MICROSCOPIC FUZZY URBAN TRAFFIC SIMULATION WITH VARIABLE DEMAND

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ABSTRACT

Some microscopic traffic simulations on urban road network are developed up to now. However, the effect of urban transport policy in the local city is influenced with the complex interaction of automobile traffic and public transport traffic. Particularly, behaviours of vehicles should be described with the fuzziness of the subjective recognition and operation.
On the other hands, the trip makers are influenced by various transport policies in terms of mode choice behaviour. The change in mode choice behaviour and number of public transport mode users would eventually affect traffic flow conditions on road network. Modal spilt and traffic conditions of a network are interrelated. Therefore, the present study mainly aims to integrate mode choice model and microscopic traffic simulation model based on fuzzy logic.
In the study, the fuzzy logic based mode choice model is proposed. The proposed mode choice model and the existing microscopic traffic simulation model are combined. The developed model has been applied on real urban network to demonstrate the effectiveness of the installation of LRT system. Finally, it is helpful for evaluation of transport policy that the fuzzy logic based microscopic traffic simulation with modal choice model has been constructed.

Keywords: Microscopic Traffic Simulation, Mode Choice, Fuzzy Reasoning, LRT

INTRODUCTION

Motorization is progressing in the local city. Suitable public transport policies are required from the viewpoint of mobility for transportation poor. If the present condition of development of public transport system is taken into consideration, the public transport policy mainly concerned with bus traffic and LRT system is important in a local city. The traffic condition including operation of buses and LRT has serious influence for the evaluation of public transport policies. Particularly, when implementing public transport policies, such as a public transport priority lane, a local action of individual vehicles may affect traffic condition with wide range because of the complicated interaction of automobile traffic and public transport traffic. Therefore, it is necessary to use the microscopic road traffic simulation model for evaluation of public transport policy.

The problems can be mentioned about the driver behaviour models in the microscopic traffic simulation systems, such as 1) the judgment of the minute change besides the cognitive range of a driver, 2) the operation depending on the process of state change and 3) the decision process in a various and complicated situation. For example, the asymmetry of the acceleration to the change of the relative speed on the car-following model cannot be described simply. Therefore, in order to describe the complicated interaction of automobile traffic and public transport, it is important to pay the attention to the driving action corresponding to the subjective recognition and subjective operation of each driver. Taking a dynamic change of many factors into consideration, a driver evaluates plural intentions of action synthetically, and makes decisions continuously and strategically. In order to develop such serious complicated information processing by the function type model, it is necessary to structure very complicated composition. In fuzzy reasoning, the rule base can be constituted such complicated information processing with language, and a model can be developed by trial and error.

In the study, the fuzzy logic based microscopic traffic simulation model on urban road network is constructed for evaluation of public transport policy. About the impact of public transport policies, the influence on a traffic flow over the wide area can be grasped, and a detailed traffic condition can be analyzed locally. The LRT system as a public transport policy is proposed for actual urban road network, and the proposed policies are evaluated from both sides of the wide area and the local point.

Firstly, the fuzzy logic based mode choice model is proposed. In the study, the comfort of public transport is considered as well as travel time, travel cost and access time. The comfort index is some number based on the seat availability in a public transport vehicle mainly depends on the number of passengers travelling at that time and capacity of public transport. These variables are described as linguistic variable with membership functions. After the definition of the linguistic variables, the fuzzy rule set for mode choice is formulated in the form of IF-THEN rule. It can be observed that the fuzzy reasoning approach is able to estimate the mode choice of an individual more accurately compare to the logit model.

Secondly, the proposed mode choice model and the existing microscopic traffic simulation model are combined. The fuzzy logic based microscopic traffic simulation model on urban road network has been already constructed for evaluation of transport policy by the authors. The vehicle behaviours such as car following, lane changing, route choice and steering clear of parking could be described easily with the fuzziness of recognition and operation of drivers. The mode choice model is applied to the vehicle generation stage of the microscopic traffic simulation. On the other hands, the microscopic traffic simulation provides current travel time and comfort index in specific intervals as the input of the mode choice model. The validity of the fuzzy logic based microscopic simulation model could be statistically verified by comparison with survey data.
Thirdly, the integrated microscopic traffic simulation is applied to evaluate the installation of LRT system in the network of Gifu city, Japan. At-grade LRT system are assumed to improve the commuter travel in the study. At-grade LRT system would be operating on priority rights-of-way similar to priority bus lane. The lane change behaviour for avoiding the following bus on the priority lane is described with fuzzy reasoning. The traffic condition of road network on the peak morning time is estimated with the developed simulation system. The number of public transport passenger is also calculated. The effect with implementation of each option of LRT system can be evaluated with the proposed microscopic traffic simulation.

