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

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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. Introduction

It is clear from examination of an integrated traffic accident database that traffic accidents frequently occur near road junctions[1)]. 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. Previous Research

Existing evaluation methods to assess the degree of danger of a intersection use techniques such as study of accident statistics[2)], traffic safety audit, operation simulation, conflict study[3)], and the questionnaire method[4)].

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 Simr[6)], the authors show that it is possible to evaluate the effect of an intersection improvement plan in advance.

3. Safety evaluation of a intersection according to vehicles running characteristics

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.

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(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**.

$$S = \frac{V^2}{2gf(3.6)^2} + \frac{V}{3.6} \times t \qquad (1)$$

S : Braking stop distance (m)
V : Vehicle speed (km/h)
g : Gravitational acceleration
f : Friction coefficient of road surface[11]
(0.3, 0.45, and 0.7)
t : Reaction delay time (0.75 sec)

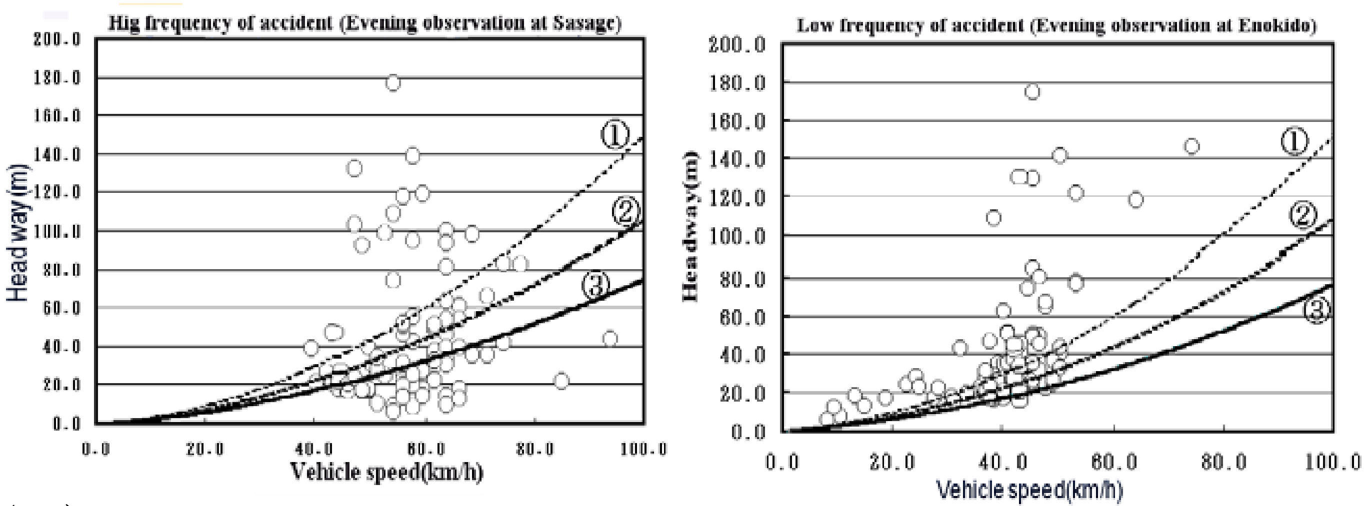
When the headway is less than the braking stop distance, the danger of a rear-end collision becomes high. The data shows that there is a significantly higher proportion of vehicles with inadequate spacing at the high-frequency location compared to the low-frequency location. The same observations were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

4. Outline of the method of micro-traffic simulation

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

Table-1 Calculation conditions of braking stopping distance

①	Reaction delay time t = 0.75 Friction coefficient of road surface f = 0.3	Limit of Road surface management
②	Reaction delay time t = 0.75 Friction coefficient of road surface f = 0.45	Road surface Slide situation at the time of wet
③	Reaction delay time t = 0.75 Friction coefficient of road surface f = 0.7	Road surface Slide situation at the time of dry



(**Note**)
(1) Curve ① ② ③ is the calculation value of the braking stop distance corresponding to the calculation conditions of table-1.
(2) Sasage and Enokido are the intersection in the vicinity of national highway (NH) 354 (In Tsukuba city).

