An Assessment of Heavy Vehicle Safety at Level Crossing Using Petri Nets: South Australia Case Studies

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Abstract: In Australia, level crossing safety has been a major concern to road and rail authorities. This paper considers the issues related to heavy vehicles safety at level crossings. The aim of the paper is to introduce Petri nets—a graphical and mathematical modelling tool in assessing the scale of risk at level crossings when heavy vehicles passing through intersecting areas. The Petri nets tool, Π–tool is used to establish the model which is tested using different heavy vehicle percentages on selected level crossing locations in South Australia. The results demonstrated factors such as traffic level of service (LOS), heavy vehicle percentages and the distance of the level crossings to or from the nearest intersection are associated with an increased risk when a heavy vehicle being involved in level crossing collisions. The Petri nets and Π–tool appear to be suitable for assessing the safety and performance of level crossings.

Key Words: heavy vehicle, level crossing, Petri nets

1. INTRODUCTION

Rail transport is one of the oldest efficient technologies used for carrying people and goods. An alternatives form of transporting goods over short or long distances is the use of heavy vehicles. In the next 5 to 10 years in eastern Australia, heavy vehicle traffic is predicted to be doubled (Davey et al., 2008). This prediction may imply the likelihood of heavy vehicle–train accidents at level crossings. For example, in 2008 the Australian Transport Safety Bureau conducted a study to investigate accidents at level crossings from 2006 to 2008 (ATSB, 2008). Eleven of the 14 level crossing accidents involved a train collided with heavy vehicles. Of these accidents, five involved passenger trains. One reason for these accidents was that trains are often unable to stop at a short notice. For example, a freight train can be in excess of 1500
m long and weigh more than 5000 tonnes. To stop such a train safely, it needs to begin braking several kilometres in advance from the point it intends to stop. The same principles, although to a lesser extent, apply to heavy vehicles. Due to the large load carried, they will also take some time to stop. The failure of heavy vehicles to stop or clear a level crossing may have disastrous consequences.

This study aims to identify the potential risk posed by heavy vehicle when passing the level crossing locations in South Australia. To investigate progressing interaction factors for complex dynamic systems, Petri nets—the mathematical modelling languages is used for the description of discrete distributed and concurrent systems. This model provides a comprehensive modelling approach on different transport modes by considering the interactions for active controlled level crossings. The dynamic process demonstrated for different elements can be described by high level Petri nets types with the extension of time and hierarchy, as offered by extended Deterministic Stochastic Petri nets (eDSPNs) and Π–tool. Factors assessed include engineering, human and level crossing surrounding environments. The effect of heavy vehicles safety at level crossings can also be observed.

The paper first highlights issues related with heavy vehicle safety at level crossings. The rest of the paper is organised as follows: Section 2 provides review of studies related with heavy vehicle-train accidents and the use of Petri nets in safety studies. Section 3 presents the research method in highlighting the Petri nets model structure and Π–tool. Section 4 highlights the estimation of model parameter and model development. The discussion on the model analysis of case study locations is provided in Section 5. Section 6 concludes the paper and provides recommendations for future research.

2. LITERATURE REVIEW

Limited studies have been conducted in Australia in understanding the mechanism associated with level crossing accidents. Human errors are generally regarded as a primary cause of railway crossing accidents. Davey et al. (2008) conducted a social research on the experiences and perceptions of heavy vehicle and train drivers on the danger at level crossings by consulting both groups of drivers. The risk of heavy vehicle–train accidents was identified as resulting from the following factors on heavy vehicle aspects: size and mass (e.g. difficulties in gauging time required to cross, underestimating space to clear the crossing and overhang of long vehicles), driver behaviour (e.g. signal violation and try to ‘beat the train’), crossing design (e.g. inappropriate layout, inadequate warning and protection systems) and over familiarity with some crossings and intentional violation (e.g. avoid delay in waiting for train to pass). Other studies related to level crossing safety considered factors such as signal control (Wiglesworth 1978, 2001) and human behaviour (Edquist, 2009).

