SIMULATION ANALYSIS OF BUS PRIORITY SYSTEM IN KAMAKURA CITY

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Abstract: The purpose of this study is to simulate and estimate unique bus priority scheme that called "bus only overtaking system" in historical area in Kamakura-City. Kamakura-city is famous as tourist city where about twenty million tourists visit every year. But serious traffic problems such as heavy traffic congestion, residents' safety and accessibility occurred on every holiday, because of historical and geographical feature. The citizen committee for TDM in Kamakura conducted detailed traffic surveys and proposed innovative "bus only overtaking system", which has special traffic signal system. Then this the committee has conducted the micro traffic simulation analysis of this system to be realized.

1. INTRODUCTION

The traffic simulation method is effective for planning stage. In this paper, authors discussed outline of traffic situation of Kamakura city and traffic simulation analysis for development of TDM plan in Kamakura city by using original micro traffic simulator called "tiss-NET".

2. OUTLINE OF KAMAKURA CITY

Kamakura city was once the political, economic and cultural center (actual capital) during 1192 and 1333. The reason why the governor selected Kamakura as the center at that time was its topographical advantage for defense, because it was surrounded by sea on the south side and by steep hills on the other three sides. Both topographical and urban structures of Kamakura City have not almost changed even today, after 800 years since foundation.

Figure 1 shows road network of historical area at present. Some thick solid lines are two-lane roads and there is only one four-lane road in downtown. Other solid lines are narrow roads of which width is as much as 4 to 5 meters. Hatch areas are green heritage zones of which almost are hummocks. Small diamonds are historical structures such as temple and shrine.

Today, about 47 thousand people live and more than 20 million tourists visit the historical area of Kamakura city, of which area is 7.7km^2. On most every holidays, a lot of private vehicles of tourists rush to the area, where network capacity is quite low, causing heavy traffic jam almost paralyzing activity of the city. For example, it can take more than two

hours by bus from suburb to the city center on holidays whereas it usually takes only 15 minutes.

