Developing a Simulation Tool for Traffic Safety Assessment at Signalized Intersections

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The global objective of this study is to develop a new traffic simulation tool for the safety assessment of signalized intersections. In this study, the requirements to develop a simulation tool dedicated for the safety assessment is discussed. The essential idea is that safety levels of signalized intersections can be measured by estimating frequency and severity of potential of conflicts as well as the distribution of conflict locations. By incorporating several crucial models which represent the stochastic behavior of different road users, the potential conflicts can be reproduced inside the microscopic simulation environment as stochastic distributions that are sensitive to intersection geometry and signal timing. It is concluded that the proposed approach to assess the safety is unique and promising; however a proper validation is necessary.

Key Words: *Traffic flow simulation models, traffic conflicts, signalized intersections, safety assessment*

1. INTRODUCTION

In Japan in 2009, over 40% of all urban traffic accidents happen at intersections[1)]. One third of these accidents happen at signalized intersections. It is necessary to make explicit considerations of safety assessment development in order to improve traffic safety at signalized intersections.

Behavior of road users at signalized intersections is very complicated. It is variant and sensitive to layouts as well as traffic operational policies. In order to find the best way to improve the safety performance of signalized intersections, it is necessary to know how road user behavior changes based on different layouts and operational policies and to know how each behavior contributes to the risk of conflicts. In the same way, safety levels of signalized intersections can be evaluated. In order to conduct a comprehensive evaluation process, it is needed a tool which can quantitatively evaluate traffic safety performance of signalized intersections. For recent years, many researchers and practitioners have utilized microscopic simulation tools as an innovative approach for conducting traffic safety evaluation. That is because of their cost effectiveness, flexibility and the fact that different settings can be tested without putting road users at risk. However, existing microscopic simulation tools are mainly used to evaluate the traffic flow quality. They cannot sufficiently represent impacts of intersection layouts, operational policies. The movements and decision making of road users at signalized intersection in these tools are not sensitive to changing of intersection layouts and operational policies. There is no agreement about the suitability when using these tools to assess traffic safety at signalized intersections. Thus, it is very necessary to develop a new traffic simulation tool for traffic safety assessment at signalized intersections.

The objective of the study is to discuss the requirements of developing a simulation tool dedicated for the safety assessment of signalized intersections. The safety assessment inside the simulation tool is based on microscopic analysis of the potential conflicts between various road users in terms of frequency and severity as well as distributions of conflict points. It incorporates many crucial road users' behavior models such as turning paths, turning speed as well as decision making of road users to signal timing and other conflicting traffic streams etc. These models have been empirically modeled and they reasonably represent movements as well as decision making of road users at signalized intersections. Although, the simulation tool itself has not been completely developed, this paper introduces the basic concepts and requirements to assess safety by simulation, as well as behavior models which are used as components of the simulation model.

2. LITERATURE REVIEWS

This part starts with an overview of methodologies of traffic safety assessment. It is followed by reviews and discussions regarding the applicability of existing traffic simulation tools in evaluation of traffic safety.

For assessing safety of traffic facilities, many studies have been conducted using the historical crash-based methods[2), 3), 4), and 5)]. The most recent study by FHWA which can be considered as a typical example of this methodology is shown in Highway Safety Manual 2010[5)] (HSM 2010). Main methodology within the manual is the historical crash-based method for predicting expected average crash frequency of a traffic system. The most significant challenge of this method is that, it requires a very large amount of data for processing and analysis such as accident historical data, traffic volume data, and roadway physical characteristics, etc. It would be very expensive and time consuming to collect as well as to verify data. In addition, these macroscopic models try to use some explanatory variables such as type of intersections, angle of the intersection, AADT and type of signal phase, etc, to predict total number of crashes. It is difficult to perform predictions of safety performances at signalized intersections because of dynamic changes of conditions such as intersection layouts and signal timing, etc.

