The study of traffic safety at intersections by micro-traffic simulation

Kazuhiko Takashima¹, Hirotaka Koike², and Akinori Moromoto³

Abstract: Traffic safety measures are generally designed based on historical traffic accident data. Therefore it is difficult for us to evaluate the exact effect of proposed junction modifications until the works are constructed and new accident data gathered. In particular, safety improvements may be designed in accordance with existing traffic flows, but the characteristics of traffic flow will change once the improvements are made. To address this problem, we examined the use of micro-traffic simulation using software packages NETSIM and Simr to model the effect of junction safety improvements. Actual case studies were modelled, and as a result, new safety evaluation techniques for junctions are proposed.

Keywords: traffic safety, traffic accident, simulation, intersection, junction

1. あらかじめ検討

It is clear from examination of an integrated traffic accident database that traffic accidents frequently occur near road junctions¹). When undertaking safety improvement design, reference is made to historical traffic accident data. Evaluation of the effect of the improvements is made after implementation once accident data has been gathered for a reasonable time period. But if the effect of safety improvements could be modeled in advance, selection of a more suitable design might be possible. In addition, intersection improvements modifications that significantly alter traffic flows such as provision of a bypass route or an additional interchanges cannot be modeled at present, and due to the complicated effects of such a change, it is difficult to assess the real safety effects of the improvements.

2. 評価方法の開発

Existing evaluation methods to assess the degree of danger of an intersection use techniques such as study of accident statistics²), traffic safety audit, operation simulation, conflict study³), and the questionnaire method⁴).

The questionnaire method is largely subjective and there is substantial deviation in the results according to the interviewee. Therefore, the authors propose a new evaluation method to evaluate the degree of danger of a traffic intersection. This considers the running characteristics of the cars, which is a function of the speed and headway. A strong correlation can be shown between accident rates and an inadequate headway. An inadequate headway is defined as a distance less than the braking distance (rear-end collision marginal distance)⁵).

By examining the running characteristics of vehicles at the intersection before and after improvement works using a micro-traffic simulator NETSIM or Simr⁶), the authors show that it is possible to evaluate the effect of an intersection improvement plan in advance.

Surveys were carried out using the proposed intersection danger evaluation method. Observation of vehicles running characteristics was carried out at a distance around 200-300m from the intersection, i.e. at a location where traffic is not influenced by braking behavior near the intersection.

¹) Member of JSCE, Ph.D., Japan Construction Information Center
(7-10-20, Minato-ku, Akasak, Tokyo 167-8416, JAPAN, E-mail: takashik@jacic.or.jp)
²) Fellow of JSCE, Ph.D., Professor, Department of Civil Engineering, Utunomiya University.
³) Member of JSCE, Ph.D., Associate Professor, Department of Civil Engineering, Utunomiya University.
(1) The investigation method

Two groups of intersections were studied, one of which has a high-frequency of accidents, and another with a low-frequency of accidents. All of the intersections studied are located in the jurisdiction of Tsukuba police station and Tsukuba north police station (Ibaraki Prefecture, Japan). The high-frequency locations record six or more accidents per year, and the low-frequency locations record two or less accidents per year. The running characteristics of vehicles at both types of location were studied.

(2) Analysis result

Fig. 1 shows the measurement results at two junctions for 99 vehicle spacings. Curves 1, 2 and 3 show the relation between running speed and braking stop distance using Equation (1)\(^5\), and reaction delay times and sliding friction coefficients as shown in Table 1.

When the headway is less than the braking stop distance, the danger of a rear-end collision becomes high. The data shows that there is a significantly higher proportion of vehicles with inadequate spacing at the high-frequency location compared to the low-frequency location. The same observations were made at five other pairs of intersections, and the same tendency was confirmed\(^5\).

