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The Effect of Speed on Pedestrian Crossing Risk at Signalised Crossing Facility

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ABSTRACT

Background: High speed vehicle when approaching to the pedestrian crossing facility with unsuccessful braking might kill or severely injured the vulnerable road users. **Objective:** The relation of vehicular speed with pedestrian accident have been commonly mentioned in the literature, however there is still limited research that attempts to quantify the risk of vehicular approaching speed toward pedestrian. In this paper, the risks of pedestrian crossing related to approaching speed were quantified through the analysis of Petri Nets model. **Results:** The effect of speed on pedestrian crossing risk with different number of crossing lanes and different road surface condition were analysed and presented. **Conclusion:** The model analysis shows that the approaching speed of more than 40km/h is risky to the pedestrian particularly with greater number of crossing lanes.

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INTRODUCTION

Pedestrian safety studies remain as a major concern due to the high number of deaths and injuries in pedestrian accidents worldwide (Kim, J., 2010). In pedestrian safety studies, many researchers investigated the factors and relation of various possible variables that significantly affect pedestrian accident. One of the factors that have been identified as a major contributor could increase the risk of pedestrian is vehicle speed (Zegeer, C.V. and M. Bushell, 2012). This factor not only associated with the frequency of pedestrian accident occurrence, but also becomes the factor that linked with the pedestrian severity and fatality.

A number of studies explored the relation of speed and pedestrian accident. For examples, Gårder (2004) examined pedestrian accident data from the state of Maine to study the impact of speed on pedestrian safety. From his study, it is found that high speed locations having an average of speed above 40km/h has a strong relation to higher pedestrian accidents. In another study, Siddiqui *et al*. (2011) studied the occurrence of pedestrian accident using the macro level prediction model. The model retained nine significant variables include the roadway length with 35mph posted speed limit.

Speeding not only increases the occurrence of the accident, but it also increases the likelihood of being fatal or severely injured in an accident. Anderson *et al*. (1997) found that speed gives an effect to the fatality probability in pedestrian accidents. An association of speed and the risk of pedestrian fatality were studied by Kong & Yang (2010) for Chinese condition using logistic regression analysis. The results from their study conclude that the risk of pedestrian fatality increase with an increase of an impact speed. The risk of fatal pedestrian is increasing once the impact speed reach 30km/h and they may not survive at an impact speed of 80km/h. Furthermore, Rosén and Sander (2009) also conclude that the risk of fatality for pedestrian is more than twice with an impact speed of 50km/h compared to the impact speed at 40km/h.

The effect of speed to the pedestrian accident occurrence and their severity is a particular interest of the researchers. However, the previous studies have focused on the impact speed and average speed based on the posted speed limit. Quantifying the effect of approaching speed to the risk of pedestrian accident is still limited in the literature.

In this paper, the Petri Nets (PN) model is used to quantify the effect of vehicle approaching speed towards pedestrian at signalised crossing. This model predicts the potential risk based on the probability of pedestrian accident occurrence. The occurrence of pedestrian accident is translated as a hazard event in this model. It

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acquires an understanding of the complex interaction of pedestrian and vehicle as a sequence of events in accident process.

PN have been recognised as a powerful and flexible modelling tool for risk analysis and system safety (Nývlt, O. and M. Rausand, 2012; Vernez, D., 2003). The applications of PN in safety assessment cover various areas including railway operation (Patra, A.P., 2009), air traffic control (Vismari, L.F. and J.B.C. Junior, 2011) computer based system (Aloini, D., 2012), nuclear power plant (Németh, E., 2009) and many more. The uses of PN in many diverse fields are due to its capability in modelling the dynamic system through graphical net.

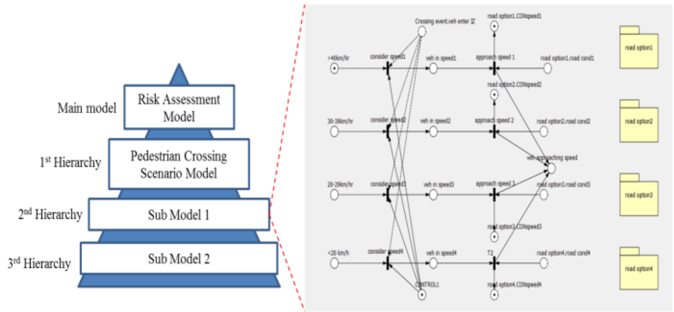
Petri Nets Model For Pedestrian Crossing Risk:

PN are a graphical modelling tool that consists of two basic nodes called place (drawn as a circle) and transition (drawn as a bar). A set of places and a set of transitions connected with the directed arrow called arcs representing as a system in the formal graph model. Places represent the condition or passive element in the model, while transitions represent the event or active element. Places may contain a token which drawn as a small black circle inside the places indicate that condition holding in the PN model.

