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PEDESTRIAN POTENTIAL RISK WHILE CROSSING AT SIGNALIZED INTERSECTIONS

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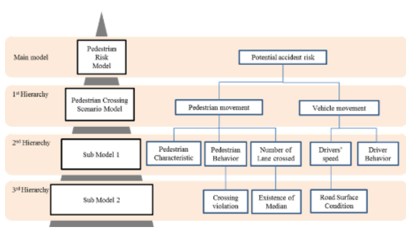
Graphical abstract



Abstract

Risk of pedestrian while crossing a road section may influence by several factors, including their crossing behaviors which might be difficult to be measured. In this paper, a model using Petri nets is introduced to consider the behavioral factors in measuring pedestrian risk. The crossing scenario of the pedestrian was observed to identify the pedestrian accident event. Sequence of event in pedestrian accident was modeled into Petri Nets elements. The model is designed in the hierarchical structure to consider risk factors related to human behavior, engineering and environment. The analysis of the model provides the numerical value of pedestrian potential risk as they crossed at a signalized intersection. The effect of each factor on the potential risk can be observed through sensitivity analysis. The use of Petri Nets is a novel approach in predicting pedestrian potential risk through the modeling of pedestrian accident process.

Keywords: Accident risk, crossing, signalized intersection, Petri Nets

1.0 INTRODUCTION

Road accidents, including pedestrian accidents have become a great lost due to a large number of people died and injured. The Global status report on road safety 2013 showed that about 273,000 pedestrians were killed in 2010, which constituted 22 percent of the world road traffic deaths [1]. In addition, vulnerable road users such as pedestrians have a higher risk of death per kilometer travelled and become a large portion of road victims in low and middle income countries [2].

In the light of the pedestrian safety issues, many researchers have put their initiative to understand the association of the risk factors to the estimation of pedestrian accidents. Through the conventional risk analysis, the risk factors can be identified, and the effect of these factors on the pedestrian accident can be examined. Different techniques have been proposed and applied in the conventional risk analysis, which favor the statistical approach.

However, many accident prediction models developed through the statistical approach rely on the information available in the historical data [3]. For examples, Leden in [4] utilized accident data at signalized intersections to established simple and practicable models using generalized linear model. The model was useful to predict the expected number of accidents at particular places and to identify factors associated with the accidents. While in [5], the 4 years data of pedestrian accident were analyzed using the log linear model to explore the exposure of pedestrian risks while walking on the roads. The result revealed the strong relation of pedestrian and driver characteristics, road geometry, traffic and environmental conditions to pedestrian accidents frequency and injury severity. In another study, Pulugurtha and Sambhara [6] estimated the risk of pedestrian accident using accident data for 176 signalized intersections and other predictor variables. The results concluded that pedestrian accident estimation models will be more accurate if the number of pedestrians at a signalized intersection is more than forty.

Issue related to the poor quality of data, especially in the developing country will lead to the misleading estimation on the risk factors [7]. One of the most important risk factors in pedestrian accident actually relates to their behavioral factors [8], which normally missing in the conventional statistical approach. In addition, the violation behavior of pedestrian and dangerous crossing are commonly observed at signalized intersections [9], [10]. An absent of pedestrian behavioral information in most accident data, come to be a reason of why most accident prediction models using statistical approach seem to neglect the pedestrian behavior as one of the risk factors. Apart of the pedestrian behavior, the violation of drivers is also contributed as one of the risk factors in pedestrian accidents [11]. Driver violation can be classified as committing a violation at a signalized intersection when the driver is either not stopping for pedestrians or proceed without considering pedestrians leaving the crosswalk after they have stopped [12].

Even though modeling the pedestrian accidents using a statistical approach is able to relate pedestrian accident with its associated factors and reveal the significant factor, the triggered factors close to the accident may be ignored or eliminated. The reliance of accident data in modeling somehow becomes a restriction to consider the behavioral factors when it is unavailable in the data set. In considering the behavior of pedestrian in accident modeling, Yannis in [13] has proposed a method to merge a nested logit and linear regression model. However, merging two models in developing hierarchical modeling framework to estimate the risk of pedestrian is not always straightforward.