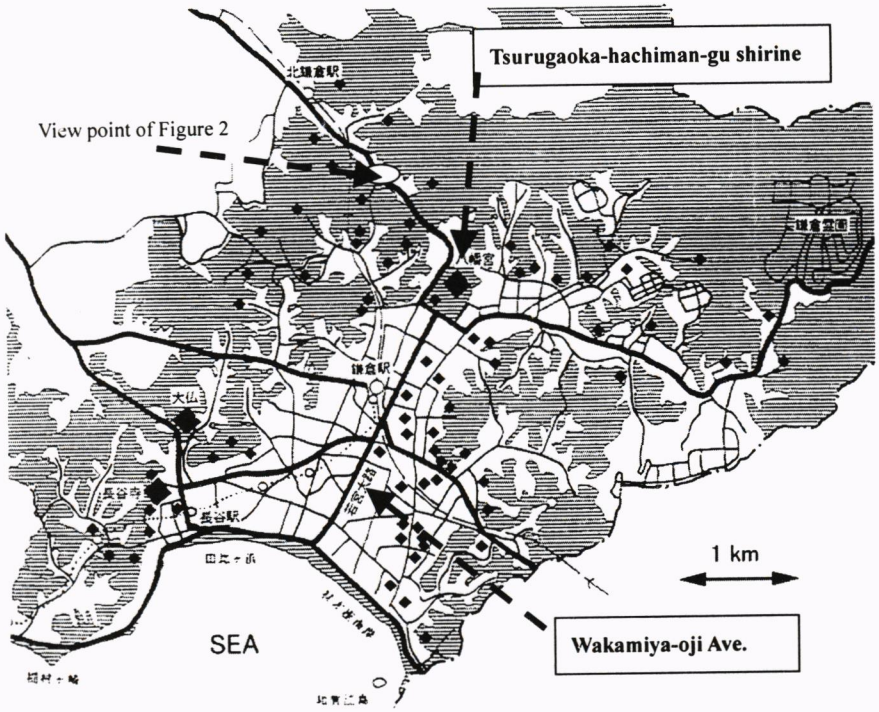


Figure 1. Historical Area of Kamakura City

Figure 2. Typical Road Congestion

2.1. Road Characteristics

Road network in Kamakura historical area is based on that build in the Medieval time. In the heart of the area, Wakamiya-oji, Main Street approaching to Tsurugaoka-hachiman-gu, the symbolic shrine of Kamakura, runs from north to south, which is the only artery for north-south traffic flow in the area. Historically, the governor limited the number of routes as much as seven to come in and out the area deliberately for the defense. Even today, it became only nine. The Figure 2 illustrates traffic jam of typical road as gateway on holiday.

2.2. Traffic Problems

Kamakura historical area gathers about 20 million tourists every year. For example, on autumn holidays, the number of tourists reaches at as much as 53% of the number of residents living in the area. About 38 thousand vehicles are entering in the area during 12 hours in daytime of autumn holidays.

Severe traffic congestion is occurring on most holidays in this area. The average speed of traffic is only about 6 km/h on holidays. In main intersections, queuing length becomes more than 500 meters on holidays. On streets that has no sidewalks, pedestrians are obliged to share the street surface with motor vehicles. Even on streets with sidewalks, because the width is too narrow, a lot of pedestrians should use roadway to make the traffic confusion.

Improvement of such situation has long been one of the most serious political issues of Kamakura City. Nevertheless, constructing new road has long been ceased in this area because there has been serious argument to construct new road in historical area in this city. In mid-1990s, Kamakura City decided to seek short-term TDM policy besides long-term infrastructure planning under the newly elected mayor who has advocated sustainable policy in general. Kamakura City also decided to adopt thorough public involvement approach to make the plan because they judged that Demand Management policy should fundamentally be made by citizens' voluntary decision not by enforcement by city government.

In 1995, Kamakura City established a citizen committee to develop a plan to solve traffic problems on holidays.

3. ACTIVITES OF CITIZEN COMMITTEE

3.1. Organization of citizen committee

The citizen committee was established to discuss above problems and find the solution to improve them. In the committee, voluntary citizens and shopkeepers participated as well as public officials and academic specialists and consultants. Those of shrine, temples, transport company members also participated.

Fourteen meetings of the committee were held during July 1995 and November 1998. First in the meetings, committee members confirmed that the discussion would be focused on TDM measures, in which the volume of automobiles in the area on holidays would be reduced. In the following, the discussions proceed to the type automobiles to be reduced. Someone insisted on that automobiles of outsider tourists should be controlled or excluded, because they are the cause of the serious traffic congestion. Nevertheless, after the serious discussions, they determined that every types of automobiles except for emergency vehicles and public transportation should be equally controlled because, they judged, Kamakura will be criticized for its egotism if they try to control only automobiles of tourists and if citizens of Kamakura enjoy driving in the controlled area.

The way of controlling the traffic volume was next discussed. Several kind of control measures such as traffic regulation, parking control, odd-even regulation, and so on. After the discussions, the combination of road pricing and park & ride is the best solution for Kamakura from the viewpoint of equity and feasibility.

3.2. Questionnaire survey

A questionnaire survey was conducted to know the citizens' consciousness of the traffic problems and preference of traffic control measures. As a result of the survey, 71% of citizens think "It is most important to make the safe and comfortable traffic environment for pedestrians in Kamakura", and 44% recognize the necessity of "reducing the traffic volume in the area". In terms of the question about the way of controlling traffic volume, 72% of citizens think, "every kind of automobiles should equally controlled", whereas only 17% insists that "only tourists' cars should be reduced". The majority also insisted that the level of service of public transportation should be enhanced when controlling traffic. Through the survey, the committee could confirm that the argument of the committee corresponds to the citizens' preference.

3.3. Traffic Survey

During the discussion of the proposals, the committee used Road Traffic Census Data (Car OD data) and Person Trip Data as well as the questionnaire survey data mentioned before. After submitting the proposal, the committee and the city of Kamakura judged that they need more precise data to make the proposal more concrete.
The survey was consist of following two part

- Car-OD survey to grasp automobile movement in the historical area precisely,
- Questionnaire survey to know both citizens' and visitors' preference toward the committee's proposals.

