 2. Input parameter and criteria

Traffic volume	Traffic parameter	Criteria	Train parameter	Criteria
Traffic/hr Train/hr	Approach speed	≤ 60 kph > 60 to 80 kph > 80 kph	Approach speed	≤ 60 kph > 60 to 80 kph > 80 to 100 kph > 100 to 120 kph > 120 kph
	Heavy vehicle percentage	5%, 10%, 25% & 50%	Length of train	< 60 m 60 to 300 m > 300 to 1000 m > 1000 m
	Level of Service (LOS)	LOS A, B, C, D, E & F		

5.4 Petri nets Model Structure

The Petri nets model structure is designed following a hierarchical system. The system hierarchy design for level crossing modelling using Petri nets approach is illustrated in Figure 5. The hierarchical architecture allows the model to be viewed separately while considering the different aspects or important parameters clearly.

There are at least three hierarchical stages demonstrated in this model. The detail of the parameters considered and the hierarchy is explained in Table 3. Table 3 shows all the activities taking part in the whole operation, represented by places and transitions as demonstrated in the Petri nets model. No. in the table represents the number of hierarchy in the model. Places represent conditions and transitions represent events or activities during the operation. Further explanation on the symbols and terminologies used in this model are given in Section 4.2.

The first hierarchy in the model represents the event that needs to be monitored—the desired event of no accident occurrence and undesired event where the potential accident occurrence may take part at the end of level crossing operation.

The second hierarchy of the model represents the basic level crossing operational systems— integrating elements such as train operation, traffic operation and signal control operation. The first model is designed in such a way that the model operation should satisfy the safety requirements as briefly described in the desired state in section 3.3.1. However, *Type 1 hazard* is allocated in the model as the first observed accident mechanism.

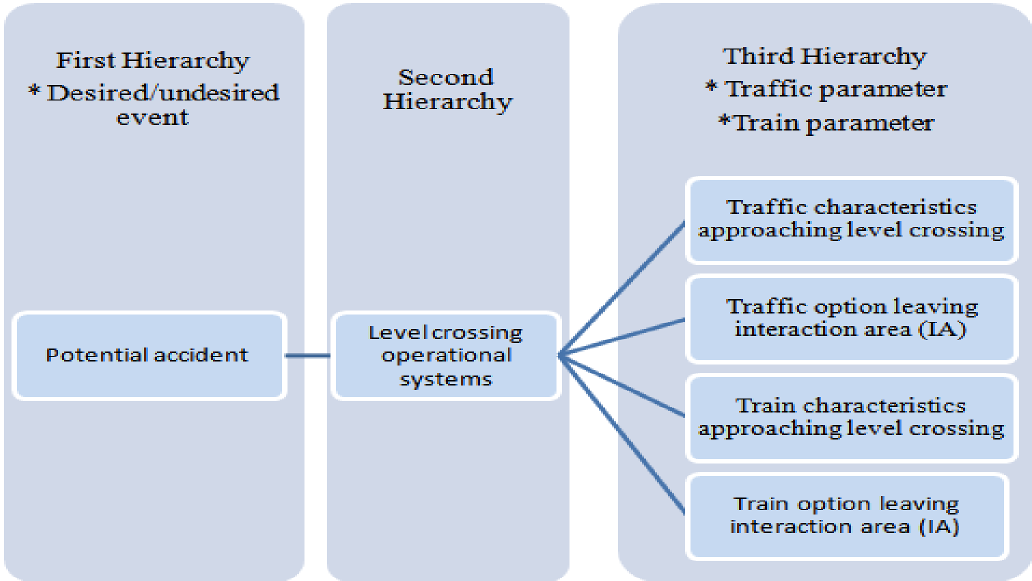


Figure 5. Modelling system hierarchies

Table 3. List of places and transitions in the hierarchy within Π–tool

No.	Description	Places	Transition
1.	*Desired or undesired event*	no_accident potential_accident	Potential_accident_occurence accident_removal
2.	*Hazard type 1*	normal_system_operation hazard_situation	hazard
	Signal control	barrier_closed_stop_traffic barrier_open_to_traffic	signal_activation signal deactivation
	Traffic and train operation	traffic_out_of_LC_area traffic_approaching traffic_in_IA train_out_of_LC_area train_in_signal_zone train_approaching train_in_IA	traffic_enter_approaching_area consider_factor_traffic_entering_IA traffic_passing_IA train_enter_signal_area_zone train_enter_app_area consider_factor_train_enter_IA train_passing_IA
3.	*Traffic characteristics*	speed_less_or_equal_to_60_kph speed_more_than_60_to_80_kph speed_more_than_80_kph traffic_in_approach_speed hgv_per_5 hgv_per_10 hgv_per_25 hgv_per_50 traffic_selection traffic_app_no_train_option1 traffic_app_train_app_option2 traffic_app_train_in_IA_option_3 traffic_entering_IA train_in_length2 train_in_length3 train_in_length4 train_in_length_speed_leaving_option	traffic_approach_speed1 traffic_approach_speed2 traffic_approach_speed3 consider_hgv_per_5 consider_hgv_per_10 consider_hgv_per_25 consider_hgv_per_50 traffic_app_no_train traffic_app_train_app traffic_app_train_in_IA traffic_entering_option1 traffic_entering_option2 traffic_entering_option3