A different approach of modeling to estimate the risk of pedestrian accidents was introduced by Hamidun *et al*. in [14], [15] through the application of Petri Nets. This model provides an alternative modeling method that able to integrate the behavioral factors with other factors in one model. A successful model that considered twelve (12) risk factors including behavioral, engineering and environmental factors as explained in [16] will undergo sensitivity analysis to observe the effect of each factor to the value of risk. Taking pedestrian accidents at signalized intersections as a case study, the employment of Petri Nets to estimate the risk of pedestrian while crossing a road section, and result of sensitivity analysis are presented in this paper.

2.0 PEDESTRIAN ACCIDENTS AT SIGNALIZED INTERSECTIONS

Pedestrian accidents are one of the major accidents happen at signalized intersections [17]. A collision between a pedestrian and a vehicle at this location can be expected as they share the same space. The movement of pedestrians and vehicles is only separated by allocating certain time period as their right of way to pass the intersection. The allocation of their right of way at a signalized intersection can be notified with the green signal phase for specific traffic movement. Thus, obedience to their right of way at a signalized intersection is important in avoiding a pedestrian accident.

2.1 Pedestrian Accident Process

The developed model in this study is adopted from the pedestrian crossing scenario observed in the study locations, which was filming using video cameras to be used as a qualitative data for model development. This data is very important to understand the risky situation of a complex interaction between pedestrian and vehicle at signalized intersections.

A scenario can be characterised as an arrangement of a set of events [18], and each event in the pedestrian crossing scenario can be modeled using Petri Nets elements. A set of events in the pedestrian crossing scenario is expected to identify the hazard event for crossing pedestrian. This hazard event has been extracted from an observation of the conflict situation occurred during the field studies. Conflicts are the event that is close to the accident. An interaction of people in a system that possess hazardous characteristic can be used to describe risk scenario [19]. Therefore, observing the interaction between pedestrian and vehicle in the conflicts event provide the most similar scenario in the accident event. Starting from the safe event and ending to the hazard event (conflicts) can be seen as a process. Thus, the sequence of event is structured as the pedestrian accident process at signalized intersections. The terminology of the pedestrian accident process is linked with the sequence of events that consider the movement of pedestrian and vehicle can be refer to [15], [20].

2.2 Modeling

The event sequence of the pedestrian accident process is arranged in the stochastic Petri Nets model to build the net structure consists of places, transitions and arcs. The place defines an elementary state of Petri Nets marking, and the transition change the elementary state of the place. While the arcs specifies the relationship between places and transitions. The net structure must comply with the Petri Nets qualitative measure, otherwise the model is considered in deadlock condition and the analysis of the model cannot be performed. Thus, the net structure needs to be refined and acquires several trials of modification such as rearranging the place and transition, change the type of arc used or the direction of the arc arrow.

In this study, the whole model structure was designed in the hierarchical form, which consist of several sub models is shown in Figure 2. The top hierarchical model, recognized as the main model considers the potential risk of pedestrian accidents.

An identification of hazard state events as a risk of an accident from the pedestrian accident process was translated into Petri Nets elements. The representation of this hazard state event in the Petri Nets model, which placed in the top hierarchy, is depicted in Figure 3. The potential risk can be observed when pedestrian and vehicle were simultaneously arrived in conflict zone (CZ). This condition is replicated by the simultaneous token fired from two places *Crossing event.veh in CZ* and *Crossing event.ped in CZ*.