The major cause of accidents is human behaviour. This issue needs more attention from governments, industries and the community (Ford and Matthews, 2002). This view was supported by a Commonwealth of Australia investigation into fatal crashes at level crossings. They concluded that a high source of accidents is due to human fault (ATSB, 2002). Accidents at active level crossings are more common than the ones at passive level crossings. 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 only.
Numerous efforts have been directed to minimise level crossing accidents. These include the use of a comprehensive level crossing safety model developed in Australia in the late 90’s—the Australian Level Crossing Assessment Model (ALCAM). It established a platform with the aim to gain a better understanding on the phenomenon of accidents, site improvement and development of countermeasures to improve safety. The model considers physical characteristics and controls in the existence at both road and pedestrian level crossings. The model includes elements such as common motorist and pedestrian behaviour at crossing locations to provide a Risk Score and Exposure Rating. The combination of these scores produces a Total Risk Exposure Score (TRES) for each level crossing which enables a comparison of relative risk across all level crossings within a given jurisdiction. By sorting level crossings in relation to their TRES, a priority listing can be created which can then be used to develop safety improvement program. The model is designed to be applied to both active and passive level crossings. Currently, the ALCAM model has been adopted nationally and implemented across Australia. The comprehensive database stored in Level Crossing Management Systems (LXM). However, the ALCAM model has generally not considered the effects of heavy vehicle and has mainly considered the overall performance of level crossing operation.

In this research, a Petri net which was invented by Carl Adam Petri in 1962 is introduced. Petri nets have been widely applied in many application areas—for example, in performance evaluation (Marsan et al., 1984, Molloy, 1982), communication protocols (Merlin, 1976), discrete event systems (Krogh, 1987), fault tolerance systems (Leveson and Stolzy, 1987), human factors (Van Biljon, 1988) and neural networks (Zargham and Tyman, 1985). Recently, the application of basic Petri nets and other Petri net extension—such as Hierarchical nets, Stochastic Petri nets (SPNs) or Coloured Petri nets (CPN)—is broadly used in the field of railway networks, operation and safety. Due to its versatility with large calculation capabilities and abilities, Petri nets are popular in railway engineering and widely studied.

The SPNs have been chosen and selected as a suitable Petri nets type used for this type of modelling process. The computer science community introduced SPNs in the early 1980s. SPNs are a probabilistic extension of the original Petri nets and are suitable for complex systems. SPNs offers a graphical format for system design and specification and its facility to describe synchronisation in concurrent events (Falko and Pieter, 2002, Haas, 2002). Another advantage of SPNs highlighted by Ciardo and Li (1998) is that they are well suited for model-based performance and dependability evaluation and have the capability to describe large system state spaces. Petri nets and their stochastic timed extensions have proven to be a useful formalism for real-time systems (Zimmermann and Hommel, 2003).

Studies using SPNs for level crossing safety were conducted by Slovak et al. (2003). The methodological design concept based on Process, FUNctional and Dependability (ProFUND) was established. The approach is used to describe the railway control process, the function of the railway control systems and the system’s function dependability. From the basic ProFUND model, other factors such as human behaviour at level crossings by using Extended Deterministic and Stochastic Petri nets (EDSPNs) are also taken into consideration (Slovak, 2007). Slovak et al. (2007) also explained the specialities of SPNs in dealing with qualitative and quantitative types of analysis which allow functional, performance and safety properties of the system to be described by net. The qualitative analysis allows state space investigations and can be used for the validation of developed models. Meanwhile quantitative analysis
offers safety and performance evaluation. This allows the 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. A recent study conducted by Wei et al. (2009) used EDSPNs to estimate traffic risk at passive level crossings. Parameters such as traffic users and train density, human behaviour and social data—Gross Domestic Production (GDP)—were included.

The aforementioned studies have looked into the main events (top level event) or scenarios that lead to accident at level crossings and the findings are seen as limiting the understanding of the causes of incidents and precursors. Therefore an improved methodology is proposed in this paper to provide a deeper understanding not only of the top level event but also of the contributing events which then lead to the main event (sub event). Top level events and sub events will be further categorized into various factors which include engineering infrastructure, level crossing surrounding environments and human factors.