MODE CHOICE MODEL FOR TRAFFIC SIMULATION

The fuzzy logic based mode choice model is proposed in the chapter. In the study, the comfort of public transport is considered as well as travel time, travel cost and access time. After the definition of the variables, the fuzzy rule set for mode choice is formulated. It can be observed that the fuzzy reasoning approach is able to estimate the mode choice more accurately than the logit model.

Review of Mode Choice Model in Traffic Simulation

The mode change behaviour of driver has to be critically modelled and integrated with the simulation model to describe trip maker's behaviour from starting of a trip to reaching destination. Also mode choice model has to be necessarily integrated with simulation model to enable to consider wide range of transport polices. In this direction, PCATS/DEBNetS, a micro-simulation model has been developed recently by Kitamura et al (2000). PCATS (Prism-Constrained Activity-Travel Simulator) is a system of behavioural models for individual's daily activity and travel. DEBNetS (Dynamic Event Based Network Simulator) is micro-meso scale simulator of network flow. PCATS generates the individual trip maker's activities and travel using a host of model components, including activity type choice models, activity duration models and mode-destination choice models. DEBNetS simulates vehicles' behaviour using flow-density relationships.

These two simulators has been integrated to form a demand forecasting and policy analysis tool for regional transportation planning. Vehicle trips generated by PCATS are fed to DEBNetS and traffic characteristics estimated by DEBNetS are given as input to PCATS to generate trips along a continuous time axis. Combining the mode choice behaviour with network simulator is successfully carried out in PCATS with DEBNetS. However, the microscopic individual vehicular movements are not considered. On the other hands, important elements such as waiting time at bus stop at bus stop and its variation due to current traffic conditions and punctuality of buses cannot be estimated. These are most significant factors in deciding a mode by a trip maker in real situations. Moreover, the approximations involved in traffic models because of the human element and driver's perception on existing traffic conditions are ignored. Hence, there is a high need to consider microscopic behaviour of every vehicle movement and approximations involved in all traffic models to represent the driver behaviour more realistically and enable to evaluate wide range of transport policies.

The mode choice model has been proposed to integrate with microscopic traffic simulation model and proposed to simulate trip makers on urban road network rather than vehicle movement. To consider the approximations in trip maker behaviour, it is also proposed to introduce fuzzy logic technique in mode choice model.

Variables in Mode Choice

The mode choice behaviour of a trip maker mainly depends on travel characteristics of each mode and road network conditions. Many mode choice models are developed by considering mainly travel time and travel cost. It has been evident from the past studies that other factors might also strongly influence the individual in choosing mode like waiting time and walking time which are considered as access time rather than only journey time and cost alone (Errampalli et al, 2004). In the present study, it has been considered that driver assesses mainly travel parameters and comfort issues involved with all the modes before selecting his mode for his trip. In this study, it is assumed that driver decides utility of each mode based certain influencing variables and finally selects the mode for his trip considering all the estimated utilities for each of the available modes. A total of four influencing variables have been considered to describe mode choice behaviour and they are Travel Time (TT), Travel Cost (TC), Access Time (ACT) and Comfort (CFT).

The travel time (TT) is considered as journey time spent inside the vehicle and as well as in waiting at bus stops and measured in minutes and travel cost (TC) is considered as money spent for that trip towards fuel in case of car or fare in case of bus. And access time (ACT) is the time required to reach bus stop for an individual by walking in minutes. The variable Comfort (CFT) is some number assigned between 0 and 100 based on the seat availability in a bus mainly depends on the number of passengers travelling at that time and capacity of bus. The higher number shows more comfort and plenty of seats are available. In the present mode choice modelling, it has been assumed that the above mentioned four influencing variables would describe mode choice behaviour of trip maker and other socioeconomic parameters such as sex, age etc have not considered in the modelling. This can be considered as limitation of the present mode choice model.

In the present study, the person trip survey of Gifu city, Japan has been used to model the mode choice behaviour of trip makers. The data which has been considered was collected in the year of 2001 and the choice riders who have choice between their own mode and bus have been considered for the present purpose. In that process, about 2860 samples have been selected. In that data, the characteristics such as starting time of trip, origin and destination details, distance travelled, travel time and cost by their travelling mode and perceived values by other mode and access time to reach their nearest bus stop has been included for each of the sample. The comfort data has been developed from existing bus time table data of Gifu Bus Company. A total of 44 bus routes are operating in Gifu city by company and number of buses operates in each of the route based on their scheduled time have been counted. From the person trip survey data, total number of bus users according to their starting time of trip has been estimated in every designated interval of time. These details have been estimated for every half an hour starting from 6:00 am to 11:00 am. From this data, the total number of bus users in each bus has been estimated. From this data, the comfort index has been calculated using average number of passengers in a bus and capacity of a bus. The average capacity of a bus has been assumed as 30 in the present study that means 30 seats are available in each bus. The bus user and comfort data has been given in the Table 1.