The survey was conducted on 3rd of November 1996 (sunny national holiday), including bus survey.

- Car-OD and Preference Questionnaire survey of residents in Kamakura historical area(No. of samples acquired is 5,198. Rate of answer is 27.6%)
- Car-OD and Preference Questionnaire survey of offices in Kamakura historical area(No. of samples acquired is 1,042. Rate of answer is 21.2%)
- Car-OD and Preference Questionnaire survey of inflow automobiles on the cordon line which surround the historical area (No. of samples acquired is 6,355. Rate of answer is 18.0%)
- Taxi movement survey (No. of samples is 13)
- Goods vehicle movement survey (No. of samples is 7)
- Bus survey both by on-vehicle and number plate survey
- Number plate survey and Traffic count survey on the cordon line which surround the historical area

Severe traffic jam particularly in the periods during 11 o'clock and 17 o'clock was measured by bus survey as well as traffic survey. This result also suggests that mobility public transport and private vehicles of citizens is also suffered by the severe congestion.

3.4. TDM proposals

The citizen committee's proposal includes following plans;

- Road pricing to reduce traffic congestion utilizing the topographical characteristics of the area which has only nine entrances,
- Park and Ride systems , in which fringe parking facilities are located near the gates of road pricing where drivers can select to park and ride public transportation or to come into the area by paying the fare of road pricing,
- Shuttle mini-buses, to enhance the mobility of public transportation in the area
- Traffic calming schemes both of area-wide and single streets,

- Comprehensive transportation information system,
- Bus priority signal systems, in the most congesting road, which make buses to overtake the queues using the opposite lane near the intersection by manipulating signal.

4. BUS PRIORITY POLICY

4.1. Bus Priority Policy

The Bus-priority policies proposed by the citizen the citizen committee were as follows:
- Bus Lane
- Shuttle Bus
- Park & Bus Ride(P&BR)
- Bus Only Overtaking System

The bus lane plan only can be realized on "Wakamiya-oji" Ave. as 4 lanes road. And, P&BR plans were conducted on some routes.

4.2. Bus Only Overtaking System

Through committee's surveys, serious situation of traffic congestion became clear. Especially, bus service is very low in suburb to the city center route. That route is two-lane road but there is no space that constructs an extension lane. Then the committee proposed innovative "bus only overtaking system", which has special traffic signal system (Figure 3). The bus only overtaking system is as follows;
- This system is suite for narrow two-lane road that has serious traffic jam mainly on one direction.
- The bus can only overtake the queues using the opposite lane near the intersection by manipulating signal.

Because there is no example of bun overtaking system before, the committee judged that simulation analysis should be preceded.

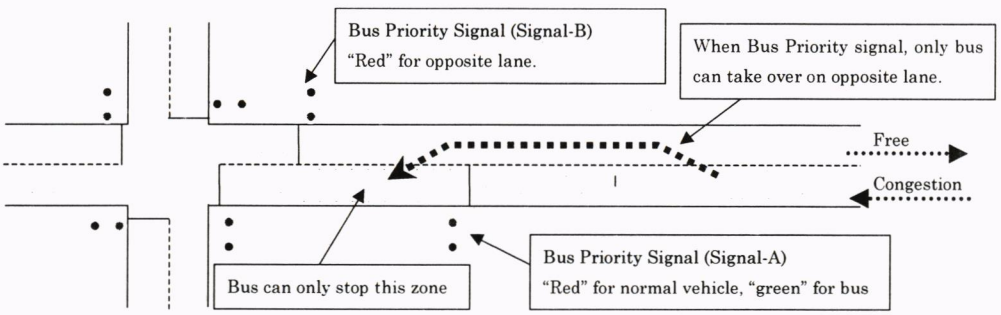


Figure 3. Bus Only Overtaking System

5. CHARACTERISTICS OF tiss-NET SYSTEM

5.1. Outline

Authors already have developed traffic simulation system of which name is "tiss-NET" for personal computer. It has following useful characteristics for investigating the micro-area traffic phenomena.