Rather than historical crash-based methods, traffic conflict techniques (TCT) have being used as one of the most prevalent methods for assessing safety of traffic facilities. There are two approaches to implement this method that includes using observation data or traffic simulation tools. Gettman *et al.*[6)] discussed the drawback and shortcoming of the TCT from observation data. They found that, the main limitation of this approach is expensive and it includes the problem of unreliable subjective observers.

In recent years, several researchers have used traffic simulation tools with TCT as an innovative way for conducting traffic safety assessment. A lot of studies and discussions about this issue can be found in Gettman *et al.*[6)], Huguenin *et al.*[7)], Archer *et al.*[8)], Pirdavani *et al.*[9)]. All these studies have the same approaches which try to utilize existing microscopic traffic simulation tools as a means of analysis. However, existing microscopic traffic simulation tools still have some weaknesses and shortcomings in the viewpoints of safety assessments. They are mainly developed for purposes of traffic flow quality evaluation[9)]. Major behavior models in existing microscopic traffic simulation tools are gap acceptance, lane changing, car following. Many crucial models for representing the movement of vehicles at signalized intersections such as turning paths, turning speeds as well as reaction to signal timing and conflicting traffic streams, and etc, are missing or not sensitive to changing of layouts and operational policies at signalized intersections. Thus, there is no agreement about the suitability when using these tools to assess traffic safety at signalized intersections.

From literature reviews, it is concluded that existing simulation tools cannot fulfill the requirements of safety assessment, thus this study proposes a comprehensive and sophisticated approach to develop a simulation tool which is reliable enough to evaluate the safety performance of signalized intersections.

3. BEHAVIOR OF ROAD USERS AT SIGNALIZED INTERSECTIONS

Safety level of a signalized intersection can be expressed by frequency of conflicts, dispersion of conflict points on the pavement area of the intersection as well as severity of the conflicts. Characteristics of a conflict depend on how involved road users behave. Therefore, it is necessary to know which behavior of road users is involved in a conflict situation and its role in contributing to the characteristics of the conflict.

Basically, behavior of road users at signalized intersections can be divided into two groups, driver behavior and pedestrian behavior. In the following parts, the typical behavior of road users at signalized intersections of each group is classified and discussions of each behavior are then given in order to identify the requirements for the simulation developments.

Fig.1 Basic models underlying road users' maneuvers at signalized intersections

(1) Driver behavior

Driver behavior of at signalized intersections can be classified into four groups as shown in **Fig.1**.

(a) Car following and lane changing behavior

These models follow the same principles at intersections and on connection roadways. For this, existing models from literatures can be used. Car following and lane changing behavior are, hence, not further discussed.

(b) Trajectory choice

Movements of vehicles are described in two components, paths and speeds. Path choice shows how vehicles move on the plane pavement area of intersections. Paths of vehicles define positions of conflicts. Thus, a larger variation of the paths leads to a larger dispersion of conflict points inside of intersections. Similarly, higher running speeds of vehicles will lead to higher level of severity of conflicts. This behavior greatly varies by intersection layouts, operational policies and other conflicting traffic streams. When changing design policies of intersections, the variation of paths and speeds will change. Thus, the safety level of intersections will change.

Existing traffic simulation tools cannot represent variations of vehicle movements at intersections. For example, in these tools, vehicle movements are based on link/node systems. While turning, all vehicles move on the same path. Regarding turning speed at intersections, most of the simulation tool allows users to define the area where vehicles need to reduce speeds and then assigns a speed distribution to that area. After passing over that area vehicles begin to accelerate to their previous desired speed. That means a different vehicles have the same behaviors such as turning paths and speeds without variation. For that reason, most existing simulation tools are not able to be used for assessing traffic safety at signalized intersection.