Table 1 – Bus passenger data and associated comfort index

time	bus passengers	number of buses operating	average passengers per bus	comfort index
~6:00 am	39	14	3	91
6:00 ~ 6:30 am	397	63	6	79
6:30 ~ 7:00 am	1809	102	18	41
7:00 ~ 7:30 am	4081	121	34	0
7:30 ~ 8:00 am	4164	101	41	0
8:00 ~ 8:30 am	2615	103	25	15
8:30 ~ 9:00 am	1518	85	18	40
9:00 ~ 9:30 am	1404	86	16	46
9:30 ~ 10:00 am	1041	80	13	57
10:00 ~ 10:30 am	838	85	10	67
10:30 ~ 11:00 am	628	76	8	72

The comfort index which is mentioned in above table is the probability of getting seat in that time estimated mainly from bus passengers and number of buses operating. This value has been approximately estimated from average passengers per bus and bus capacity. This value shows the percentage of unoccupied seats in each bus and this has been estimated from the above data. For example, if a trip maker start his trip at 6:45AM and the comfort index is 71 so that means the chance of getting seat is 71% and the chance of getting a seat between 7:00 and 8:00 are zero as the bus passengers are more than the capacity of bus hence comfort index is zero. This data basically estimated considering all the buses operating on the network at that time however the number of passengers might be different from each bus in reality. However, in the present study it is considered as constant in all the buses and average passengers per bus have been taken into consideration. It can be considered as limitation in the present model and detailed investigations are proposed for future study.

Logit Mode Choice Model

Logit model is to be considered as most appropriated before artificial techniques come into usage in mode choice modelling area. Calibration of the model involves the estimation of the parameters for the attributes and is basically done by maximum-likelihood method of estimation. For the purpose of calibration of logit mode choice model, person trip survey data which was collected in 2001 in Gifu city has been used. About 2868 samples have been selected who have the access for both car and bus modes. Out of these, 2008 samples have been used for calibration and remaining 860 samples have been used to validate the developed mode choice model. The access time for car has been assumed as zero because the usage of a car does not involve any walking and high comfort index (i.e. 100) has been assumed for car. The estimated parameters and their statistical values for logit model have been given in Table 2.

Table 2 – Final values of estimated parameters from logit analysis

parameter	mode	estimated value	t-value	
constant	car	0.5498	0.93	
travel time	common	0.0276	12.26	*
travel cost	common	0.0075	2.42	*
access time	public transport	-0.0958	-1.71	
comfort index	public transport	0.0107	3.16	*
likelihood ratio = 0.667				

From the Table 2, it can be said that the travel time and comfort values are significantly contributing to estimate utility of mode because the parameter and t-values are high. The access time which is a walking time has negative sign and this represents the negative impact on utility of a mode. The R^2 value about 0.66 shows the moderate accuracy of the model. Using the above parameter values, the utilities of each mode have been calculated and probability of choosing mode has been calculated subsequently. These values are compared with observed data and the same has presented in Table 3. The same samples used for calibration have been used to estimate prediction accuracy.

Table 3 – Prediction table for logit mode choice model with calibration sample

caliblation		estimated samples		
observed samples	mode	**car**	**public transport**	total
	car	1792	9	1801
	public transport	203	4	207
	total	1995	13	2008
prediction accuracy = 89%				

The prediction accuracy of the model has been estimated using the number of samples correctly classified considering both observed and estimated choices and it is coming about 89%. Though the accuracy seems to be high and over all modal split value also seems to be closer to observed value, the model looks partial towards car and many bus samples have been predicted as car samples.

The calibrated mode choice model has been validated using different sample set (860 samples) which are not used for calibration to assess the accuracy of present mode choice model. The mode choices have been estimated for these samples and the results have been presented in Table 4.

Table 4 – Prediction table for logit mode choice model with validation sample

validation		estimated samples		
observed samples	mode	**car**	**public transport**	total
	car	712	2	714
	public transport	142	4	146
	total	854	6	860
prediction accuracy = 83%				

The prediction accuracy coming about 83% and it has been estimated using the number of samples correctly classified considering both observed and estimated choices. Though the accuracy seems to be high and over all modal split value also seems to be closer to observed value, the model looks partial towards car and many bus samples have been predicted as car samples.

From the logit model results, it can be concluded that it has high accuracy in predicting choice for car but poor performance in terms of choosing a bus. This phenomenon would cause inappropriate modal split values and more number of cars would be generated on the network than the observed cars. Hence, it would eventually change the network conditions and unrealistic phenomenon such as more congestion and more travel times would be predicted and this will further change mode choice behaviour. Moreover, the results from logit model might be accurate when the influencing variables have been exactly perceived by an individual. In reality, there is a lot of approximations involved in perceiving the influencing variables and there is always a human error exist while taking decisions. Under these situations, there is a high chance that mode choice predictions might be deviated from real behaviour. On the other hand, it has already been reported that fuzzy logic is a suitable technique that considers the approximations and human perceptions and it is able to estimate the decisions of the driver more realistically (Mizutani and Akiyama, 2000). Therefore, in view of all these, it has been proposed in the proposed study to consider the fuzzy logic technique in modelling mode choice and the details of proposed fuzzy logic based mode choice model have been described in subsequent sections.