3. RESEARCH METHOD

A comprehensive research methodology development using Petri nets in assessing the safety at level crossing has been introduced in the earlier study by Ishak, Yue & Somenahalli (2010). The structure of Petri nets is visualized as a bipartial graph. The two disjunctive types of nodes are places and transitions. The places are represented by circles, and transitions represented by rectangles. A transition is an active component of a Petri nets and represents activity. Place can be considered as a passive component and represents conditions for events or local states. A token in Petri nets is the volatile component and is used to model objects variables. The causal structure of the systems is determined by oriented arcs. An arc will allow the change of state by transferring a token from one place to another by firing the transition. 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 this condition. This means, a transition occurrence is allowed only if the place connected by an inhibitor arc is free from the token. The EDSPNs is used to meet the requirements of the method chosen. The EDSPNs allows four types of transitions which reflect temporal behaviour depending on the time parameter—immediate, deterministic, exponential and general stochastic transitions. The EDSPNs 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 can be obtained.

An example of basic operation in level crossing systems is shown in Figure 1.

![Simple Petri nets process](image)

Figure 1 Simple Petri nets process

In this simple net, one token is assigned in the first places. This operation shows that traffic (for example, a heavy vehicle) is in the traffic stream and located outside the level crossing
areas. Then the heavy vehicle is approaching the level crossing (LC) area and entering the interaction area (IA). This process is assigned by a normal arc by firing the transition to execute the activities of \textit{traffic\_enter\_IA}. During this process, the token is transferred from \textit{traffic\_out\_of\_LC} to \textit{traffic\_in\_IA} places which are directed by arc. The arc is used to represent the change of state from places to transition or vice versa.

The suitable SPNs tools, \Pi–tool is selected to support the modeling power of EDSPNs. The \Pi–tool allows creation of complex models with proper classification of states and transitions. The entire operation and the appropriate parameter estimates obtained from the existing ALCAM database are built into the Petri nets model structure and translated into Petri nets language containing places and transitions. Then the complete model is tested and measured through simulation and automatic model checking using the \Pi–tool. This tool allowed automatic verification for Steady State analysis and Steady State Simulation—Monte Carlo simulation.

### 3.1 Level Crossing Systems Hierarchy

The Petri nets model structure is designed with hierarchical extensions. The system hierarchy for level crossing modelling using Petri nets approach is illustrated in Figure 2. The hierarchical architecture allows the keeping of an overview over the model by separation of different aspects or important parameter need to be considered. The highest hierarchy represents the main model. It shows the events or scenarios in the operation. In this study, the two main scenarios observed are desired and undesired scenarios. The desired scenario means that there is no potential risk and undesired scenario means there will be a potential risk.

The top hierarchy of the model represents the basic level crossing operational systems—integrating elements such as train operation, traffic and signal control operation. The second hierarchy incorporates the parameters which need to be observed in this model. Two sub models are categorised as traffic characteristics and train characteristics. Under traffic characteristics category, two potential events included are traffic entering the interaction area and traffic passing the interaction area. The same event is considered under train characteristics category. The third hierarchy is basically the sub model—type of vehicle passing the interaction area. The choice of either car or heavy vehicle passing will depend on...
the heavy vehicle percentages given in the traffic characteristics—traffic entering parameter as in the second hierarchy. The fourth hierarchy involves the option of traffic type—car or heavy vehicle chosen to pass the interaction area. The option depends on the traffic LOS condition at the location. The leaving option for car and heavy vehicle is categorised into three options depending on the LOS groups—option 1 for LOS A and B, option 2 for LOS C and D and option 3 for LOS E and F. Therefore, cars and heavy vehicle passing the interaction area need to consider their location’s LOS category. The other parameters considered by these three options are the level crossing distances from or to the nearest intersection. It is an important parameter since the distances will affect the drivers’ judgment when passing the interaction area.

4. MODEL DEVELOPMENT

The basis of understanding on the function and design of level crossing systems is referred to Australian Standard; Manual of uniform traffic control devices; Part 7: Railway crossing; AS 1742.7(2007). An example of a typical active level crossing with a straight approach design layout with the provision of flashing lights and half boom barrier is taken as the example in this case study. Other terms used in this research are explained as follows:

- Interaction Area (IA) is the potential intersecting area for train and traffic at the level crossing. The size of the area varies according to the location, e.g. the number of railway tracks and road lanes and crossing configuration
- Level crossing (LC) area starts when the road users see a level crossing ahead sign at a distance (m) and ends when they leave the IA.