Token in this model started in place *No Risk* represents the normal condition or desired condition of the system. Only when all input places, namely *No Risk*, *Crossing event.veh in CZ* and *Crossing event.ped in CZ* have token, the transition *Potential Risk* in this model will be fired. Once it fired, the token is transferred to the *Risk* place that represents the occurrence of an accident or risk state in the system. When an accident happens in the system, several actions need to accomplish to clear the accident, such as sending the pedestrian to the hospital. This action is represented as firing action by Removing risk transition in this model. This transition distributes the token to the *Risk removed*, the *Crossing event. ped outside WZ* and *Crossing event.veh out IZ* places.

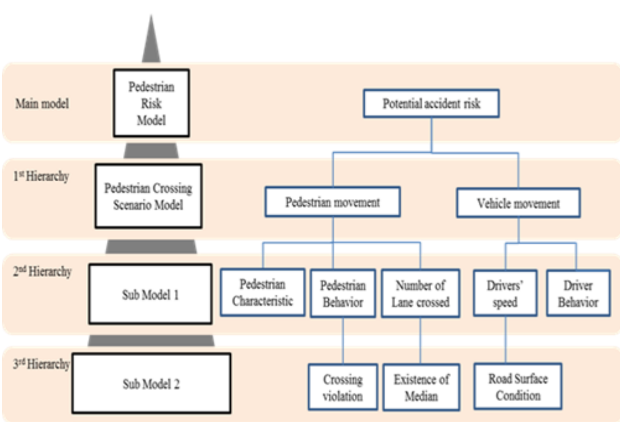


Figure 2 Structure of the model in hierarchical format

After the accident has been cleared from the system, the condition is reset to be normal again, and represent by assigning the token back into *No Risk* place in this model.

Under laid the main model is the first hierarchy model named as the pedestrian crossing scenario model, which consider the movement of pedestrian and vehicle passing the road section. This model represents the event sequence in the pedestrian accident process, was explained in [15]. This model was developed through the imitation of the pedestrian crossing scenario which has been extracted from video recording during data collection at the study locations.

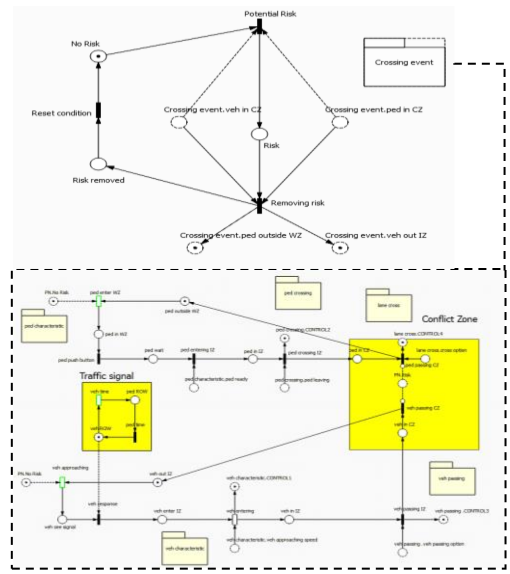


Figure 3 Pedestrian risk assessment model, placed on the top hierarchy as the main model

Several sub models that consider the effect of other factors, were laid under the pedestrian scenario model, as the second hierarchical model. These sub models were used to represent the effect of the pedestrian behavior, number of lanes crossed and the drivers' approaching speed, to the risk of pedestrian accident at the signalized intersections.

Figure 4 shows the representation of the sub model that considers the behavior of pedestrians, called as complier and jaywalker pedestrian. On the left side is the second hierarchy sub model that has two folders marked as 'complier crossing' and 'jaywalker crossing'. Each folder contains the third hierarchy sub model that considers the crossing violation, either to comply or to violate the signal indication at the intersections which illustrated on the right side of Figure 4.