Fuzzy Logic Based Mode Choice Model

Formulation of mode choice model with fuzzy reasoning

In this study, fuzzy logic based mode choice model has been proposed to estimate the mode choice behaviour of the individual by considering four significant influencing variables. These variables mainly estimate utility of mode and probability of mode would be estimated subsequently. They are travel time (TT), travel cost (TC), access time (ACT) and comfort index (CFT). The output variable is utility of mode (UTL). The trip maker decides utility of each mode from the above mentioned four influencing variables. The trip maker mainly uses some simple rules using influencing variables rather than applying any mathematical model such as logit model. Hence, trip maker refers influencing variables into certain groups and sets because of non-availability of crisp information on them and uses certain linguistic description for fuzzy sets. For all these input variables TT, TC, ACT and CFT and output variable UTL, five fuzzy sets with triangular membership functions (i.e. very small, small, medium, large and very large) have been considered. A typical shape of membership function for fuzzy sets of input/ output parameter has been shown in Figure 1.

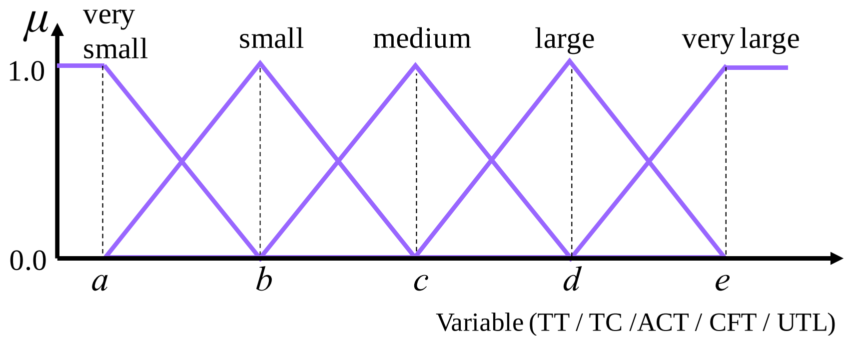


Figure 1 – Linguistic description of fuzzy sets of variables in mode choice model

After considering membership functions of all influencing variables and output variable, appropriate fuzzy rule base in the form of IF-THEN rule has been formulated. For this purpose, the relation between all influencing variables and the output has been carefully examined. The various combinations of influencing variables with linguistic description have been identified logically to determine the actions of trip maker in terms of utility of mode (UTL) to construct the rule base. In this process, a total of 35 rules have been formulated to determine the decision in terms of utility of a mode as shown in Figure 2.

Rule - 1	If	*TT*	is	very large	and	*TC*	is	very large	Then	*UTL*	is	small
Rule - 2	If	*TT*	is	very large	and	*TC*	is	large	Then	*UTL*	is	very small
Rule - 3	If	*TT*	is	very large	and	*TC*	is	medium	Then	*UTL*	is	small
Rule - 4	If	*TT*	is	very large	and	*TC*	is	small	Then	*UTL*	is	small
Rule - 5	If	*TT*	is	very large	and	*TC*	is	very small	Then	*UTL*	is	small
Rule - 6	If	*TT*	is	large	and	*TC*	is	very large	Then	*UTL*	is	small
Rule - 7	If	*TT*	is	large	and	*TC*	is	large	Then	*UTL*	is	very small
Rule - 8	If	*TT*	is	large	and	*TC*	is	medium	Then	*UTL*	is	small
Rule - 9	If	*TT*	is	large	and	*TC*	is	small	Then	*UTL*	is	small
Rule - 10	If	*TT*	is	large	and	*TC*	is	very small	Then	*UTL*	is	small
Rule - 11	If	*TT*	is	medium	and	*TC*	is	very large	Then	*UTL*	is	medium
Rule - 12	If	*TT*	is	medium	and	*TC*	is	large	Then	*UTL*	is	small
Rule - 13	If	*TT*	is	medium	and	*TC*	is	medium	Then	*UTL*	is	medium
Rule - 14	If	*TT*	is	medium	and	*TC*	is	small	Then	*UTL*	is	medium
Rule - 15	If	*TT*	is	medium	and	*TC*	is	very small	Then	*UTL*	is	medium
Rule - 16	If	*TT*	is	small	and	*TC*	is	very large	Then	*UTL*	is	large
Rule - 17	If	*TT*	is	small	and	*TC*	is	large	Then	*UTL*	is	medium
Rule - 18	If	*TT*	is	small	and	*TC*	is	medium	Then	*UTL*	is	large
Rule - 19	If	*TT*	is	small	and	*TC*	is	small	Then	*UTL*	is	large
Rule - 20	If	*TT*	is	small	and	*TC*	is	very small	Then	*UTL*	is	large
Rule - 21	If	*TT*	is	very small	and	*TC*	is	very large	Then	*UTL*	is	very large
Rule - 22	If	*TT*	is	very small	and	*TC*	is	large	Then	*UTL*	is	large
Rule - 23	If	*TT*	is	very small	and	*TC*	is	medium	Then	*UTL*	is	very large
Rule - 24	If	*TT*	is	very small	and	*TC*	is	small	Then	*UTL*	is	very large
Rule - 25	If	*TT*	is	very small	and	*TC*	is	very small	Then	*UTL*	is	very large
Rule - 26	If	*ACT*	is	very small					Then	*UTL*	is	very large
Rule - 27	If	*ACT*	is	small					Then	*UTL*	is	large
Rule - 28	If	*ACT*	is	medium					Then	*UTL*	is	medium
Rule - 29	If	*ACT*	is	large					Then	*UTL*	is	medium
Rule - 30	If	*ACT*	is	very large					Then	*UTL*	is	medium
Rule - 31	If	*CFT*	is	very large					Then	*UTL*	is	very large
Rule - 32	If	*CFT*	is	large					Then	*UTL*	is	large
Rule - 33	If	*CFT*	is	medium					Then	*UTL*	is	medium
Rule - 34	If	*CFT*	is	small					Then	*UTL*	is	small
Rule - 35	If	*CFT*	is	very small					Then	*UTL*	is	very small