Table 1 Calculation conditions of braking stopping distance

<table>
<thead>
<tr>
<th>Condition</th>
<th>Reaction delay time</th>
<th>Friction coefficient of road surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>High surface wet</td>
<td>t = 0.75</td>
<td>f = 0.45</td>
</tr>
<tr>
<td>High surface dry</td>
<td>t = 0.75</td>
<td>f = 0.7</td>
</tr>
<tr>
<td>Low surface</td>
<td>t = 0.75</td>
<td>f = 0.7</td>
</tr>
</tbody>
</table>

NETSIM (developed by US federal road agency FHWA) and Simr (developed by Hokkaido Civil Engineering Research Institute) are microscopic simulation models.

Table 1

<table>
<thead>
<tr>
<th>Calculation conditions of braking stopping distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction delay time</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>High surface wet</td>
</tr>
<tr>
<td>High surface dry</td>
</tr>
</tbody>
</table>

Fig. 1 Relationship between headway and the vehicle speed ①Observation at time of day having high rate of recorded accidents ①

Source: Bibliography 5 p.48,
In addition, there is a future theme that to check validity verification of a simulation result by standard verification manual. Furthermore, a simulation also needs to consider fluctuation of a calculation result in order to treat vehicles discretely.

(1) Outline of NETSIM (NETwork SIMulation)

NETSIM\(^9\) is a microscopic stochastic simulation model. It uses detailed simulation models involving the use of probability to describe the action of vehicles which run on a road network (refer to Fig. 2).

Each vehicles movement for each time interval is calculated as it moves through the network. Each vehicle's position, speed, and amount of time in the network are kept in memory throughout the run. This provides a trajectory for each vehicle throughout the simulation run. Vehicles can react to traffic control apparatus (signals), other vehicles, a pedestrian's action etc.

In addition, NETSIM Japanese version (Ver3.00) with improved lane change logic, induction type signal control logic, pedestrian crossings, and modelling of traffic information boards was used.

The various capabilities and limitations of the model are as follows:

- **Road network**
  A road network is expressed by links and nodes. A link expresses a single lane in a single direction.

- **Additional lanes**
  It is possible to input additional lanes, extensions and gradient, free running speed, and driver's reaction time to green light etc.

- **Traffic signals**
  Modelling of signals are possible, including actuated signals using induction loop detectors.

- **No right turn**
  Turning rules may be specified for check lane.

- **Influence of pedestrian crossings**
  Modelling of pedestrian crossings is possible, with four volume settings from zero to 500 persons or more per hour.

b ) Items that cannot be modelled in NETSIM\(^9\)

- **Influence of sight distance**
  Although sight distance may be expressed as input data, there is no sensitivity to this factor in the output.

---

**Fig. 2** Simulation flow of NETSIM

**Fig. 3** Simulation flow of Simr
· Route selection
Origin destination cannot be assigned to the data. Since the turning ratio is set as an input parameter, the change of turning rate that occurs following modification of the junction cannot be modelled.

· Effect of lane width
Lane width cannot be specified.

· Crossing geometry
Crossing geometry cannot be specified.

(2) Outline of Simr (Simulation of roads)
Simr is a simulation model which repeatedly calculates vehicles actions based on the surrounding situation (spacing to preceding vehicle or following vehicle etc.), and the situation (link information) of the road segment from the start of the simulation until its completion (refer to Fig. 3).

Simr currently models the factors shown in Table 2.
In future, further developments are expected to add features to model lane width, crossing geometry and pedestrian flows to increase the completeness of the model. The various capabilities and limitations of the model are as follows:

a) Items that can be modelled in Simr

· Road network
A road network is expressed by links and dividing lines (a dividing line corresponds to a node). An average vehicle speed is assigned to each link.

· Additional lanes
Adding an additional lane can affect change of approach speed to a junction. Modelling of the length of the additional lane is also possible.

· Stop line position
By altering the position of a stop line, it is possible to evaluate the change in average speeds at a crossing.

· No right turn
Restrictions on turning movements can be modelled.

b) Items that cannot be modelled in Simr

· Effect of lane width
Lane width may be reflected in the average running speeds assigned to a road, but clear at this time.

· Influence of pedestrians (effect of grade separation)
It is difficult to directly model the effect of pedestrians. It is possible to assume a hindrance time on left-turning traffic by pedestrians, and hence make some allowance for the impact of pedestrians.