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

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:

a）Items that can be modelled in NETSIM[9]

・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.

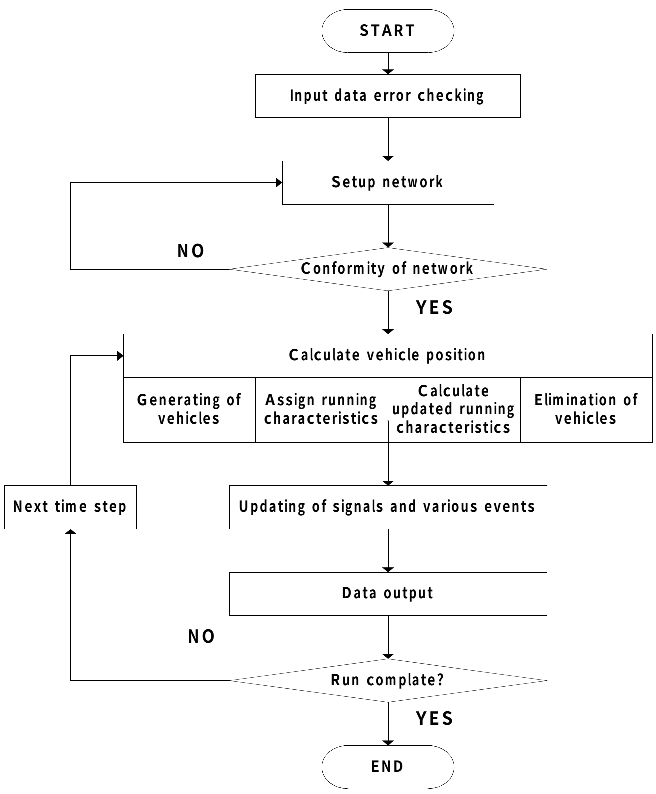


Fig. 2 Simulation flow of NETSIM

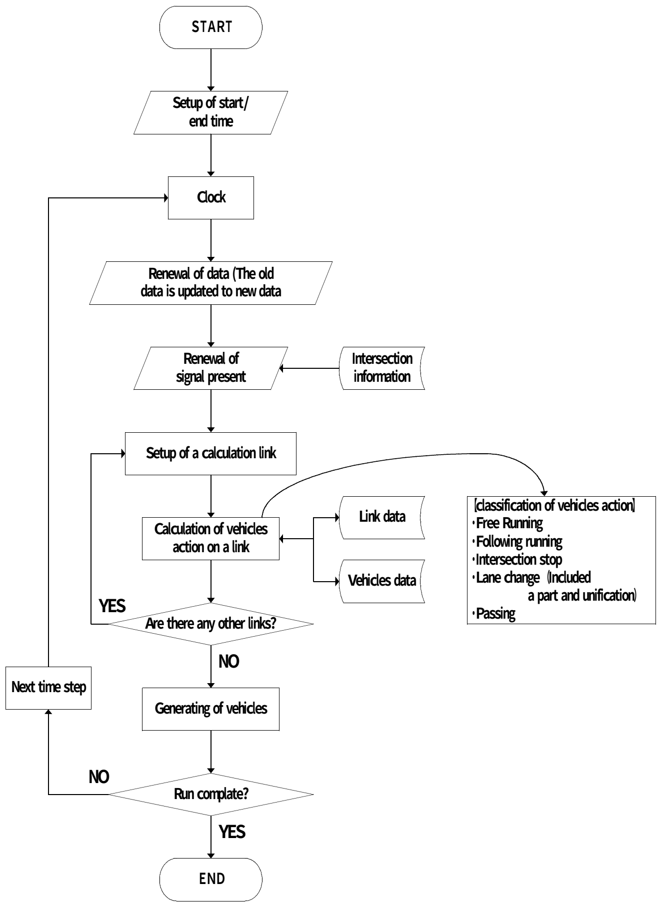


Fig. 3 Simulation flow of Simr

・**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 (Sim**ulation of **r**oads**)**

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.