4.1 Parameter Estimation

The input parameters used in the model include basic operation at level crossings—train, traffic and signal control. The main input parameter is traffic and train volume per hour. Traffic parameters consider factors such as approaching speeds, heavy vehicle percentages and level of service (LOS). Traffic LOS is a qualitative measure of traffic conditions on the road. In this research, the LOS is referred to Highway Capacity Manual (HCM) and does not take any effect of the level crossing area. The HCM defined LOS as LOS A (free flow), B (stable flow, reasonable freedom to select speed), C (stable flow, restricted freedom), D (flow becoming unstable, all drivers restricted in free), E (traffic volumes at or close to capacity) and F (forced flow) respectively. The factors considered for the train parameter are an approaching train speed and the length of the train. The approximate level crossing distance from the nearest intersection is a parameter considered in taking into consideration the surrounding environment of the level crossing. Input data considered as the main variables in this model are the criteria of traffic, train and level crossing. Details criteria of the input parameter can be referred to Ishak, Yue & Somenahalli (2010).

4.2 Model Structure

The main model exemplifies the observed scenarios overall. The desired scenario is no risk and the undesired scenario is a risk presented by places in Figure 3. During normal operations, a token is always assigned in the no_risk places. The potential_risk transition is only fires if the tokens exist in train_in_IA and traffic_in_IA. A risk means that accidents happened, so risks need to be removed. During risk removal, the transition fires and tokens in train_in_IA and traffic_in_IA are transferred to train_out_of_LC_area, traffic_out_of_LC_area and the risk_removed places. Then, the system—train, traffic and signal control will be reset back to
normal operation and safe to operate as the token is located in no_risk places. In the main model, there is no indication of time given to transition. The immediate transition is used for all activities. The places connecting from the other sub model are notified by an indication of double operation, for example LC_operational_systems. Train_out_of_LC_area. These places show that the train_out_of_LC_area is taken from LC_operation_systems sub model or from the first hierarchy. To avoid deadlock in the Petri nets model, the control places are located, e.g. Traffic.passing.TFcontrol2. Note that several other places provide control places with one token. Therefore for the purpose of model explanation, the control is not discussed.

![Figure 3 The main model](image)

The level crossing operational systems is illustrated in Figure 4. This model represents that the complete operation at level crossings includes three important elements—train, traffic and signal control. The interaction between these elements demonstrates the safety operation at level crossings. The dangerous state illustrated in the Petri nets model is the potential state where the risk might take place. The traffic operation starts with a token in place representing traffic_out_of_LC_area. One token is released to activate traffic_enter_approaching_area exponential transition. Here, the token is transferred from traffic_out_of_LC_area to the traffic_approaching place. Traffic needs to consider several factors as in traffic characteristics indicated in the sub model. After traffic considers all factors and there is a token in PN.no_risk, the consider_factor_traffic_entering_IA transition is fired and traffic can enter the interaction area to be at traffic_in_IA. However, no token in PN.no_risk means that the level crossing is in risk, the consider_factor_traffic_entering_IA transition cannot be fired. The factors in the traffic passing sub model need to be fulfilled before traffic can pass the interaction area safely. The traffic_passing_IA transition can only be fired if no token is in the risk places. If a token exists in risk places, it means that there is a risk and the traffic needs to stop and cannot be allowed to pass the interaction area. When all factors are already considered, the traffic can pass the interaction area safely and continue the journey as in normal operation. The places contain tokens as indicated in the traffic_passing. TFcontrol2 is a control used in this model to avoid deadlock in the Petri net model.

The train operation starts with a token in place to represent the train_out_of_LC_area. The activity takes place when the train_enter_LC_area and the token transfer to the
train_in_signal_area_zone. In this zone, the track circuit detects the oncoming train and activates the signal control. A signal is given to stop the traffic and the barrier is closed. Then, the train approaches the level crossing area. Train needs to consider train characteristics as indicated in the sub model and enters the IA as train_in_IA. The train needs to consider train passing speed factors as designated in the next sub model. Then the train can continue the journey safely and train_passing_IA transition is executed. The signal control detects the leaving train and the signal given to deactivate the signal by opening the barrier to traffic and permitting the traffic to pass the level crossing safely.