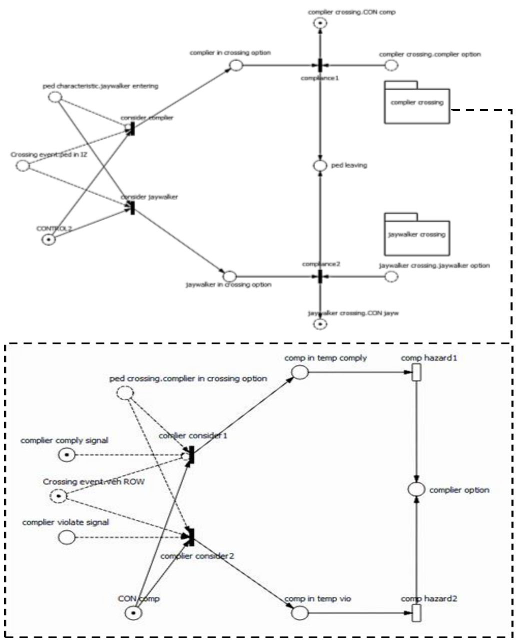


Figure 4 Sub model that considers pedestrian violation behavior

The Petri Nets representation of the sub model that considers the number of lanes is illustrated on the left side of Figure 5. The consideration of lane crossed by the pedestrian in this model covers the shortest length of 1 lane to the widest length of 8 lanes. Thus, eight places were used to represent the option of lane crossed for this model. There are four sub models laid under this model, positioned in the respective individual folder; median option1, median option2, median option3and median option4. These sub models were placed under the third hierarchy sub model to consider the effect of the median existing at signalized intersections. The effect of number of lanes and the median existence represents the risk factors related to engineering. However, the effect of width of the median is not considered in this study.

Figure 6 represents the sub model that considers drivers' approaching speed. The approaching speed was categorized into four different groups: <20 km/h, 20-29 km/h, 30-39 km/h and >40 km/h. Another four sub models that consider the combined effect of different speed group with the road surface conditions, were placed in four folders as the third hierarchy sub model; road option1, road option2, road option3 and road option4. The road surface conditions take into account the effect of either dry or wet road surface. An example of the road option1 sub model was shown on the right side of Figure 6. The effect of the drivers' approaching speed and the road surface conditions represent the risk factors related to the environment.