- Considering of road types and traffic control; the tiss-NET is able to consider micro road character such as width of road, speed limited, on and off street parking, types of the intersection, signal parameters and so on.
- Considering of individual vehicle behavior; the tiss-NET can take account of micro-scale vehicle phenomena such as car following movement, car starting delay, car behavior on the intersection and influence of on-street parking.
- Integration of traffic assignment model and micro traffic simulation; each car has independent information such as speed, acceleration, location, Origin-Destination, route which is described in node tree and so on. Each car routes that is minimum path of each OD is calculated at generate time by the Dijkstra-method using not only initial link/node data but also real trip time that calculated by simulation self.
- User friendly interface for traffic planner; the tiss-NET has the highly sophisticated GUI (Graphical Use Interface) function to help users. Especially in traffic impact study of district area, details and graphical output that helpful for unskilled persona for computer system is simulated easily.
- Flexible traffic modeling; this system can take account of detailed modeling of vehicle moving and multiple vehicle types. The programmer can customize flexibility tiss-NET system if new traffic plan is conducted in this case.

5.2. Event Type Simulation

The most basic concept of the tiss-NET system is that it is event-type simulation system. Streets are divided into 5m length "compartment", on which each car moves. "Moving vehicle on street" is expressed as "moving information of vehicles between compartments" in tiss-NET (Figure 4).

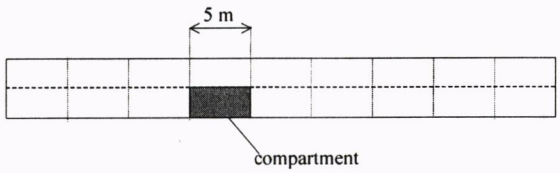


Figure 4. Street divided into "Compartment" for tiss-NET

Relationships between other vehicles can be considered as well as physical conditions of streets. Basically, a vehicle is allowed to move only when the next compartment is empty. When changing the lanes or doing overtaking, compartments of neighboring lane and/or opposing lane will be investigated to know the length of "gap" time. There are three basic models, which describe car movement. These are general car following model, starting delay model and slow down model in front of signal light. While the tiss-NET is design for district road network, built-in models deal with less than 50km/h.

5.3. Monte-Carlo Simulation

In the tiss-NET system, pseudo-random numbers, which are generated by the C-language, are used as follows;

- Generation time of each vehicle is corresponded by exponential distribution. This is

based on OD matrix.

- Dispersion of starting delay time, desire speed and etc. is corresponded by normal distribution. The average and variance are decided by investigation.
- Parking time is corresponded by Erlang-distribution.

5.4. Graphical User Interface (GUI)

The GUI function of the tiss-NET is also improved, so that planner can easily understand the result of the simulation, which is expressed by animation as well as by statistics (Figure 5), but is not real-time simulation system.