・**Crossing geometry**

Crossing geometry cannot be specified but may be reflected to a certain extent in the average running speeds assigned to the traffic, but the logic of this correlation is also not 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 a intersection improvement using **NETSIM** and **Simr** simulations as described by author[5)].

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)

	Factor		Parameter
Physical factors	Road Conditions	Plane alignment	Setting speed, curvature radius, etc.
		Road structure	Number of lanes, Tunnel, etc.
	Traffic Restriction Conditions	Signal/ Intersection	Signal and intersection position
		Various Regulations	Prohibition act （No passing / Speed regulation）
Internal factors	Characteristics of drivers	Desired running speed	Running speed of desire, and standard deviation
		Athletic ability	Driver Reaction delay time
	Characteristics of Vehicles	Type of a car	Type-of-a-car classification
		Acceleration performance	Determines from car classification
		Reaction ability	Vehicles reaction delay time
External factors	Traffic situation	Situation of congestion	From the running speed of each route to path planning
	Behavior of Pre-run vehicle	Vehicles position	Distance to car in front
		Move speed	Speed
	Behavior of following vehicle	Vehicles position	Distance to following car
		Move speed	Speed

（**Note**）The influence of a pedestrian and a bicycle does not contain

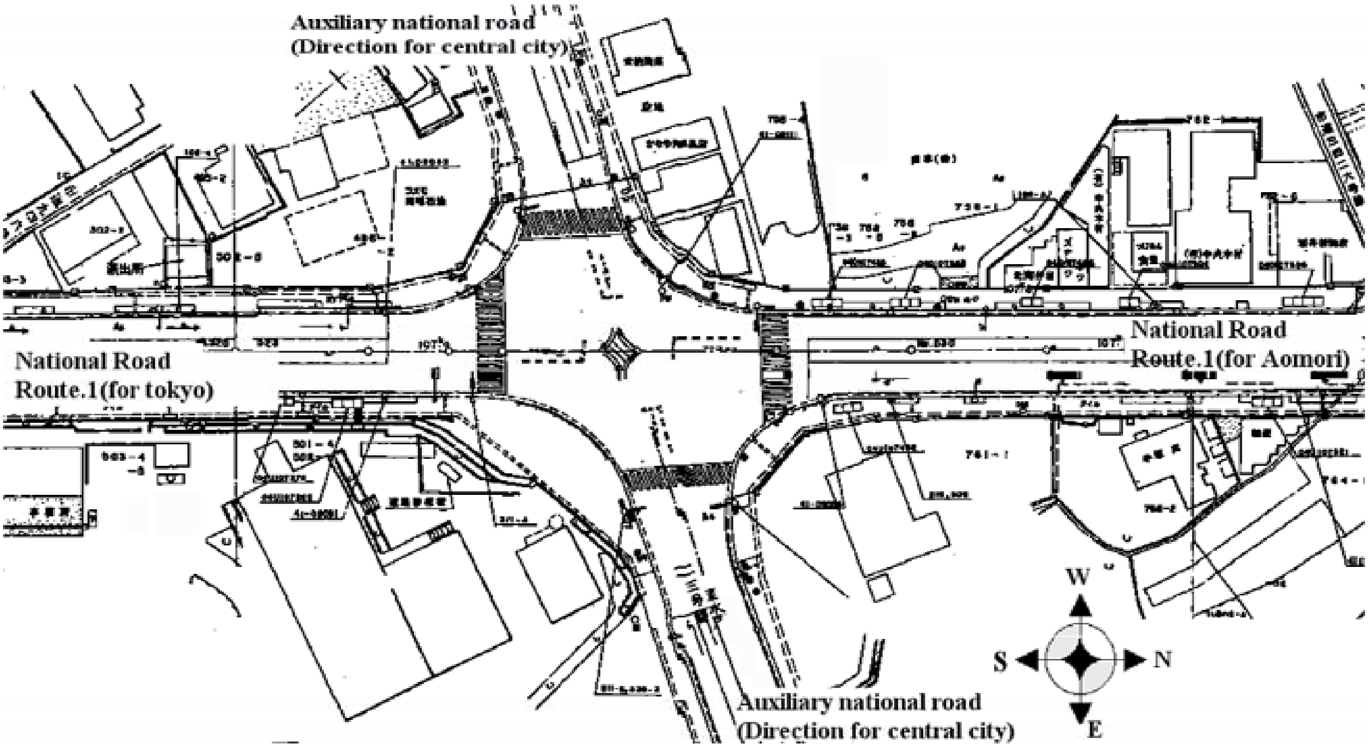


Fig. 4 Intersection modelled in NETSIM（the present situation）

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.

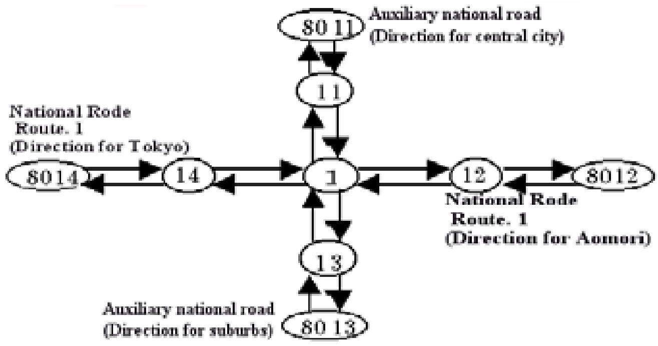


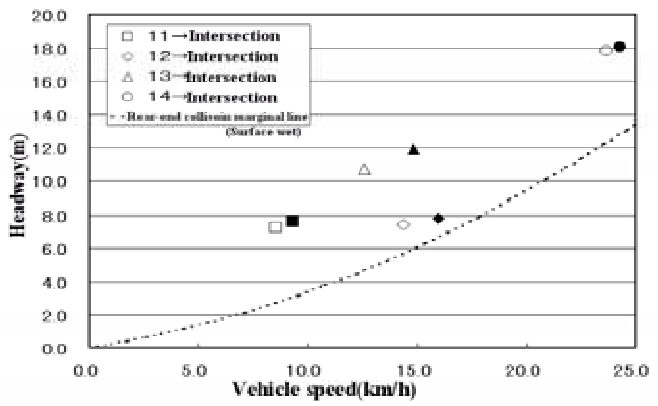
Fig. 5 Network model

Table -3　Lane arrangement of intersection

(Present condition)

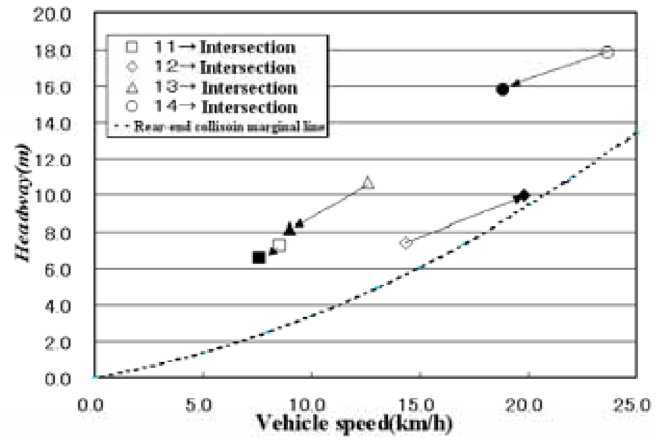
Run direction	Crossing lane composition	
12 → Intersection (Southward movement)	Right-turn	Going-straight / left turn
14 → Intersection (Nothward movement)	Right-turn	Going-straight / left turn
11 → Intersection (Eastward movement)	Right-turn	**Going-straight + left turn**
13 → Intersection (westward movement)	Right-turn	**Going-straight + left turn**

(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.