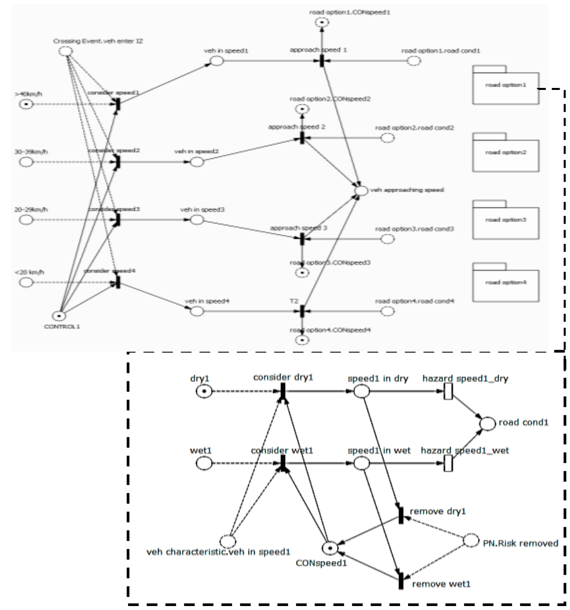


Figure 5 Sub model that considers the number of lanes and median existence

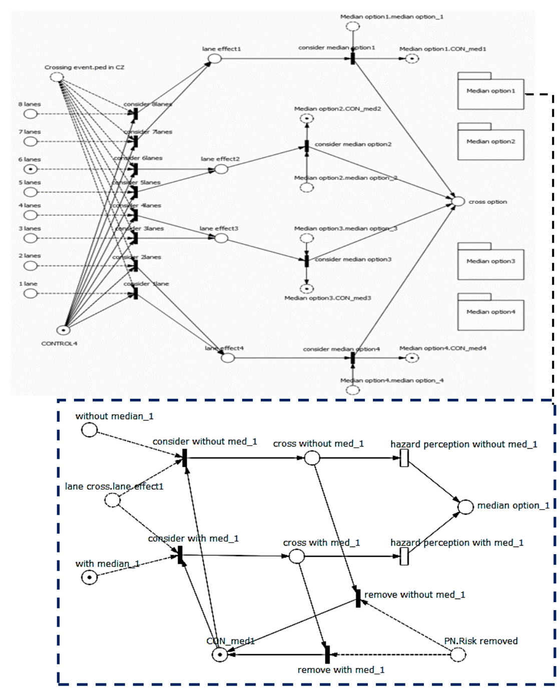


Figure 6 Sub model that considers the approaching speed of drivers

3.0 MODEL ANALYSIS AND VALIDATION

A total of twelve risk factors was tested to observe the effect of each factor on the estimation of risk through the sensitivity analysis. However, only four risk factors showed the significant effect on the risk estimation. These risk factors include the number of lanes, existence of median, approaching speed of vehicles and temporal violation of pedestrian. The effect of these combined factors on the risk of pedestrian while crossing at signalized intersections were tested again and the results are illustrated in Figure 7. The value of potential risk for pedestrian crossing was taken as an occurrence of pedestrian accident per hour. Other factors such as pedestrian volume, vehicle volume, green signal time, pedestrian age group, pedestrian gender, jaywalking behavior, driver behavior and road surface condition would only give mild effect on the risk estimation.

The road section with 1 and 2 lanes, with or without a median gives a lower potential risk to the pedestrian. The risk is slightly increased with the increase of approaching speed. However, the effect of pedestrian temporal violation is noticeable though the road section that needs to be crossed by pedestrian was only 1 and 2 lane sections. The risk almost doubled when pedestrians crossed at 3 and 4 lane roads and triple when crossing 5 and 6 lane roads. The highest potential risk can be observed when pedestrians crossed at 7 and 8 lane roads. With a larger number of lanes while crossing the road, pedestrians need to spend more time in the interaction area (road section) and more likely to be exposed to the risk of an accident with an oncoming vehicle. This finding is supported by Aziz et al. [21], where a greater number of lanes is found to be significant to the probability of pedestrian fatal injury.

The effect of medians to the potential risk can be observed when the number of lanes increase to the 3 and 4. At this level, the increasing trend of potential risk seems to be noticeable between road sections having medians and without medians. Similar trends can be observed for 5 and 6 lanes, and 7 and 8 lanes. Moreover, the potential risk for 5 and 6 lanes with medians is lower compared to 3 and 4 lanes without medians, and the potential risk of 7 and 8 lanes with medians is lower than the potential risk for 5 and 6 lanes without medians. These results show that the existence of medians on the road section gives more visible effect in dropping the risk of pedestrians. This result is comparable with findings from Zeeger et al. [22]. Thus, placing a median at wide intersections to be used as a refuge island for pedestrians seems to be reasonable for their safety, where it is usually used for pedestrians to stop and wait at a different position [23].

The effect of approaching speed and road surface conditions were also analyzed using this model. High approaching speed would give higher potential risk compared to the low approaching speed in all situations. The effect of higher speed is more observable when the number of lanes increased. This finding is consistent with Elvik et al. [24] who found that with an increase of approaching speed to the pedestrian crossing area, the number of accidents was expected to be increased. On the other hand, the effect of road surface conditions either wet or dry is neglected in this case, due to very low effect compared to other factors. Wet road surface is expected to have slightly higher risk compared to the dry road surface.

The effect of pedestrian behavior can also be observed from the results. The risk of pedestrians is higher in all cases if they violate the signal while crossing at signalized intersections. Crossing the road section when the signal indicates green for the vehicles' right of way would risk the pedestrian to be exposed to an accident. The result is consistent with the finding concluded by King et al. [25] which states that the risk of crossing against light is higher compared to the legal crossing at signalized intersections. The frequent occurrence of such behavior on the signalized intersection increases the likelihood of being involved in road accidents since they tend to cross at the same time as when the vehicle traffic is moving. In addition, the risk of violating pedestrians seems to be obvious with increasing approaching speed, and it gets worse as the number of lanes increased without the existence of a median.