Figure 4 Level crossing operations in Petri nets structure

In the traffic characteristics sub model, the factors considered include traffic approaching speed and heavy vehicle percentage on the road as displayed in Figure 5. The option of parameters considered varies according to location and indicated by the token in places. Only the transition that is connected with a place contains tokens that will fire. However, the number of tokens at those places will not change with the existing test arc. The operation at this sub model continues from the traffic in traffic_approaching place. Here, traffic needs to consider the approach speed and heavy vehicle percentages on the road. Different heavy vehicle percentages could create different scenarios or events. In this case, two categories of traffic are assigned—car and heavy vehicle. The token is always assigned to be zero per cent heavy vehicles (constant). This constant indicates that the car is always allowed to pass the level crossings together with any percentages of heavy vehicles assigned—5%, 10%, 25% or 50%. The next event taking place depends on the existence and the location of the train at that
time. The transition assigns as car_approach and hgv_approach when there is no train detected, a train in approaching area and a train in the interaction area. The traffic is only allowed to enter the interaction area if only the $\text{barrier\_closed\_to\_stop\_traffic}$ places do not contain any token.

In the traffic passing sub model, the events start with the $\text{traffic\_in\_IA}$ places as indicated in Figure 6. Depending on the existence of tokens in $\text{hgv\_approaching}$ places, the type of traffic is selected here. A car is allowed to proceed if there is no token in the $\text{hgv\_approaching}$ places or else only a heavy vehicle is permitted to proceed. Few factors need to be considered in the interaction area to pass the level crossing area. Those factors are discussed in the following sub model. Figures 7 and 8 illustrate the selection of heavy vehicle passing the interaction area.

![Figure 5 Traffic characteristics](image)

![Figure 6 Traffic passing](image)
Figure 7 presents the Petri nets representation of the dynamic leaving option for heavy vehicles. This sub model is only granted if a token is assigned in the traffic_characteristics. HGV_approaching. The heavy vehicle needs to consider the LOS A (free flow) to LOS F (forced flow). At this stage, the LOS is categorised into three groups such as LOS A and B, LOS C and D and LOS E and F to simplify the model structure. After the LOS is considered, the next stage involves further selection of passing—option 1, 2 or 3. For example, if the heavy vehicle passing level crossing experienced LOS A or B, then the heavy vehicle will precede with heavy vehicle option 1 sub model.

Figure 7 Heavy vehicle leaving option

Figure 8 Heavy vehicle passing option 1

The heavy vehicle option 1 sub model is displayed in Figure 8. The next parameter considered is the level crossing distance from the nearest intersection. The shortest distance from the level crossing is designed as less than 20 m and the longest distance is more than 200 m.
m. The distances are designed to give an effect to the hazard perception. At this stage, the exponential transition type is designed and time is allocated to each car driver reaction towards the oncoming train in considering the level crossing distance from the nearest intersection.

5. ANALYSIS AND DISCUSSION OF CASE STUDY LOCATION

The sensitivity analysis was conducted to determine the parameter effect to the overall model performances. The potential risk values obtained from the steady state analysis generated automatically using the Π–tool are illustrated in Figure 9. The vertical axis represents the potential risk value per hour and the horizontal axis represents the three important traffic characteristic parameters considered in the model—heavy vehicle percentages, LOS and the approximate level crossing distance from the nearest intersection. LOS has been grouped into three—A and B, C and D and E and F. The level crossing distances from the nearest intersection can be classified into four criteria—more than 200 m, from 200 m to 50 m, from 20 m to less than 50 m and less than 20 m.