Notwithstanding the above limitations, it is possible to evaluate in advance the effect of an intersection improvement using NETSIM and Simr simulations as described by author5).

5. Results of micro-traffic simulation

(1) Traffic simulation by NETSIM

a) Outline of the case study
The layout of the junction used in the case study is shown in Fig. 4, with lane composition shown in Table 3. The intersection is not specified as having a high-frequency of accident occurrence, although 5 accidents were recorded in 1999 to 2000.

Table -2 The factors reflected in a simulation (Simr)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>Plane alignment</td>
</tr>
<tr>
<td>Conditions</td>
<td>Setting speed, curvature radius, etc.</td>
</tr>
<tr>
<td>Road structure</td>
<td>Number of lanes, Tunnel, etc.</td>
</tr>
<tr>
<td>Traffic restriction conditions</td>
<td>Signal/ Intersection</td>
</tr>
<tr>
<td>Various Regulations</td>
<td>Signal and intersection position</td>
</tr>
<tr>
<td>Characteristics of drivers</td>
<td>Desired running speed</td>
</tr>
<tr>
<td>Athletic ability</td>
<td>Running speed of desire, and standard deviation</td>
</tr>
<tr>
<td>Characteristics of Vehicles</td>
<td>Type of a car</td>
</tr>
<tr>
<td>Acceleration performance</td>
<td>Type-of-a-car classification</td>
</tr>
<tr>
<td>Reaction ability</td>
<td>Determines from car classification</td>
</tr>
<tr>
<td>External factors</td>
<td>Vehicles reaction delay time</td>
</tr>
<tr>
<td>Traffic situation</td>
<td>From the running speed of each route to path planning</td>
</tr>
<tr>
<td>Situation of congestion</td>
<td>Move speed</td>
</tr>
<tr>
<td>Distance to car in front</td>
<td>Speed</td>
</tr>
<tr>
<td>Behavior of Pre-run vehicle</td>
<td>Move speed</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Distance to following car</td>
</tr>
<tr>
<td>Behavior of following vehicle</td>
<td>Move speed</td>
</tr>
</tbody>
</table>

Note: The influence of a pedestrian and a bicycle does not contain
b ) Simulation model

The traffic situation used in the model is that recorded in a survey around 8 a.m. in February 2000. The simulation considered a base case of the present situation, and examined the effect of providing a pedestrian overpass and of intersection improvement (going-straight / left turn lane changed to left turn lane).

The network model used is shown in Fig. 5. On this figure, the intersection to be examined is labelled 1. Outflow / inflow nodes are 8011 to 8014. The nearest nodes to the crossing are 11 to 14.

Using the model, analysis was made of the effect on traffic flow of the presence of pedestrians at the crossing, and of the effect of replacing the going straight /left turn lane with a going straight lane and a dedicated left turn lane.

c ) Simulation results

The outputs of NETSIM are statistical data for each 5 minute and 30 minute period. Evaluation was made based on the longer period data. For evaluation a conservative assumption regarding pavement condition is made and a sliding friction value of 0.3, i.e. wet conditions and poor pavement condition, is assigned.

<table>
<thead>
<tr>
<th>Run direction</th>
<th>Crossing lane composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 .intersection (Southward movement)</td>
<td>Right-turn Going-straight / left turn</td>
</tr>
<tr>
<td>14 .intersection (Northward movement)</td>
<td>Right-turn Going-straight / left turn</td>
</tr>
<tr>
<td>11 .intersection (Eastward movement)</td>
<td>Right-turn Going-straight + left turn</td>
</tr>
<tr>
<td>13 .intersection (Westward movement)</td>
<td>Right-turn Going-straight + left turn</td>
</tr>
</tbody>
</table>

(Note)
(1) Left-turn lane length is 67m.
(2) 12  14 are run directions of Fig. 5.
(3) The direction 13  intersection (westward movement) is congested in the morning.
The effect on traffic safety is seen to be marginal since the distance above the vehicle speed / required stopping distance curve is seen to be virtually unchanged after the improvement works.

- **Influence of sight distance**

  Even when the sight distance was altered in the input data to NETSIM, no influence was observed in the output data, and it was judged that the parameter of sight distance was not being reflected in the modelled vehicle action.