This model has been validated by comparing the potential risk estimated with actual risk values obtained from historical accident occurrences at 30 signalized intersections located in Kuala Lumpur, Malaysia. The chi-Square goodness of fit was used to test if the estimated and actual risk value follows the same distribution. The calculated Chi-Square value for the 30 selected signalized intersections is much smaller than the critical Chi-Square value. Thus, the test indicated that the estimated potential risk s from model and accident data follow the same distribution trend at a 5 percent significance level ($p = 0.05$).

4.0 CONCLUSION

The applicability of the Petri Nets in modeling the pedestrian accident process observed at signalized intersections was described in this paper. The model developed using Petri Nets approach, serves as an alternative method in the pedestrian safety study to predict the potential risk of crossing pedestrians. This involved an interpretation and understanding of the sequence of events in the pedestrian accident process while crossing the road sections. The risk for pedestrian is recognized when the pedestrian has a great potential to be colliding with the incoming vehicle they were crossing. The hierarchical structure of the model would be benefit in integrating several factors associated with the pedestrian accident risk. Analysis of the model showed that the risk of crossing pedestrians would be lower when they comply with the signal indication at the low traffic with a low approaching speed on the road with 1 and 2 lanes equipped with a median. Greater potential risk can be expected when pedestrian cross at busy roads with cars having a high approaching speed, 7 and 8 lanes, without a median, and pedestrians adopting a dangerous crossing style.

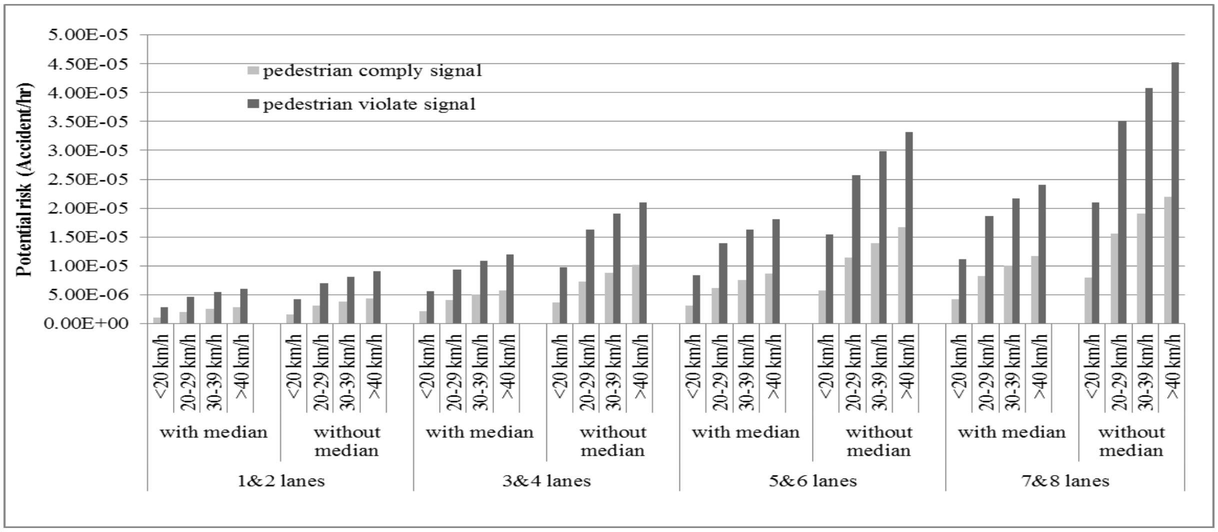


Figure 7 The effect of the number of lanes, approaching speed, median existence and pedestrian violation on pedestrian risk

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