Figure 2 – Fuzzy inference rules for mode choice model

The trip maker first thinks on travel time and travel cost to estimate utility of that particular mode and describe such behaviour, inference rules from Rule No 1 to 25 has been formed. For instance, the Rule No - 5 says if TT is very big and TC is very small, the utility is small.

Because, time is very high even though cost is cheap, the utility is small. From this it can be said that the mode choosing probability would also become less. The trip maker would be influenced with the access time associated with the mode and the Rule No 26 to 30 would describe such behaviour and associated utility can be estimated from these. For example, the Rule No 30 explains that if access time is very big, the utility of that particular mode is very less. The comfort index associated with the mode also greatly influence the behaviour of trip maker and this has been explained from Rule No 30 to 35 and associated utility can be estimated. For example, the Rule No 35 says that if comfort of any mode is very small, the utility of that particular mode is very less thus the probability of choosing that mode also become very less from this rule. Finally, all these rules would be considered simultaneously to estimate final decision on utility of particular mode and calculate the probability of choosing mode. The trip maker estimates utilities of all modes one by one and finally selects the probabilities of all modes.

The fuzzy reasoning process is summarized with three elements namely implication from inference rules, integration of conclusions and defuzzification. The popular implications are Min-Max-Gravity operation and Product-Sum-Gravity operation. The min-operation would be clipping off the fuzzy set and the implication result becomes flat and same for some values of mode choice decision. However, the mode choice decision corresponding to the truth from antecedent condition cannot be constant and vary across different values. The product-operation considers this effect and the implication result would be scaled across the values of mode choice decision so that every decision has different weight from each other. In mode choice, drivers respond to small change in the variables and need to consider the influence of all inference rules in the conclusion. The sum operator is able to consider the implication results simultaneously by summing and consider all implications into conclusion so that even small implication is considered in mode choice decision. For defuzzification, center of gravity of the distributed area is often considered as a representation in conclusion. Since Min-Max-Gravity method generates undesirable nonlinearity, Product-Sum-Gravity has been proposed to many applications in the practical fields and might provide better performance and easy to tune besides its simplicity and low computations (Okushima et al, 2002 and Kim, 2002). Therefore, the "Product-Sum-Gravity" operation is considered as appropriate and implemented in fuzzy reasoning to produce the practical mode choice model in the present study.

Calibration and validation of fuzzy logic based mode choice model

For each input/ output variable, the parameters have been appropriately calibrated mainly by trail and error method to determine the shape of membership functions. The trail and error process has been carried out till the error in estimated mode choices gets minimized and until prediction accuracy which has been mentioned in Section 4.3.3 becomes high. The same samples (sample size is 2086) which are used for logit model in calibration have been used for calibration of fuzzy logic model. The utility decisions have been estimated using fuzzy inference rules by Product-Sum-Gravity method and mode choice decisions have been estimated for all the samples from that. The final parameter values after calibration have been depicted in Table 5.

Table 5 – Calibrated membership parameters for input and output variables

membership parameter	input variable				output variable
	TT [min]	TC [yen]	ACT [min]	CFT	UTL
a	30	100	1	10	0.25
b	40	150	3	12	0.50
c	75	300	5	15	0.75
d	100	500	7	100	1.00
e	150	600	9	130	1.50

The membership parameter a, b, c, d and e mentioned in the above table are same values which are mentioned in Figure 1. Out of 2868 samples, 2008 samples have been used for calibration and remaining 860 samples have been used to validate the developed mode choice model. Using the above parameter values mentioned in Table 4, the utilities of each mode have been calculated and probability of choosing mode has been calculated subsequently. These values are compared with observed data and the same has presented in Table 6.