(c) The reaction to traffic signals

This behavior is divided into two aspects: the signal changes from green to red (stop-go decision) and the signal changes from red to green (start-up behavior). These decisions are necessary to evaluate the conflicts between vehicles from different traffic streams at intergreen period. For instance, when the last clearing vehicle decide to enter the intersection at the late-minute of the signal phase or during the red-light (stop-go decision), thus an entering vehicle, coming from the other direction will have a risk of collision. Risk of the collisions is higher if the entering vehicle chose to enter the intersection earlier before the green start (start-up behavior). These decisions are also made probabilistically, considering the existence of other vehicles inside the intersection, intersection size, signal timing and so on.

This behavior is combined with speed and path choice in order to determine the position of vehicle and then the conflicts will be defined and evaluated.

(d) Reactions to other travelers

At signalized intersections, Reactions to other travelers include reactions between conflicting vehicles as well as reactions of vehicles to pedestrians. This behavior is necessary to predict the movements of the road users which involved in a conflict situation. For instance, in a conflict situation between turning vehicles and pedestrians at crosswalks of signalized intersections, the behavior of turning vehicles depends on the locations of pedestrians to conflict positions, distance between pedestrians and speeds of pedestrians. Furthermore, usually drivers make decision not at the crosswalk but upstream of the crosswalk. Therefore anticipation of near-future conditions is also important.

(2) Pedestrian behavior

Pedestrian behavior greatly influences on the behavior of conflicting vehicles. In order to predict the behavior of vehicles it is necessary to know behavior of pedestrians. The behavior of pedestrians at crosswalks of signalized intersection is a very complicated issue. It is influenced by many factors such as layouts of crosswalks, operational policies, surrounding and opposition pedestrians, conflicting vehicles and so on. Until now, realistic models for representing movement of pedestrians at crosswalk are not available yet. Therefore, this is needed to be further considered and developed.

At this section of the paper, essential concepts of the behavior models of road users at signalized intersections have been clarified. This put the requirements for the simulation developments. By incorporating such kind of behavior models, the simulation model will be able to estimate the traffic safety of signalized intersections.

4. DEVELOPMENT OF THE TRAFFIC SIMULATION TOOL

Based on the essential concepts for traffic simulation developments as previously discussed, a simulation tool has been being developed. This section aims to introduce components and a simple example to illustrate initial capabilities of the simulation tool.

(1) Component of the simulation tool

The simulation tool includes following components, road traffic environment, road users' behavior model integrations as well as evaluation components.

a) Road traffic environment

Road traffic environment is necessary for generating traffic scenarios. It consists of a network of roads with intersections, as well as detailed intersection facilities such as intersection angle, radius of curbside corners, traffic island, pavement marking, crosswalk, traffic sign and traffic signal and so on.

b) Road user behavior model integration

Several different behavior models have been developed and incorporated in the simulation program. These models include:

(i) Paths of turning vehicles at the intersection

Paths of right-turning and left-turning vehicles at signalized intersections have been empirically modeled. A left turning path model is developed by Asano *et al.*[10]. They found that, the paths of left turning vehicles varies depending on intersection layouts (angle and radius of curbside corners), vehicle types (passenger car or heavy vehicle), entering speed and exit position on receiving roadways. Generally these concepts are similar to right turning paths. Yellow dots in **Fig.2** illustrate the outputs of the path models which are implemented to the simulation program. Variation of paths is clearly shown in this figure.

(ii) Speed of turning vehicles at the intersections

The turning speed models include right turning and left turning speed profile models. The speed profile models have been developed based on influence of the intersection geometry, the approach speeds of the vehicles among others as well as speed adaptation when vehicles react with other road users, such as pedestrians[11]. They were modeled in piecewise cubic curves. **Fig.3** shows an illustration of simulated right turning speed profiles of free flow vehicles, which are not influenced by other vehicles and pedestrians.

(iii) Stop-go behavior at the onset of yellow

The probability of drivers to decide to stop when approaching the intersection at the onset of the yellow signal is modeled by using a Logit Model[12]. By using this model, the stopping probability can be estimated and each vehicle makes stop-go decision following the probability.