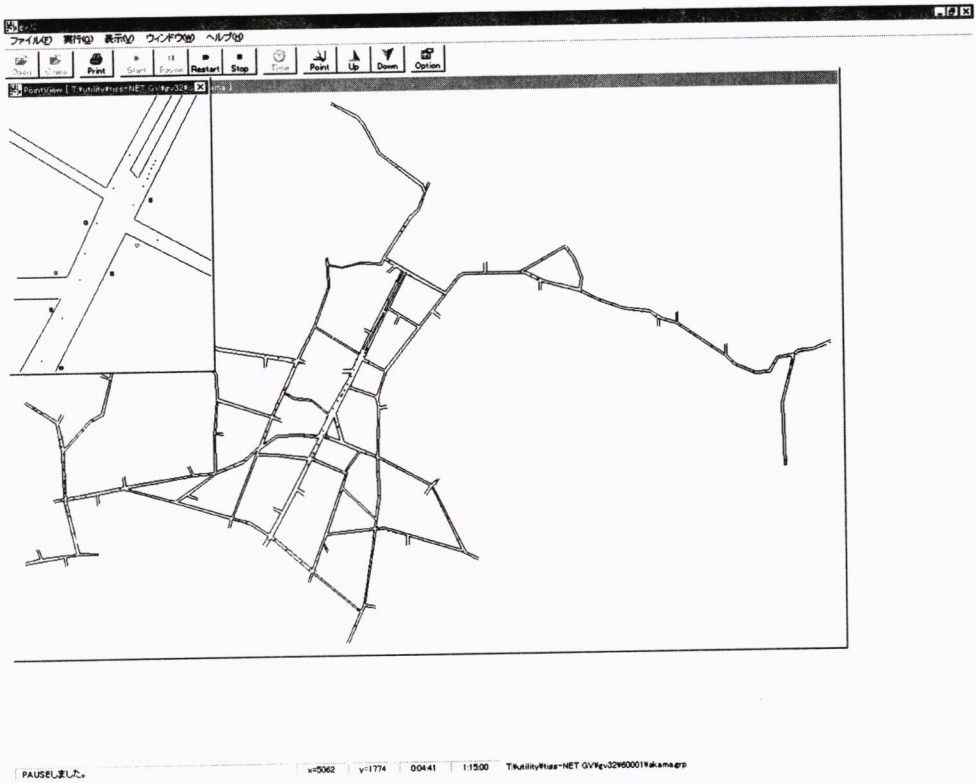


Figure 5. GUI function of tiss-NET

6. TRAFFIC SIMULATION ANALYSIS

Figure 6 shows the duration time of bus service during suburban origin (Kamakura-reien) and downtown destination (Kamakura station), on which it takes about 15 minutes by bus when it is not congested. As shown in the figure, the congestion in this area suddenly begins at about 11 o'clock in the morning, and the bus departed at about noon took more than two hours to get to the destination. From this data, traffic in this area in the afternoon on holidays can be suggested to be totally paralyzed.

On the other hand Figure 7 shows the duration time of opposite direction. There is no congestion as heavy as direction toward to downtown. This case is suitable for bus

overtaking system. Then the citizen committee decided that the target route of traffic simulation should be the road from "kamakura-Reien" to "Hachiman-gu" that is most congested in peak period (Figure 8).

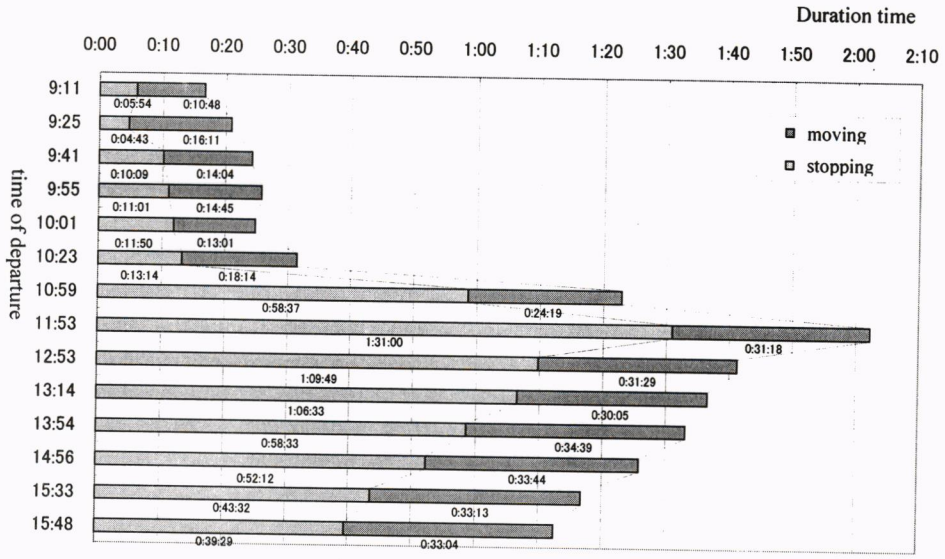


Figure 6. Duration Time of Bus (toward to downtown)