(Note)
(1) Hollow markers indicate 100-250 pedestrians/hour (present condition).
(2) Solid markers indicate zero pedestrians (grade separation).

Fig. 6 Effect of grade separation



(Note)
(1) Hollow markers show improvement (left turn going straight traffic lane) (the present condition).
(2) Solid markers show after improvement (left turn traffic lane + going straight traffic lane).

Fig. 7 Effect of intersection improvement

・**Influence of pedestrian crossing**

Provision of a pedestrian overpass provides complete safety for pedestrians, and an improvement in vehicle running speed, it was found that the expected rate of rear-end collisions (as shown by the relation of running speed and vehicle spacing) is virtually unchanged (refer to **Fig. 6**)

・**Intersection Improvement**

The effect of replacing the going straight / left turn lane with a going straight and a dedicated left turn lane was examined as a method of increasing capacity of the intersection, the safety benefits of the intersection improvements were examined in the NETSIM simulation. The results are shown in **Fig. 7**.

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)

	Rate of left turn (%)	Rate of going straight (%)	Rate of right turn (%)	Traffic volume (cars/h)	Rate of large-size car mixing (%)
Eastward (Route 1)	6.6	81.0	12.4	2010	6.8
Westward (Route 1)	11.3	76.2	12.5	***	***
Southward (R.362)	23.2	74.7	2.1	723	8.2
Northward (R.362)	7.5	89.5	3.0	909	8.0

(Note)
(1) Data is input to the model for 3 directions, with for the 4th the traffic volume is calculated by the model.
(2) Traffic in the east-west direction is heaviest.

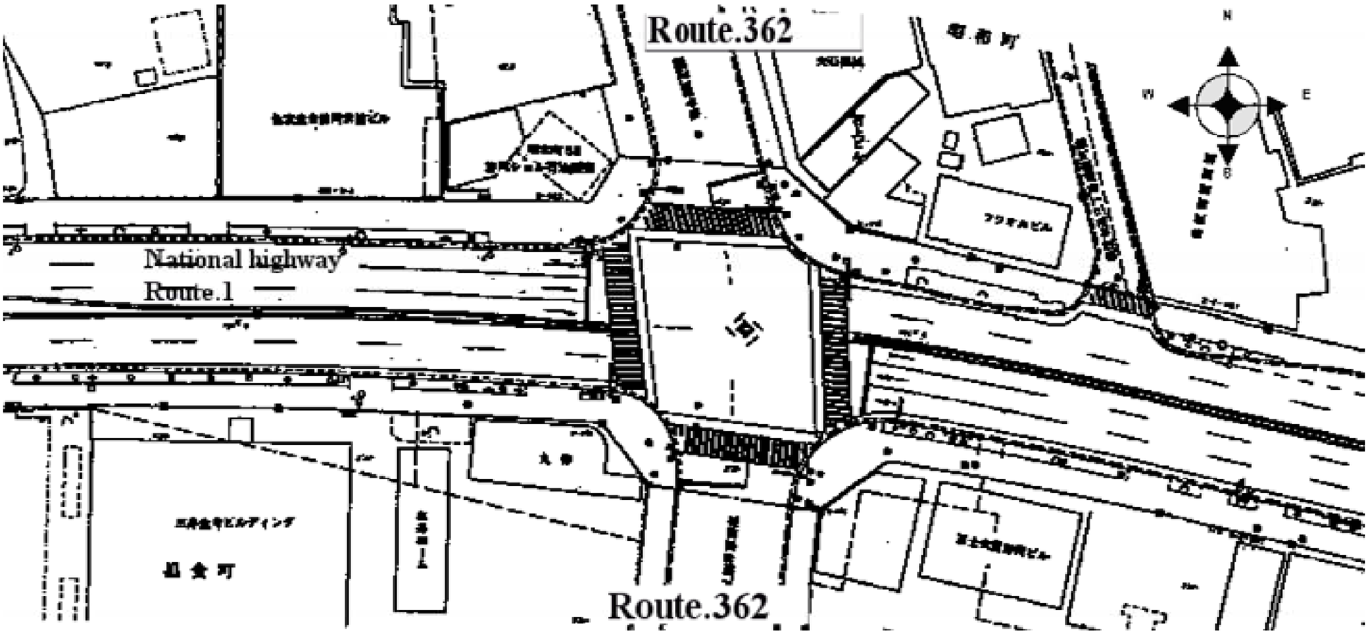


Fig. 8　Intersection modelled in Simr (the present situation)

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.