(2) Traffic simulation by Simr

a) Outline of the case study

The layout of the intersection used in the case study is shown in Fig. 8. It is located at the intersection of National Highway Route 1 (east-west) and National Highway Route 362 (north-south).

Traffic data as surveyed around 8 a.m. on Tuesday March 17, 1998 (prior to the junction improvement) is shown in Table 4. In the present junction arrangement, exclusive right-turn lanes are now provided for each of the four directions. The length of the right-turn lanes on each direction are 130m, 80m, 30m and 40m for the east, west, north and south limbs respectively.

Simulation was carried out for the cases of with and without right-turn lanes. The simulation results for the case with right-turn lanes can be compared to actual data recorded in 1999.

The base case modelled the existing condition with right-turn lanes, and this compared with the case without right-turn lanes.

| Table-4 | The traffic situation of an object crossing |
|---------|
| (the simulation input value) |

<table>
<thead>
<tr>
<th></th>
<th>Rate of left turn</th>
<th>Rate of going straight</th>
<th>Rate of right turn</th>
<th>Traffic volume (cars/h)</th>
<th>Rate of large-size car mixing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastward Route 1</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
</tr>
<tr>
<td>Westward Route 1</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
</tr>
<tr>
<td>Southward Route 362</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
</tr>
<tr>
<td>Northward Route 362</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
<td>☐ ☐ ☐ ☐</td>
</tr>
</tbody>
</table>

[Note] Data is input to the model for 3 directions, with 4th the traffic volume is calculated by the model. Traffic in the east-west direction is heaviest.
b) Simulation results

Simulation results for the cases with and without right-turn lanes are shown in Table 5.

Fig. 9 also shows the rear end collision marginal line for the case of sliding friction of 0.3.

Fig. 10 shows the fluctuation for each 5-minute period of the simulation result expressed as the distance between vehicles. This is for the east-bound lane, in the case without right-turn lanes.

Fig. 11 shows the same data for the case with right-turn lanes.

Analysis of the effect of the right-turn lanes

The installation effects of right-turn lanes may be considered with reference to Fig. 9. The running speed on National Highway Route 1 (east-west directions) can be seen to have increased substantially. At the same time, the plotted points are further from the rear-end collision marginal line, which shows improved safety of the modified junction layout. The running speed on National Highway Route 362 (north-south directions) shows no increase in running speed.

However the plotted points are further away from the rear-end collision marginal line, and it can be judged that the modified junction layout gives safety improvements.

Fluctuation of simulation result

A traffic simulation reproduces disorder in traffic by introducing vehicles using different rates of acceleration and deceleration, resulting in varying running speeds. The actions imposed on the vehicles, represented by random variables, gives varying traffic conditions with time.

As a result, the simulation output varies with time as shown in Fig. 10 and Fig. 11. For this reason, to obtain meaningful results, the simulation must be run a number of times, say 10 times, and average values taken.

Table 5 Simulation result

<table>
<thead>
<tr>
<th>Direction</th>
<th>Running speed (m/s)</th>
<th>Headway (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-turn lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastward</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Getting up National highway Route 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(westward)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Getting down National highway Route 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(southward)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auxiliary national highway Route 362</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(northward)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note 1: The simulation averaged 24 data for 5 minutes for every conditions. A change situation referring to Fig. 10 and Fig. 11.

Note 2: The inside of a parenthesis shows standard deviation.
The example of Fig. 10 shows an average headway of 9.3m, with a standard deviation of 3.3m. Fig. 11 shows the case after introduction of exclusive right-turn lanes, where congestion has been eliminated, and running speed increased to an average of 16.3 km/h. It can be seen that there is a tendency for the standard deviation of vehicle spacing to reduce resulting in smoother output results.

Given such tendency, in this research 24 simulation cases were run, each of 5 minutes duration, and averaged values used for evaluation.

6. Conclusion

The research has produced the following conclusions.

(1) The effect of installation of a pedestrian overpass, and of construction of exclusive right-turn lanes can be modelled in micro-traffic simulation.