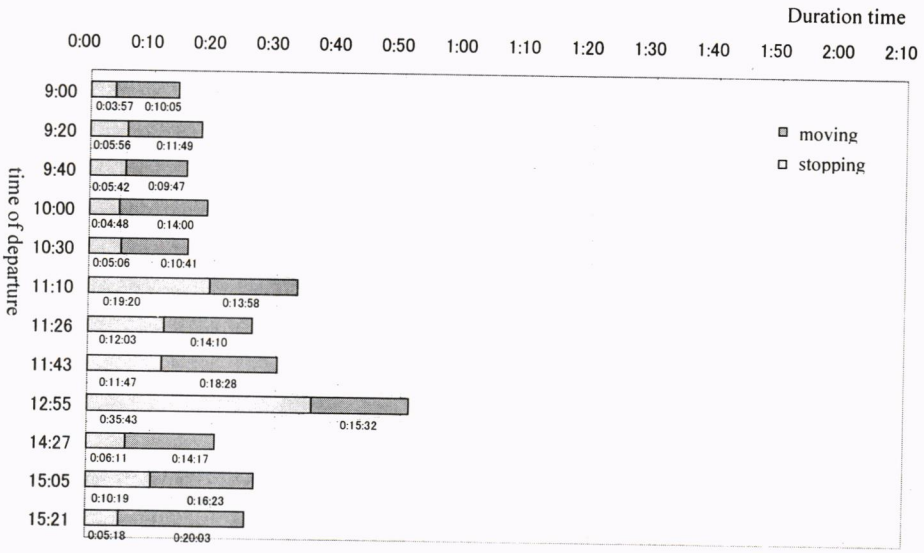


Figure 7. Duration Time of Bus (toward to suburban)

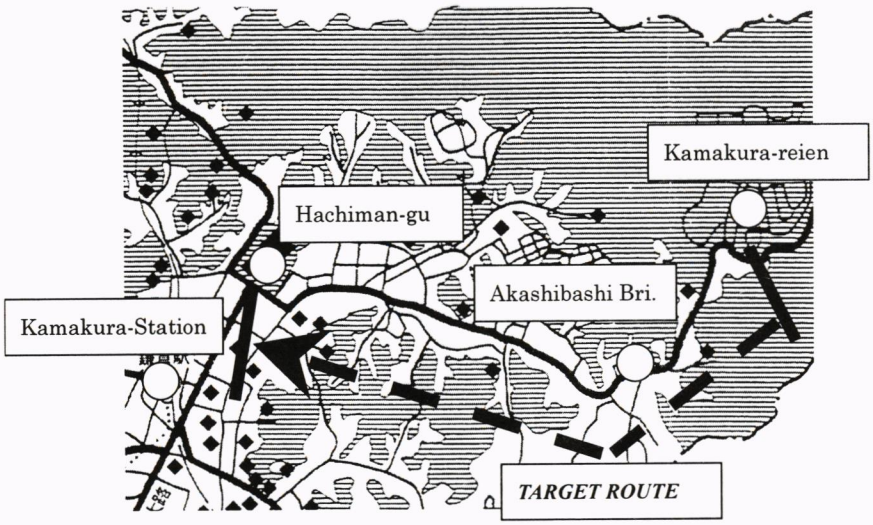
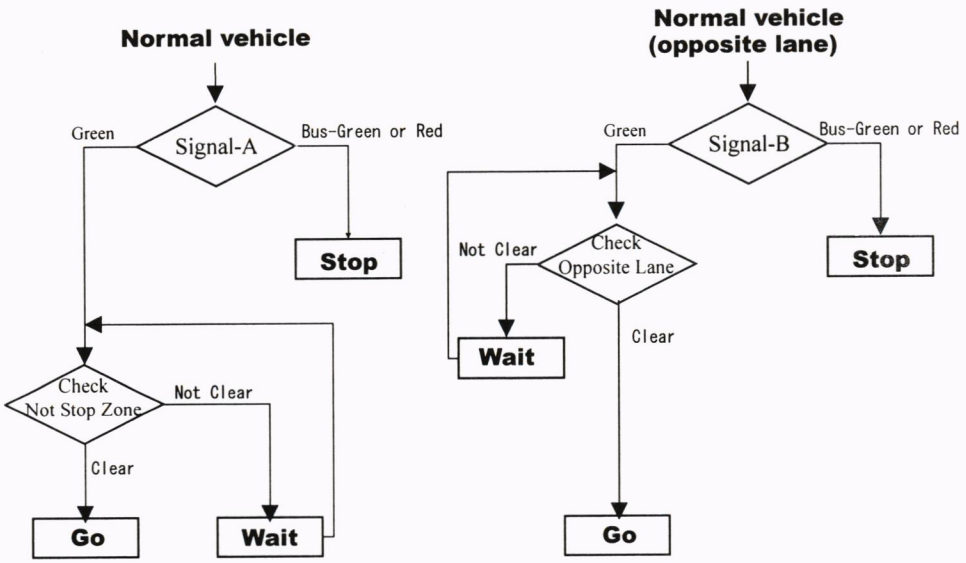