① **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.

② **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

Direction	Running speed (km/h)		Headway (m)	
Right-turn lane	With	Without	With	Without
(Eastward) Going up National highway Route. 1	16.3 (1.14)	5.9 (1.82)	24.0 (3.89)	9.3 (3.30)
(westward) Getting down National highway Route. 1	19.6 (1.48)	6.9 (1.90)	31.9 (4.65)	9.2 (2.92)
(Southward) Auxiliary national highway Route. 362	10.0 (1.38)	10.1 (1.12)	42.3 (11.96)	27.2 (6.27)
(Northward) Auxiliary national highway Route. 362	9.8 (1.0)	10.1 (1.05)	31.9 (7.81)	21.4 (3.59)

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

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.

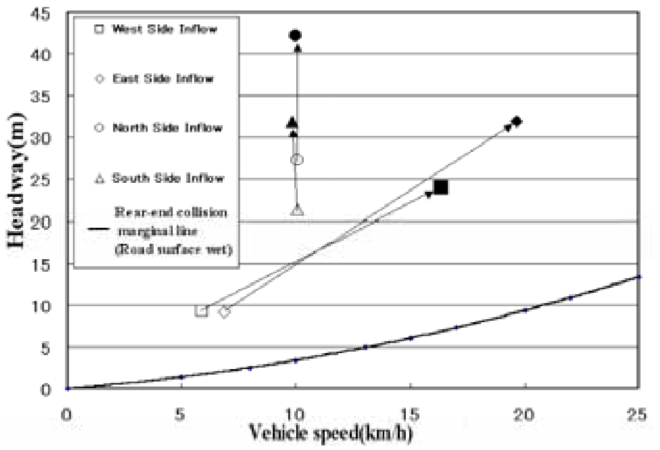
7. Subjects for further study

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.

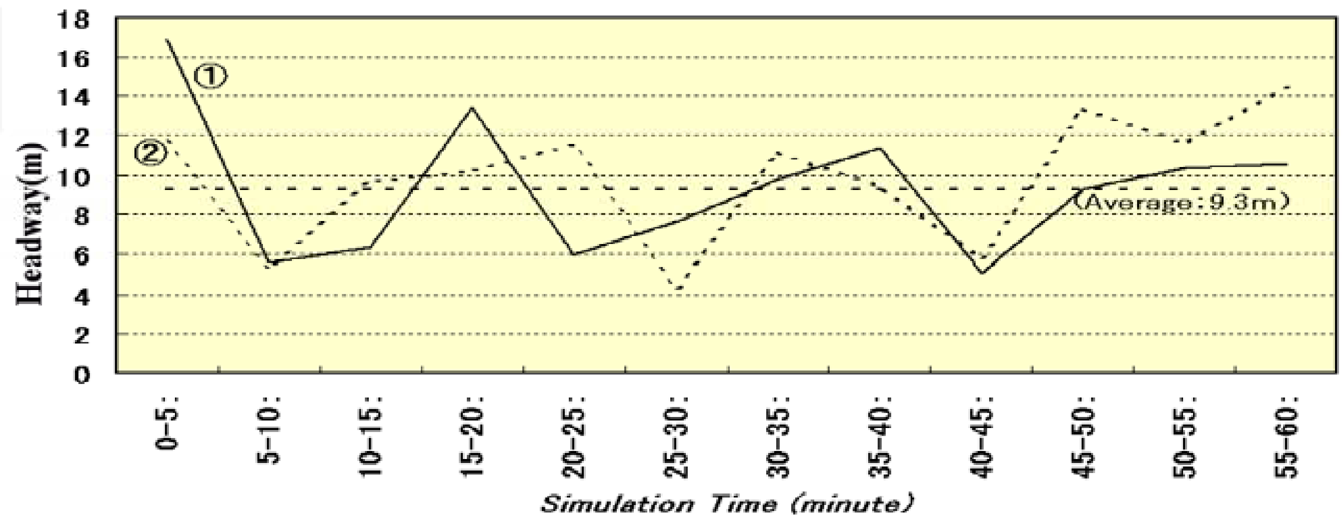


(**Note**)