(2) The capabilities and limitations of micro-traffic simulation have been examined and listed.

(3) The traffic safety effects of junction modifications have been examined by applying the concept of a relationship between running speed and headway as being the determining factor in accident probability.

subjects suggested for further research are as follows:

(1) Micro-traffic simulation

a) Verification of software

Since the software is using stochastic and probability-based methods rather than direct calculations, there is a need to conduct some form of verification of the results.

Fig. 9 Effect of Right-turn lane

Note

1 Hollow markers show without right-turn lane.
2 Solid markers show with right-turn lane. The present condition.

Fig. 10 Natural variation in simulation results distance between vehicles traffic congestion situation

Table 5

- NH.1 eastward direction vehicle spacing(headway) for the case “without” right turn lane, as shown in Table 5.
-  and  are run ID numbers.
Note

1 NH.1 eastward direction vehicle spacing(headway) for the case “with” right turn lane, as shown in Table 5.
2 The run ID numbers.

Fig. 11 Natural variation in simulation results
distance between vehicles

Flowing traffic

Sensitivity analysis may be carried out by varying input parameters and examining the effect on output data, although it is difficult to determine the degree of certainty of the results.

Accordingly a standard verification procedure is needed that can be used to check the influence of assumed road conditions and running conditions.

b ) Discrete model use

Since the micro-traffic simulation is a discrete model, it is affected by time duration of each simulation. More research is needed to determine the effect of this parameter.

c ) Simplification of input data

The first task in a simulation is prepare a model of the existing condition. Study is required on methods to simplify setting up the existing condition model and to carry out sensitivity analysis to ensure the model output correctly represents existing conditions.

( 2 ) Marginal value of traffic safety

In this research a proposed relationship between running speed and required headway is proposed using a relationship based on sliding friction of the pavement surface. Further study is required on the appropriateness of this relationship by examination of statistical data.

Acknowledgement

The author is grateful to Mr. Toshio Kamiizumi of consulting engineers Pacific Consultants International for independent confirmation of the analysis results, and to the assistance of Mr. Teppei Osada, a graduate student of Utsunomiya University.

Appendix: Glossary of Technical Terms

【Integrated Traffic Accident Database】

This refers to the integrated database created by the National Police Agency and the Ministry of Land, Infrastructure and Transport. It covers the whole country and includes information on license holders, registered vehicles, and road network data, and traffic accident reports. It is used in traffic accident analysis, and design of traffic safety improvement measures.

【High-frequency accident location】

These are locations where the possibility of one or more fatal accidents in a ten year period is high. The number of such accident danger zones according to the integrated traffic accident database is (data), of which are junctions of some sort. The average traffic accident rate for high-frequency accident locations is per year, while for junctions on trunk roads in general it is per year. Similarly, for trunk roads overall, the accident rate is per lane-km per year, while for high-frequency accident locations it averages per lane-km per year.

Since this research targets intersections, intersections averaging or more accidents per year were considered.
【Braking stop distance】
Rear-end collision marginal distance. This is the average stopping distance from the time that a driver observes an obstruction, to the complete halt of the vehicle. It includes driver reaction time and braking distance. In this paper, the stopping distance is termed the rear-end collision marginal distance, and is used as a reference distance when evaluating safety of the calculated output headway from a simulation. Since the driver reaction time increases significantly with age of driver, it is necessary to consider high values of rear-end collision marginal distance in future plans.

【Road surface sliding friction】
Road surface sliding friction is a function of the tire conditions (quality or rubber, tread pattern, pressure, vehicle load, tire size), road surface conditions (kind of surface, roughness of surface, leaves or material on the road, presence of water, road surface temperature etc.), braking conditions (speed at time of braking, driver, brake performance) etc. Road surface sliding friction in wet weather is about and in dry weather about based on field measurements.

REFERENCES

8) Japan Society of Civil Engineers, The Infrastructure Planning Committee, ITS research subcommittee for increasing efficiency of road use and environmental mitigation. A standard verification process of traffic flow simulation model : The standard verification process of a traffic flow simulation model Verification manual proposal 2000.