![Figure 9 The potential risk according to traffic parameter](image)

The trend in the graph shows that the potential risk value is almost zero when the LOS are at A and B in considering heavy vehicle percentages and the distances of level crossing from the nearest intersection. The potential risk values increases as shown at LOS C and D, and continues to increase and reach the maximum values for LOS at E and F. The other traffic parameter that influences the potential risk values is the level crossing distance to or from the nearest intersection. The potential risk values are higher when the distances of the level crossing to or from the nearest intersection are closer. For example, the potential risk value is greater at LOS E and F and when the distance of the level crossing from or to the nearest intersection is less than 20 m. These explain that the higher risk is posed at a level crossing when the traffic LOS is at LOS E and F. It was due to the fact that at LOS E and F, the traffic
is close or at capacity and caused immovable traffic. Furthermore, the intersection location which is closed to the level crossing also will significantly increase the risk especially when it is a signalised intersection. Due to stop and go traffic and a possibility that the front traffic stops due to a red signal or slows down to change direction, the delay time for traffic to clear the IA before the train comes increases.

The effect of heavy vehicle percentages on the road is also discussed. The potential risk values obtained represents risk posed by cars and heavy vehicles when passing the interaction area. Only cars pass the level crossing when the heavy vehicle percentage is assigned as zero. As the percentage of heavy vehicles increases, the heavy vehicles potential risk values also increases. However at 50% of heavy vehicles on the road, the risk posed by heavy vehicles is higher compared to cars even with equal traffic volume on the road. Heavy vehicle risk is about 54% of higher than cars when the percentages of traffic types on the road are equal. In reality, the risk of heavy vehicles passing the level crossing is higher due to various reasons such as size of heavy vehicle and the load carried. Davey (2008) reported that in recent years the number of heavy vehicles and train accidents at level crossing in Australia has been increasing compared with cars.

From 125 level crossing locations which were experiencing accidents and/or near miss incidents in South Australia, 30 locations were randomly selected for model calibration and another 30 locations for model validation. During model calibration, each location was tested using their characteristics as input parameters. The initial Potential Risk (PR) value was obtained from the steady state analysis generated automatically from the Π–tool. Further refinement is made to the initial PR value using Matrix Adjustment Factors (MAF) to obtain PR adjusted value. The MAF is established by taking into consideration other factors including historical data—accidents and near miss incidents data, queuing problems and number of track lanes at level crossing locations. Unique numbers are given to all combination of factors as illustrated in Table 1.

<table>
<thead>
<tr>
<th>Accident History</th>
<th>Near miss incident within 5 years</th>
<th>Queuing problems</th>
<th>Number of railway track</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 &amp; 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥ 5</td>
<td>4.4</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>1 &amp; 2</td>
<td>4.2</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>non</td>
<td>3.2</td>
<td>0.9</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 &amp; 4</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥ 5</td>
<td>1.2</td>
<td>0.1</td>
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<td></td>
<td>1 &amp; 2</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>non</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

The same procedure is undertaken during model validation process. At this stage, the MAF is directly applied to 30 level crossing locations selected and PR adjusted is obtained. Simple statistical comparison was conducted and the graph was plotted in Figure 10. The graph shows the ranking number using two models—ALCAM and LXsafe_Pnets on x axis, versus level crossing locations numbered from 1 to 30 on y axis. For model comparison purposes, the level crossing locations’ number is based on ALCAM rank. The lower the rank of ALCAM (e.g. ranked as number one) means that the location is identified as the higher priority given by
ALCAM. The LXsafe_Pnets ranking locations are plotted by including two rankings based on initial potential risk value before and after adjustments. At some points, the graph shows obvious difference in ranking number using LXsafe_Pnets model for PRinitial and PRadjusted. Therefore, it can be concluded that MAF is capable in increasing and or lowering the PRinitial value. At some level crossing locations, the LXsafe_Pnets (PRadjusted) rank fits the ALCAM rank. ALCAM model is used as a reference in the comparison. The reason is due to the fact that ALCAM is the only model implemented and widely used in Australia

Further test is conducted to validate the model and the result obtained is tabulated in the Table 2. The ranking locations given by Petri nets and ALCAM model are grouped into three groups based on higher to lower ranking points. The group is given as the first, second and third top ten locations. The result shows that the ranking locations based on these two models is matched at or more than 80% with lower percentage deviation value (PDV) range from 0.1 to 0.2. The PDV used to compare the rankings of the two datasets containing different locations. If the PDV is lower, that means the ranked dataset contain great numbers of common elements. Further comparison is made to examine the differences between these two models using the Chi–Square Goodness of Fit and Mann–Whitney U tests. Both tests show that the two models follow the same distributions at 95% confidence intervals.