(iv) Start-up behavior of through traffic

Start up behavior of through traffic includes Start up response time (SRT) and acceleration rate of entering vehicles. They are modeled by assuming a Weibull distribution[13]. The Weibull distribution has three distribution parameters, shape parameter α, scale parameter β, and location parameter γ. Each of them was estimated by influencing factors such as intersection geometry, signal control, and traffic conditions.

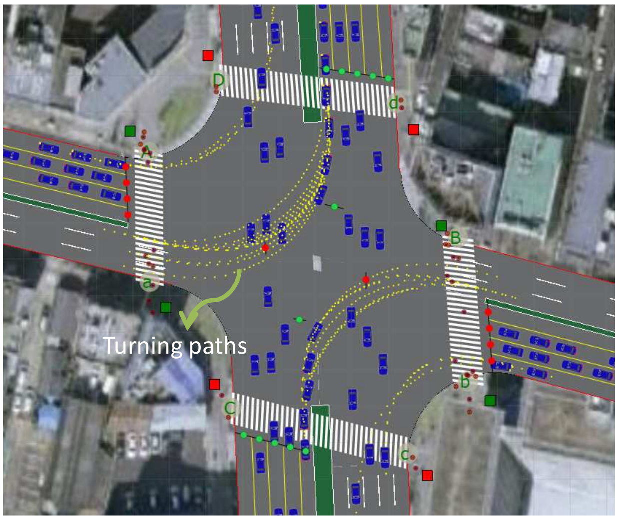


Fig.2 An illustration of turning paths of right and left turning vehicles (screenshot)

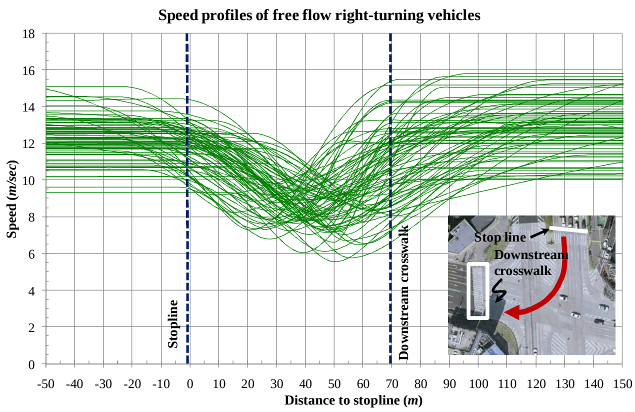
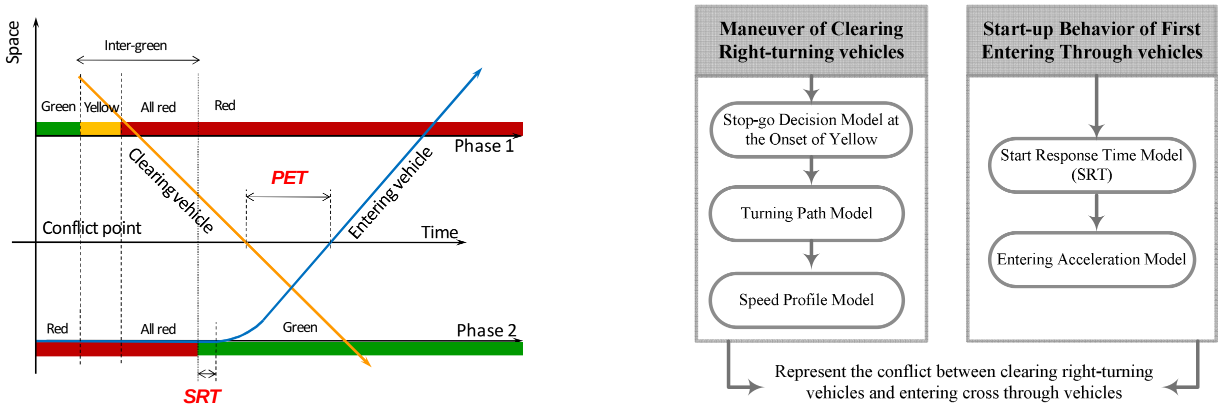