The proposed approach in analysing the effect of speed to pedestrian crossing using PN involved a series of site observations before the qualitative data of pedestrian crossing scenario had been modelled into a set of places and transitions. The methodological framework of this study can refer to Hamidun *et al*. (2013) . The arrangement of a set of places and transitions in this model represents the sequence of events in the pedestrian accident process. It acquires the translation of pedestrian and vehicle movement in the road section prior to an accident into PN nodes (places and transitions). An event that detects the simultaneous arrival of pedestrian and vehicle in this model was identified as a hazard event (accident). The occurrence of this hazard event in the model will be quantified as the pedestrian crossing risk.

The whole developed PN model in this study was designed in hierarchical format consists of several sub models. PN hierarchical model of pedestrian crossing risk is shown as in Figure 1 (a). At the top of the hierarchy is the risk assessment model that serves as a main model to quantify the occurrence of hazard event in pedestrian crossing. Under laid this model is the pedestrian crossing scenario model, designed to represent the event sequences in a pedestrian accident process that involve an interaction of pedestrian and vehicle in the road section under the control of traffic signal.

The model related to the vehicle approaching speed is arranged under the second hierarchy of PN model. Figure 1 (b) shows the graphical net structure of this model that consider the effect of different speed groups to the pedestrian crossing risk. It contains several sub models that lay under sub model 1, named as road option1, road option2, road option3 and road option4. These sub models (sub model 2) are laid in the lowest hierarchy of the PN model. The net structure of this sub model 2 characterised the effect of road surface condition for respective speed groups.



(a) (b)

Fig. 1: The PN model: (a) in hierarchical format and (b) sub model that consider approaching speed.

Speed consideration:

The consideration of approaching speed effect to pedestrian while crossing a road section was established according to the interaction zone (IZ) as shown in Figure 2. This zone is defined as the zone where pedestrian and vehicle might have a conflict. With certain approaching speed, the vehicle would possibly pass this interaction in a certain period of time and need to apply the brake to stop before the stop line. The time consider in this condition is referred to the time delay of vehicle in passing the interaction zone (IZ). If the vehicles are not able to stop before the stop line, it might collide with the pedestrian who are crossing in the designated crossing area. The movement of vehicular and pedestrian that end up with a collision were expressed as a hazard event in this study. The probability of this hazard event in this zone will be counted as the potential risk of pedestrian crossing and were identified when pedestrian and vehicle arrived simultaneously at the same point.

The approaching speeds of the vehicle in this model were classified into four categories: less than 20km/h, range within 20-29km/h, range within 30-39km/h and more than 40km/h. The selection of the speed in this study is to measure the effect of speed approaching to the intersection to the probability of pedestrian accident occurrence regardless their injury severity. Thus, the times taken for the vehicle to stop with 20m from the stop line for the respective speed group were calculated according to the dry and wet road surface condition is limited to the 40km/h.

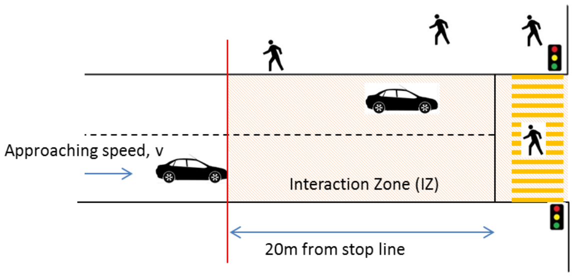


Fig. 2: Consideration of approaching speed in the model.

The calculation of time delay of vehicle in passing the interaction zone (IZ) was established based on the time taken for a vehicle to pass the road section with the consideration of the braking distance either in dry or wet surface condition. For each speed group, the average value of the speed was selected as reference speed for the calculation of time to stop. The breaking distance was calculated according to the stopping sight distance (SSD) formula given by the following equation:

$$SSD = 0.278Vt + \frac{V^2}{254(f+g)} \qquad (1)$$

Where V is the approaching speed, t is the reaction time for driver (taken as 1s for operation reaction time), f is the coefficient of friction (assume 0.9 for dry condition and 0.6 for wet condition (Ghandour, R., 2010) and g is the gradient (assume to be 1 for flat terrain). Since the gradient is assumed to 1, thus the effect of speed on the pedestrian crossing risk is only applicable to the case at the signalised crossing facility located on the flat terrain.

RESULTS AND DISCUSSION

The effect of vehicle approaching speed on the potential risk of pedestrian crossing at signalised crossing were analysed according to the PN model. The approaching speeds of vehicles were grouped into four categories and the effects were tested according to the different crossing lanes: 1-2 lanes, 3-4 lanes, 5-6 lanes and 7-8 lanes. From model analysis, the effect of speed and crossing lanes to pedestrian risk is graphically depicted in Figure 3. The value of the potential risk of crossing pedestrian from this model is referred as the accident rates per hour crossing.