Table 3. List of places and transitions in the hierarchy within Π–tool (Continued)

3.	*Traffic passing IA speed option*	LOS_A LOS_B LOS_C LOS_D LOS_E LOS_F LOS_effect1 que_prob controlLOS traffic_in_leaving_speed_1 traffic_in_leaving_speed_2 traffic_in_leaving_option_3	consider_effect_LOS_A consider_effect_LOS_B consider_effect_LOS_C consider_effect_LOS_D consider_effect_LOS_E consider_effect_LOS_F traffic_consider_LOS_and_que_prob traffic_consider_LOS_wo_que_prob traffic_leaving_speed_que traffic_leaving_without_que
	Train characteristics	speed_less_or_equal_to_60 speed_more_than_60_to_80 speed_more_than_80_to_100 speed_more_than_100_to_120 speed_more_than_120 train_in_approaching_speed	train_consider_approach_speed1 train_consider_approach_speed2 train_consider_approach_speed3 train_consider_approach_speed4 train_consider_approach_speed5
	Train passing IA leaving option	train_length_less_than_60m train_length_60_to_300m train_length_more_300_to_1000 m train_length_more_than_1000m controlTL train_in_length1 train_in_length2 train_in_length3 train_in_length4 train_in_length_speed_leaving_o ption	consider_train_length1 consider_train_length2 consider_train_length3 consider_train_length4 leaving_speed1 leaving_speed2 leaving_speed3 leaving_speed4

The third hierarchy incorporates the sub-models representing the details of parameters considered in the model. The traffic parameters considered are *traffic characteristics* for traffic approaching the level crossing, and *traffic passing IA speed option* for traffic in the interaction area. Whereas the train parameters considered are *train characteristics* and *train passing interaction area leaving option.* The places and transitions under this sub-model represent the conditions and events during the operation.

5.5. Result and Discussions

Based on the model structure, ten critical locations of level crossings in South Australia were selected and simulated. As limited historical data was available, only five years of level crossing accident data were used for comparison in the first model. Available level crossing data is only from 2003 to 2007, obtained from the Department of Transport, Energy and Infrastructure (DTEI), South Australia. The quantitative analysis using the Petri nets approach in this model allows us to evaluate the potential accident occurrence rate as well as the probability of the signal control failure, which means that the signal control was not activated. It was designated as a Type 1 hazard which causes the failure of the systems and indicated as potential accidents. This measure was based on the assumption that the signal failure happened once in every five years at locations. Therefore, the input in the model was based on the rate of hazard occurrence due to a signal failure rate per hour of 0.0000228311, and the rate of train and traffic per hour as given in Table 4 for each selected location.

Table 4. Π–tool input parameter

Crossing No.	Crossing Location	Traffic info		Traffic parameter			Train parameter	
		train/ hr	traffic /hr	hgv%	LOS	App speed (kph)	app speed (kph)	train length (m)
RLX0016	Magazine Road North, Dry Creek	0.375	21	10	A	< 60	≤ 60	> 1000
RLX0032	Morphett Road, Morphettville	5.75	983	5	F	< 60	≤ 60	< 60
RLX0034	Woodville Road, Woodville	6.5	888	5	F	< 60	> 80–100	60–300
RLX0174	Nelson Street, Birkenhead	0.33	1075	10	F	< 60	≤ 60	> 1000
RLX0533	Commercial Road, Salisbury North	5.625	725	5	E	< 60	> 80–100	> 300–1000
RLX0551	Sixth Avenue, Glenelg East	5.75	208	5	C	< 60	≤ 60	< 60
RLX0554	East Avenue, Black Forest	7.292	83	5	B	< 60	≤ 60	60–300
RLX0719	Short Road, Angle Vale	0.583	8	5	A	60–80	> 80–100	> 1000
RLX0723	Gawler Road, Virginia	0.583	75	10	B	< 60	> 80–100	> 1000
RLX0977	Junction Road, Balhannah	0.583	108	10	B	< 60	> 60–80	> 1000

The quantitative result based on this Petri nets model was evaluated. The difference in the percentages between the number of trains entering IA and the activation of signal per hour is shown in Figure 6.

The trains were tested using different approach speeds entering the IA; i.e. ≤ 60 kph, > 60–80 kph, > 80–100 kph, > 100–120 kph and > 120 kph. The simulation result shows that there is a difference in the number of trains entering the IA with the number of signal activations.