Table 6 – Prediction table for fuzzy logic model with calibration samples

caliblation		estimated samples		
observed samples	mode	**car**	**public transport**	total
	car	1642	159	1801
	public transport	5	202	207
	total	1647	361	2008
prediction accuracy = 92%				

The prediction accuracy of the model has been estimated using the number of samples correctly classified considering both observed and estimated choices and it is coming about 92%. The accuracy is high and over all modal split value also is closer to observed value.
The calibrated fuzzy logic based mode choice model has been validated using different sample set (860 samples) which are not used for calibration to assess the accuracy of present mode choice model. The mode choices have been estimated for these samples and the results have been presented in Table 7.

Table 7 – Prediction table for fuzzy logic model with validation samples

validation		estimated samples		
observed samples	mode	**car**	**public transport**	total
	car	660	54	714
	public transport	6	140	146
	total	666	194	860
prediction accuracy = 93%				

The prediction accuracy coming about 93% and it has been estimated using the number of samples correctly classified considering both observed and estimated choices. The prediction accuracy of logit model is 83% and this clearly shows the improvement in accuracy though the incorporation of fuzzy logic mode choice modelling process. As it can be seen from Table 5, the accuracy seems to be higher with fuzzy logic models, however the modal split values very different from these two models.

It can be observed that logit model is more biased towards car and this phenomenon has been eliminated in case of fuzzy logic thus model becomes more realistic. It can be clearly observed from the results that fuzzy reasoning approach is able to predict the mode choice of an individual more accurately compared to logit model.

INTEGRATED FUZZY MICROSCOPIC TRAFFIC SIMULATION

The proposed mode choice model and the existing microscopic traffic simulation model are combined in the chapter. The mode choice model is applied to the vehicle generation stage of the microscopic traffic simulation.

Fuzzy Logic based Traffic Models for Microscopic Simulation

Fuzzy reasoning has been implemented in all the travel behaviour models. These models can be easily calibrated with minimum efforts.

Route choice model with fuzzy logic

In the present simulation model, it is assumed that route travel time is a fuzzy number and driver choose his route based on possibility index, which represents possibility of choosing route. To compare the possibility indexes of all available routes, it is necessary to have a fuzzy goal, *G* (Akiyama and Nomura, 1999 and Akiyama, 2000). All the available routes would be compared with goal function and routes would be ranked based on possibility indexes. Possibility indexes for the available routes would be separately calculated using the fuzzy goal. Based on the possibility measure approach, the possibility indexes for all the available routes have been calculated and finally driver selects the route, which has the maximum possibility index. More details can be found in the previous publication of the authors (Errampalli et al, 2005a and 2005b).

Car-following model with fuzzy logic

The acceleration of vehicle is estimated based on leader vehicle behaviour and surrounding circumstances by using car-following model. From the acceleration, vehicle position on the network would be updated in every time interval. In the past studies based on fuzzy logic, only relative speed (RSP), relative distance (RDS) and leader vehicle acceleration rate (LAR) have been considered (Chakroborthy and Kikuchi, 1999 and Wu et al, 2000). On urban roads, parking on kerb side can be generally observed at many places. Therefore, partial lane change process may occur on the links. The speed would be reduced as the vehicle slightly use adjacent lane and this will make other vehicles travelling on adjacent lane also slow down in presence of parked vehicles along road side and sometimes vehicles try to change lane to avoid this area. In that case, it is assumed that vehicle movement would also be influenced by lateral obstructing distance in case of parked vehicle presence.
After creating the membership functions of all variables, appropriate fuzzy rule base consist of 85 rules has been formulated to determine the decision of driver in terms of acceleration. For each variable, the parameters have been appropriately and logically calibrated to determine the shape of membership's functions (Errampalli et al, 2007).

Lane change model with fuzzy logic

In this model, it is proposed to consider total five types of lane changing purposes, such as speed advantage, turn at next intersection, type of bus lane policy, presence of bus at bus stop and presence of parked vehicles along kerb-side. The motivation for lane changing varies based on the purpose and it is clearly different from each other and considers different input variables for different purposes. A fuzzy rule base has been formulated to determine the output variable for each purpose separately. A total of 54 fuzzy inference rules have been formulated for all purposes. As lane changing is a more sophisticated activity only three fuzzy sets as triangular membership function are used for each of input and output variables for the sake of simplicity (Errampalli et al, 2006).