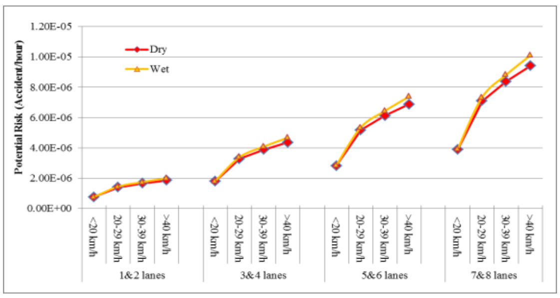


Fig. 3: The potential pedestrian crossing risk for different values of approaching speed .

The risk of <20km/h for 1-2 lanes gives the lowest risk to the crossing pedestrian. As the speed increases, the risk is slowly increasing. For 3-4 lanes, risk of <20km/h is almost at par with risk of >40km/h for 1-2 lanes. With an increase of speed, the risk for 3-4 lanes is increased with steeper line trend compared to 1-2 lanes. For 5-6 lanes, risk of <20km/h show the less risk compared to >40km/h for 3-4 lanes. The risk of pedestrian was increased with an increase in speed from 5-6 lanes. The trend line of increasing risk for 5-6 lanes are steeper than 3-4 lanes.

It can be seen from the graph that higher approaching speed gives a higher risk to the pedestrian for each crossing lane. For 7-8 lanes, risk of <20km/h is higher than >40km/h for 1-2 lanes, but lower than >40km/h for 5-6 lanes. An increasing of speed gives significant effect when pedestrian crossing 7-8 lanes compared to the other crossing lane group. It can be said that the risk of 30-39km/h and >40km/h speed are more than twice with a speed of <20km/h.

From the result, speed of less than 20km/h with shortest crossing lanes gives the lowest risk value to the pedestrian. Drive approaching to the signalised crossing with speeds of less than 20km/h might be the best option for the driver to have enough time for them to recognise the signal indication before they need to apply brakes and stop before the stop line. Consistent with a study from Gårder (2004) who concludes that with an average speed of less than 18km/h, almost 100% of driver will stop for pedestrian at a crosswalk. Unfortunately, if the speed is ranging from 18-24km/h, there is only 28% of driver will stop for pedestrian. It is shown that speed of more than 18km/h may affect the safety of crossing pedestrian since the percentage of driver who will stop for pedestrian is small. With the speed of less than 20km/h, the PN model also predicting a small value of potential risk for crossing pedestrian. Thus the limit of 18km/h speed as approaching to the at grade pedestrian crossing is appropriate in ensuring the safety of pedestrians.

Speeding is one of the significant variables that will increase the probability of an accident (Abdel-Aty, M.A. and A.E. Radwan, 2000) . When approaching to an intersection or midblock, speeding is also part of the violation made by the driver (Young, K.L., 2012) . An average speed of more than 40km/h can be considered as a high speed and dangerous to the pedestrian safety (Anderson, R.W.G., 1997) . Speed more than 40km/h would give higher risk to the crossing pedestrian as the higher speed gives no time to driver to think and braking in avoiding any collision with the crossing pedestrian. As high approaching speed might cause a driver in dilemma whether to decelerate and stop at stop line or accelerate their speed to cross the stop line (Papaioannou, P., 2007) . This dilemma possibly ends up with the violation to the signal indication which will be worst when the driver violate while the pedestrian utilizing the right of way to cross the road section.

Refer to the Figure 3, the potential risk of pedestrian crossing in dry surface condition is shown in the red line, and the risk in wet surface condition in the yellow line. The risk of pedestrian is slightly higher during rainy day when the road surface becomes wet as compared to the dry road surface condition. Contradictory, the pedestrian accidents were more likely to occur in the clear and sunny weather, where the road surface is dry (Al-Omari, B.H. and E.S. Obaidat, 2013). This may due to the decrease of pedestrian activity or driver tend to slow down during the rainy day as compared to the clear weather. However, it is a fair assumption that the risk of pedestrian is higher in wet surface condition if the crossing activities by pedestrians remain high and the drivers maintain the same speed as in dry surface condition. Results presented in this paper are limited to the effect of vehicle speed which depending on the factors covered in the equation (19). The breaking scenario that associated with the road condition and driver braking reaction time, and this condition is worsening if the friction coefficient is lower during the rainy day (Svenson, O., 2012).

Conclusions:

The analysis of PN model in predicting the effect of approaching speed of vehicle to pedestrian risk has been described in this paper. The estimation of the risk to the pedestrian is based on the occurrence of hazard event state in the PN model. Different values of vehicle approaching speeds were classified into four speed groups and modelled as a parameter that affect the risk of pedestrian while crossing a road section. The analysis of this model provides an alternative approach in quantifying the risk of pedestrian that associated with the vehicle approaching speed. The risk of pedestrian is increasing with an increase of speed for every number of lanes crossed by pedestrian. An approaching speed of more than 40km/h at a distance of 20m from stop line would result in killing a pedestrian at signalised crossing due to insufficient time of breaking. The approaching speed to the intersection or midblock with pedestrian crossing facility should be less than 20km/h to ensure the safety of pedestrian is guaranteed. An effective speed reducing measures such as speed table may be installed at some intersection or midblock with high number of pedestrian.

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