Figure 8. Target Route of Traffic Simulation

6.1. Simulation Flow

In order to estimate effect of bus only overtaking system, it is necessary that simulation system can simulate bus overtaking on opposite lane. This is unusual case as traffic simulation.



(Signal-A and signal-B are explained Figure 3)

Figure 9. Flowchart of Normal Vehicle Except Bus

The flowchart for normal vehicle except buses is illustrated in Figure 9. When signal-A and signal-B lights "red" or "bus-green", the normal vehicle except bus on each lane should be stopped. When "green" light, the normal vehicle on congested lane has to check "do not stop zone" and the normal vehicle on opposite lane has to check.

The flowchart for bus is illustrated in Figure 10. When signal-A is "green" or "red", bus control is identical with normal vehicle. When "bus-green", bus needs to check doubly for salty.

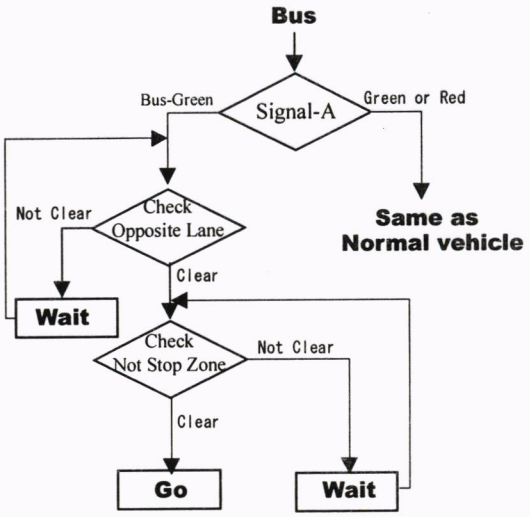


Figure 10. Flowchart for Bus

6.2. Effects of Bus Priority System

Two simulation patterns of bus priority system was simulated as shown in Table 1. The pattern-A is milder than pattern-B. Bus can not overtake on opposite lane without enough gap for overtaking. A additionally, bus lane system (length 800m) was included for simulation.

Table 1. Pattern of Bus Priority System

Pattern	Number of signals for Bus only overtaking	Length for overtaking on opposite lane
Pattern-A	4 signals	100 m
Pattern-B	7 signals	200 m

Both patterns include one side bus lane (length 800m)

Result of pattern-A simulation is shown in Table 2 and Table 3. At congested condition (afternoon time), it takes about 107.9 minutes from "Akashibashi-bri." to "hachiman-gu" by normal vehicle. On the other hand, it takes about 76.1 minutes by bus. Total advantage time for bus is approximately 32 minutes. But most effective factor is bus lane of which reduction time is 23.9 minutes. The reduction time by bus only overtaking signal system is 2 minutes per signal because of short distance as 100 meters for bus overtaking. And there is little influence for normal vehicle and opposite lane.