Integrating Fuzzy Logic Mode Choice Model with Microscopic Simulation

As it is already been discussed, it is necessary to combine mode choice model with microscopic simulation model to consider the mode choice behaviour of trip maker under the influence of various transport policies. In this direction, the developed mode choice model based on fuzzy logic has been combined with FLoMiTSiM to estimate mode choice behaviour under different transport policies during their evaluation process. The trip maker is generated in the vehicle generation module based on the determined time and if that trip maker is choice rider (who owns a car), then there is a possibility of having a choice of mode change. So the generated trip maker would be allowed to carry out mode choice phase. The processes involved in this have been given in flow chart as shown in Figure 3

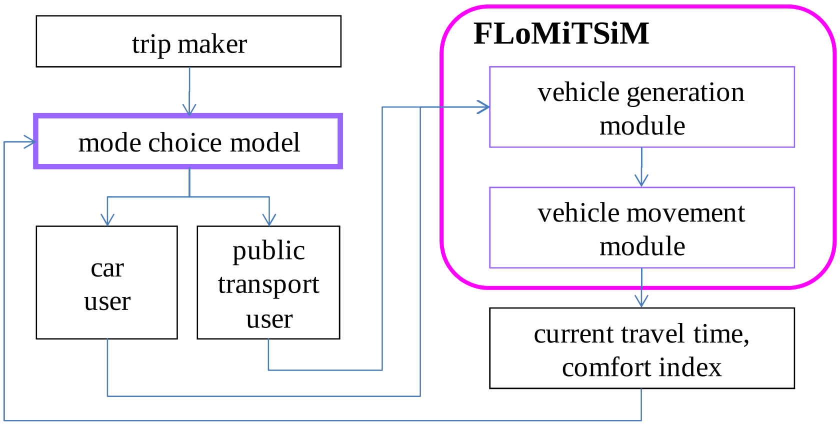
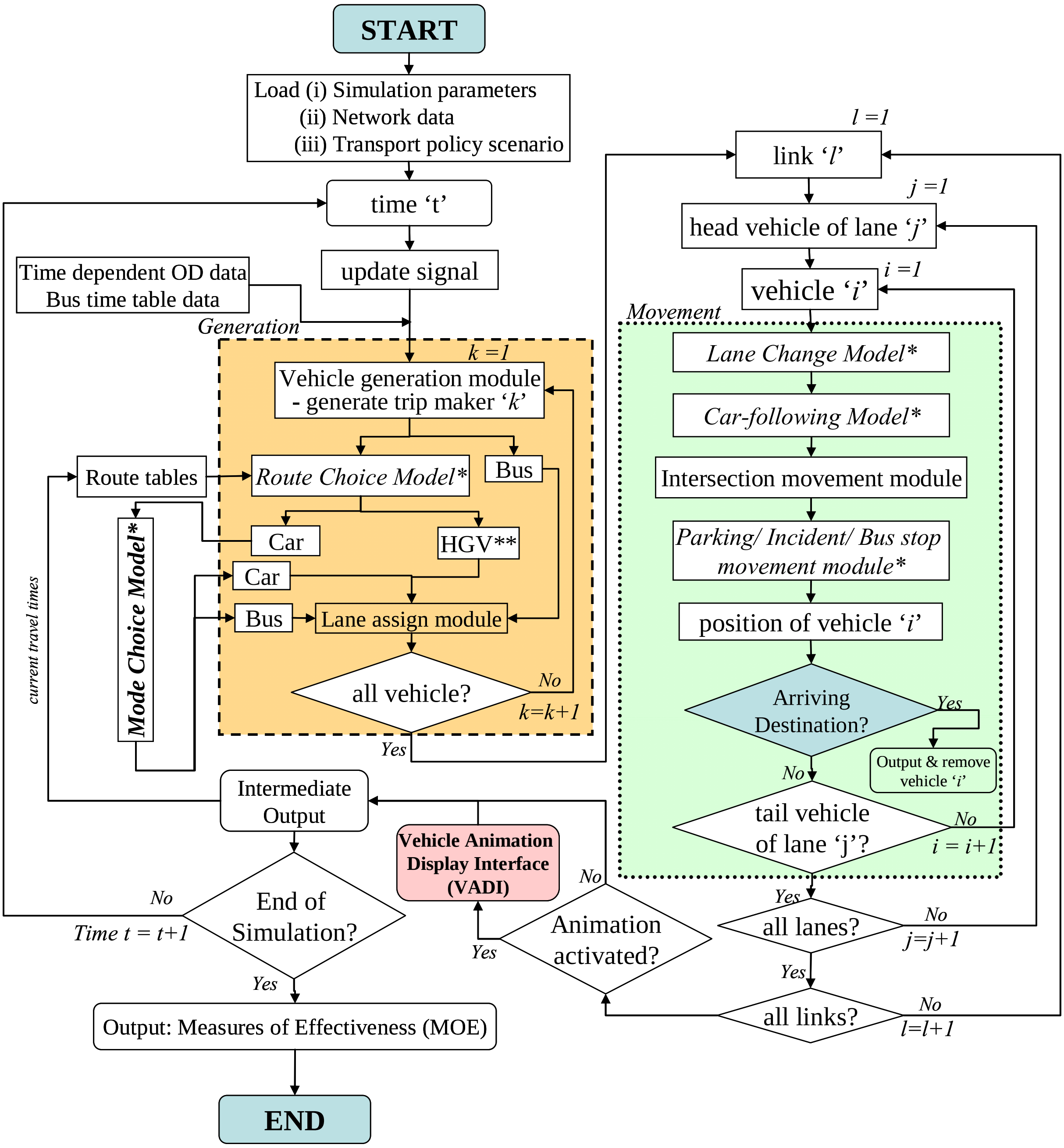