<table>
<thead>
<tr>
<th>Ranking location groups</th>
<th>Location matched ALCAM &amp; PR (adjusted)</th>
<th>PDV value</th>
<th>validation</th>
<th>Model comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chi–Square Goodness of Fit test</td>
<td>Mann–Whitney U test</td>
</tr>
<tr>
<td>1st top ten locations</td>
<td>90%</td>
<td>0.1</td>
<td>χ2 calculation (27.8) &lt; χ2 table (36.42), the two models follow the same distribution ( sig 0.05)</td>
<td>P = 0.9923 &gt; p=0.05, the two models follow the same distribution</td>
</tr>
<tr>
<td>2nd top ten locations</td>
<td>80%</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd top ten locations</td>
<td>90%</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the purpose of this research, the potential risk posed by heavy vehicle is further investigated. Only 30 locations used for model calibration is chosen. However, from the total
potential risk obtained, only 15 locations appear to give significant contribution to the level of risk involving heavy vehicles. The detail of only significant locations which posted higher potential risk is shown in Figure 11.

![Potential risk locations for cars and heavy vehicles](image)

Figure 11 Potential risk locations for cars and heavy vehicles

The potential risk location involving cars and heavy vehicles is obtained from the simulation analysis at selected level crossing locations. The model is simulated using the specific traffic volume data, heavy vehicle percentages and other important parameters as mentioned in section 4.1. The result demonstrates the risk involving heavy vehicles and cars are contributed from a chain of events which involved the association of factors. From the graph, even though higher traffic volume on the road may contribute higher risk to heavy vehicles (RLX0034), however at some locations with low traffic volumes, the heavy vehicles risk is also higher (RLX0533). The pie chart provides a clear indication of the locations with their risk percentages. The top three from the selected level crossing locations in South Australia which posted higher risk to heavy vehicle are RLX0034 (Woodville Road, Woodville) which indicated 58% from the 15 selected locations, followed by RLX0533 (Commercial Road, Salisbury North) with 9% and RLX0002 (Cross Road, Unley Park) with 6%.

6. CONCLUSION AND RECOMMENDATION

In this paper, Petri nets are introduced as an alternatives approach in assessing the risk at level crossings in South Australia. The dynamic model using EDSPNs and the П-tool allows an extension of time and hierarchy to represent real and complex systems such as at level crossings. The potential risk involving heavy vehicles at level crossings is assessed. The model is designed to consider several scenarios and parameters that can influence the formation of potential risk at level crossings. A few key parameters were chosen from the existing level crossing management (LXM) database including traffic and train volumes,
traffic characteristics (approaching speeds, level of service (LOS) and heavy vehicle percentages, train characteristics), train approaching speed and train length, and the level crossing surrounding environment—the approximate level crossing distance to or from the nearest intersection. It may be concluded that the important factors contributing to higher potential risk by heavy vehicles were the effect of LOS, heavy vehicle percentages and the distance to the level crossings from the nearest intersection. Furthermore, calibration refinement was made for the model and other critical factors were also evaluated. The matrix adjustment factor (MAF) was formed in constructing the historical database—accidents and near miss incidents, the queuing phenomenon and numbers of railway tracks at locations. Therefore additional factors as considered in the MAF can be other factors affecting the potential risk obtained at level crossings. The ranking locations obtained using the two models—Petri nets and ALCAM—are compared during the calibration and validation process. The Chi–Square Goodness of Fit and Mann–Whitney U tests demonstrated no significant difference between the two models and the models follows the same distribution. The effect of heavy vehicles on level crossing safety is assessed using 30 level crossing locations. Only 15 locations posted higher potential risk to heavy vehicles. The top three level crossing locations identified by Petri nets model were RLX0034 (Woodville Road, Woodville), RLX0533 (Commercial road, Salisbury North) and RLX0002 (Cross road, Unley Park). It is believed that the Petri nets model may help engineers and decision makers to select appropriate countermeasures especially at potential risk locations with higher heavy vehicles.

This paper is part of an ongoing research project. The next step is to incorporate the application of GIS in spatial representation of level crossings, which will link model outputs with visualisations of the surrounding land use environments, and further enhance the understanding of level crossing accidents phenomena.

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