Table 2. Average Trip Time of Pattern-A

Direction	Time	Present	Bus priority system	
		Normal vehicle	Normal Vehicle	Bus
To Downtown	9:00-10:00 (free flow)	7.3 min.	7.1 min.	6.6 min.
	12:00-13:00 (congestion)	107.9 min.	107.9 min.	76.1 min.
To Suburban	9:00-17:00 (all days)	6.2 min.	6.6 min.	—

Table 3. Details of Reduction Time (Pattern-A)

Section	Normal vehicle	Bus	Reduction time
All section	107.9 min.	76.1 min.	31.8 min.
Bus lane	25.1 min.	1.2 min.	23.9 min.
Bus priority signal system (time per signal)	—	—	2.0 min.

Seven numbers of bus priority signals and long distance for bus overtaking are set for second pattern-B (Table 4,Table 5). Total advantage time for bus is great 72 minutes. There is big improvement that the reduction time by bus only overtaking signal system is 7 minutes per signal. Nevertheless, bad influence for normal vehicle is a little as 0.1 minute. It takes approximately 13 minutes trip time to suburb twice as long as present situation, because of long distance for bus overtaking. There is a little traffic congestion toward suburb in the evening.

Table 4. Average Trip Time of Pattern-B

Direction	Time	Present	Bus priority signal system	
		Normal vehicle	Normal Vehicle	Bus
To Downtown	9:00-10:00 (Free flow)	7.3 min.	22.6 min.	11.2 min.
	12:00-13:00 (congestion)	107.9 min.	108.0 min.	35.0 min.
To Suburban	9:00-17:00 (all days)	6.2 min.	13.0 min.	—

Table 5. Details of Reduction Time (Pattern-B)

Section	Normal vehicle	Bus	Reduction time
All section	108.0 min.	35.0 min.	73.0 min.
Bus lane	25.1 min.	1.2 min.	23.9 min.
Bus priority signal system (time per signal)	—	—	7.0 min.

The citizen committee and authors simulated another case such as changing signal control parameter, but length of bus overtaking on opposite lane is the most effective factors for bus priority system.

In this case, bus overtaking is limited for 200m length, because of following reason;
- Minimum interval between signalized intersections.
- bad influence for opposite lane

6.3. GUI Output

Figure 11 shows GUI output of tiss-NET system that displayed on personal computer. Small points mean each vehicle, while large point means bus which is now overtaking on opposite lane. GUI function has a great influence on the citizen committee of which members are not necessarily experts of traffic engineering.

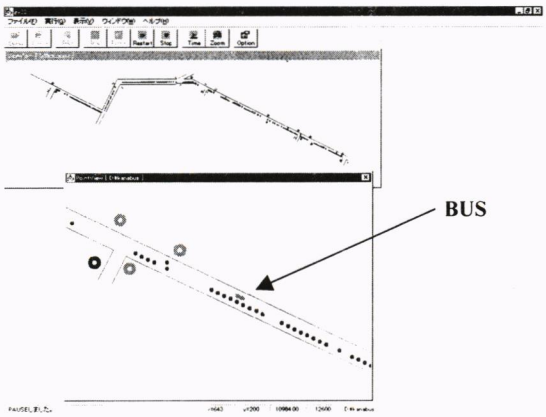


Figure 11. GUI Output of Bus Priority System

7. CONCLUSION

Traffic simulation such as tiss-NET is effective method for decision making. The tiss-NET system could forecast effectively with statistical data as well as GUI output.

It will be necessary that additional analysis including flexible and optimized signal control,

and there are many problems to soluve such as law, safety, signal control technology and so on. But bus priority system such as bus only overtaking signal system is important to realize the committee's proposal.

Kamakura City has decided to go forward to realize the TDM proposal by continuing the experimental schemes as well as surveys and traffic simulation studies. Through these actions, Kamakura City will try to establish consensus both of citizens and related organizations, and to realize a new kind of mobility and environment in historical city.

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