(1) Hollow markers show without right-turn lane.

(2) Solid markers show with right-turn lane. (The present condition).

Fig. 9 Effect of Right-turn lane

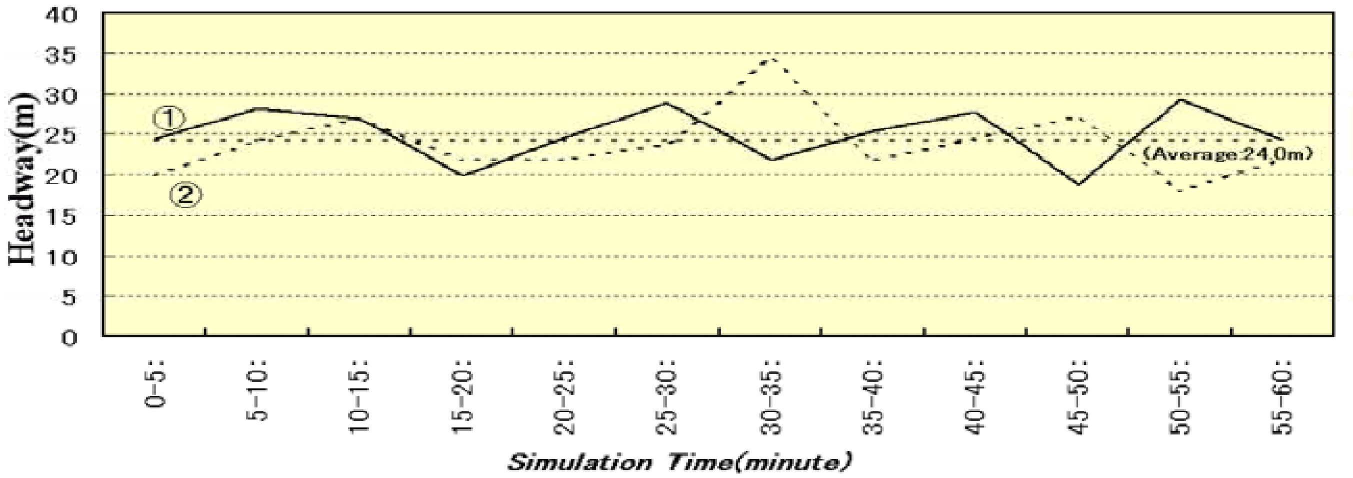


(**Note**)

(1) NH.1 eastward direction vehicle spacing(headway) for the case "without" right turn lane, as shown in **Table 5**.

(2) ① and ② are run ID numbers.

Fig. -10 Natural variation in simulation results (distance between vehicles) (a traffic congestion situation)



(**Note**)

(1) NH.1 eastward direction vehicle spacing(headway) for the case "with" right turn lane, as shown in **Table 5**.

(2) ① and ② are 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[10].

(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

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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】[1]

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 3,193 (1990 to 1993 data), of which 1,713 are junctions of some sort. The average traffic accident rate for high-frequency accident locations is 6.3 per year, while for junctions on trunk roads in general it is 0.2 per year. Similarly, for trunk roads overall, the accident rate is 0.9 per lane-km per year, while for high-frequency accident locations it averages 7.6 per lane-km per year.

Since this research targets intersections, intersections averaging 6 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】 [11)]

Road surface sliding friction is a function of the tire conditions (quality or rubber, tread patter, 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 ０.45 and in dry weather about ０.７, based on field measurements.

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