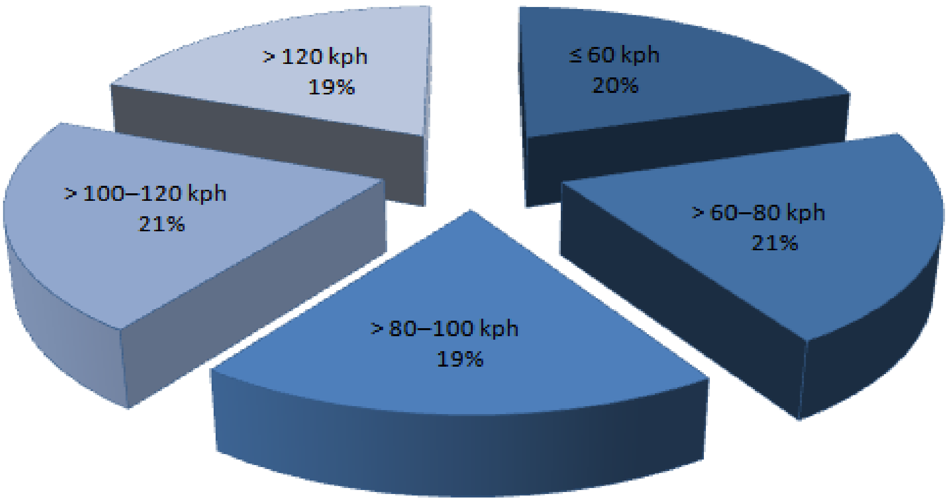


Figure 6. Percentage of difference between numbers of trains entering the interaction area (IA) and activation of the signal according to train approaching speeds

For example, there is about 20% difference between the number of trains approaching the IA and the number of signal activations. This means that about 20% of the train approaching the IA with a speed ≤ 60 kph will not be provided a signal to ring a bell and close the barrier to stop traffic. Therefore, the potential accident occurrence during this phase is designated as a Type 1 hazard. The failure of the signal and potential accident occurrence was likewise observed. Failure of signal detection can cause the signal to be not activated, thereby preventing the boom gate and barrier to open. Therefore, the potential accident can happen whenever the traffic is represented as token in the *traffic_in_IA* and *train_in_IA* places.

The simulation result for the ten locations of level crossings and the historical data from 2003 to 2007 are shown in Table 5. Historical data show that the actual accidents for the last five years are nearly constant for every location. However, the near-miss incidents vary between locations. In this paper, only the underlying engineering factors were tested to understand accident mechanism. Type 1 hazard was designated in the model as due to the non-functioning of signal control or due to signal failure in the system operations that leads to potential accidents.

The result of the simulation shows potential accident occurrences based on the assumption of a Type 1 hazard course, wherein the ratio of level crossing systems failure of about 1 accident per 5 years is almost the same as the actual accident occurrence of 1 accident per 5 years and 2 months. The sample tested is about 10^9 with a 3 percent tolerance.

Table 5. Level crossing analysis for ten locations

		5 years accident history (2003−2007)		Model simulation output Potential accident	
Crossing No.	Crossing name	Actual accident	Near miss	Accident/hr	Accident/year
RLX0016	Magazine Road North, Dry Creek	1	2	2.28218E-05	1 acc/5y2m
RLX0032	Morphett Road, Morphettville	1	5	2.28295E-05	1 acc/5y2m
RLX0034	Woodville Road, Woodville	1	4	2.28299E-05	1 acc/5y2m
RLX0174	Nelson Street, Birkenhead	1	3	0.000022828	1 acc/5y2m
RLX0533	Commercial Road, Salisbury North	1	6	2.28299E-05	1 acc/5y2m
RLX0551	Sixth Avenue, Glenelg East	1	7	2.28285E-05	1 acc/5y2m
RLX0554	East Avenue, Black Forest	1	3	2.28295E-05	1 acc/5y2m
RLX0719	Short Road, Angle Vale	1	0	2.28171E-05	1 acc/5y2m
RLX0723	Gawler Road, Virginia	1	0	2.28278E-05	1 acc/5y2m
RLX0977	Junction Road, Balhannah	1	0	2.28282E-05	1 acc/5y2m

6. CONCLUSIONS & FUTURE RESEARCH

In this paper, a model was designed by considering engineering factors; i.e. signal failure as accident mechanism which can contribute to potential accident occurrence, described as Type 1 hazard. The rate of hazard occurrence due to signal failure in the systems operation was tested at one failure in five years. The assumption was based on historical data obtained from the Department for Transport, Energy and Infrastructure (DTEI), South Australia. Based on the rate given in the model, the calculated potential accident occurrence was very close to the actual rate of one accident in five years. The model developed using Petri nets tool, Π–tool appears to be suitable for assessing the safety and performance of level crossings. However, this model is still under the process of development and interventions may be done to the model. Further refinements on the parameters used in the model and other accident mechanisms may be included and tested in future researches.

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