Fig.3 An illustration of simulated right turning speed profiles (generated from the simulation program)



a) Time space diagram

b) Necessary models

Fig.4 A simple scenario of a conflict between right turning vehicles and through vehicles

(v) Pedestrian behavior

As the first stage of the modeling, it is assumed that, pedestrian will not change the path and speed while crossing crosswalk. The origin and destination of pedestrians are randomly generated. However in reality, pedestrian speed and path may change by different signal timing and crosswalk geometry as well as surrounding pedestrians. It is necessary to consider these effects into the model as a future study.

(vi) Driver gap acceptance

The acceptance of gaps between crossing pedestrians by drivers have been modeled[11)]. When approaching the crosswalks, turning vehicles are assumed to predict the time gap between pedestrians. They would go if they accept the gap. Otherwise, they will decide to stop or yield to pedestrians if they reject the gap.

The model was quantified based on fitted Weibull distributions. By using this model, the decision of turning vehicles can be probabilistically estimated and then the speed adaptation of the vehicles can be assigned.

c) The evaluation components

The safety evaluation of signalized intersections is conducted base on the characteristic of conflict occurrence. Based on the incorporated behavior models, the location and the severity of each conflict will be calculated. According to existing studies on conflict analysis, safety indicators are used for measuring the frequency and severity of the conflicts. There is a variety of different safety indicators, such as Gap Time (GT), Time-To-Conflict (TTC), Deceleration Rate (DR), Post-Encroachment Time (PET), and so on. Gettman et al.[6)] pointed out in their study that PET is one of the best surrogate indicators. The PET indicator represents a difference in time between the passages of two vehicles or between a vehicle and a pedestrian to pass over a conflict point. PET can be used to evaluate most of the conflict occurrence at signalized intersections.

However, PET itself cannot explain the severity of the conflicts. Kinetic energy of each vehicle at conflict point is a possible measure to describe the severity in case vehicles get collision. Therefore, in the safety assessment, it is useful to consider combined measure of PET and kinetic energy for evaluation of conflict frequency and severity.

(2) A simple scenario

A simple scenario is presented here to illustrate how to combine the behavior models in the simulation programs. **Fig.4** illustrates potential angle conflicts between right turning vehicles and crossing through vehicles during intergreen time. The required models to represent angle collisions are summarized in **Fig.4**b. Potential conflicts occur when the last clearing vehicle decides to make a right turn (stop and go decision) at the end of the phase at a signalized intersection. The clearing vehicle will first decide to choose a lane on the receiving roadway. The path and speed profile of turning vehicle will be generated before the vehicle entering the intersection. The last clearing vehicle may cause a risk of collision to the first through vehicle, coming from crossing approach. SRT model and acceleration model are used to determine the time when the though vehicle starts entering the intersection and its acceleration. The conflict point will be obtained as the crossing point between the paths of the last clearing vehicle and first entering through vehicle. When turning vehicle and through traffic pass through the conflict point the information of vehicles will be recorded. The PET indicators then will be reproduced.

By comparing the characteristics of this scenario of conflicts between different intersections, the best design policy of the intersections regarding this scenario of conflicts might be found out.

5. CONCLUSIONS

In this paper, essential concepts that are necessary for developing a new traffic simulation tool for safety assessment of signalized intersections have been figured out. In addition, an overview of behavior models of road users is also presented. These can be regarded as necessary requirements for the development of the traffic safety simulation tool. It can be concluded that the concepts are very useful in guiding further research and the simulation development.

Based on the concepts, the simulation tool has been being developed. For future works, other necessary models have been being developed and the validation process should be conducted to verify how realistically the simulation tool can reproduce.

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