Figure 3 – Processes in combined mode choice and microscopic traffic simulation model

During the vehicle generation stage the mode choice model is applied if the trip maker is choice rider as shown in the above figure. This model takes the input of current travel time data and comfort data which has been calculated in specific intervals from the intermediate output of FLoMiTSiM. Based on the input supplied by FLoMiTSiM, it estimate the mode choice decision of the trip maker and the chosen mode would be generated and fed into the network accordingly at appropriate time. Then movement of that vehicle would be estimated by FLoMiTSiM at each time interval. These processes would be continuously carried out in every simulation interval for a given time duration to estimate the network situation under different transport policies. In the present study, fuzzy reasoning approach has been proposed to be considered in mode choice modelling and a methodology has been proposed to integrate with existing fuzzy logic based microscopic simulation model. The final model can be considered as an extension of FLoMiTSiM and it has been denoted as FLoMiTSiM-Ex: A Combined Fuzzy Logic Mode Choice and Microscopic Simulation Model. The FLoMiTSiM-Ex structure has been given in the form of flow chart as shown in Figure 4.

It can be seen that the fuzzy logic based mode choice model has been integrated with FLoMiTSiM after the vehicle generation module and route choice model. After that, mode would be decided from mode choice phase and that vehicle generated on the network and movements would be estimated.

Even though the combined model FLoMiTSiM-Ex almost looks similar to FLoMiTSiM, the trip maker behaviour is basically evaluated starting from origin to destination. At all the stages, trip maker decision is determined such as mode choice, route choice, lane choose, car-following, lane change etc. as shown in Figure 4.



** with fuzzy logic; ** HGV - Heavy Goods Vehicle*

Figure 4 – Flow Chart for Combined Mode Choice and Simulation Model

The proposed FLoMiTSiM-Ex which contains all major traffic models with fuzzy logic is expected to consider these approximations involved in the perceptions and decisions of the trip makers. This proposed research methodology is expected to eliminate many limitations in the past models and also bring a significant improvement towards developing a realistic microscopic simulation model to analyze trip maker behaviour for urban travel as a whole.

APPLICATION OF PUBLIC TRANSPORT POLICY

The integrated microscopic traffic simulation is applied to evaluate the installation of LRT system in the target network in the chapter. LRT systems are assumed to improve the commuter travel. The traffic condition of road network on the peak morning time is estimated with the developed simulation system.

Implementation of LRT System

In the present study, at-grade LRT system and grade-separated LRT system have been considered. In the present study, at-grade LRT system has been proposed for some streets of Gifu city network. The LRT system would be operating on priority rights-of-way on all parts of the route. The priority rights-of-way are similar to priority bus lane. The LRTs would operate on selected routes on steel rails flushed in roadway. Therefore, private vehicles can be permitted to use the lane on the LRT routes. It is assumed that private vehicles give no hindrance to the traveling LRTs on the lanes. The private vehicle on the LRT lane keeps on checking the gap to the follower vehicle. The private vehicles have to change the lane to ordinary lane, if any LRT is coming from its back.

Moreover, the LRT system would be given priority at signalized intersections in the present case to reduce delays induced by the operation of traffic signals. To minimize the delays, preferential treatment can be granted to LRTs at signalized intersections either off-line, by determining signal timings that intentionally favor LRT movements, or on-line, by allowing the signal timings to adjust to LRT detection. In the latter case, the signal timings are typically allowed to hold the green on an approach until LRT has cleared the intersection or to advance the start of the green to reduce the delay incurred by a LRT in queue. It allows a LRT to avoid stopping at traffic light. In the present study, priority phase has been introduced whenever the LRT is approaching to the intersection is detected. When the priority phase is applied for the priority direction, non-priority phase is applied for the cross direction.

In the present study, grade-separated LRT system has been proposed to consider for same streets of Gifu city network as at-grade LRT system for the comparison purpose. As the route itself is elevated from the surface, there is no need of considering any priority on roadway and intersection in this case. The frequency of LRT system has been assumed as 30 minutes. LRT starts at every 30 min at both ends starting from 6:00 am.

In the present study, LRT system have been assumed to be introduced on Chusetsu Street as route A and Kinka Street as route B to improve the commuter travel in the target city area as shown in Figure 5.

These routes basically start from the university to central station. Two types of LRT system (i.e. at-grade and grade-separated) for both route have been considered. Total four options have been considered.

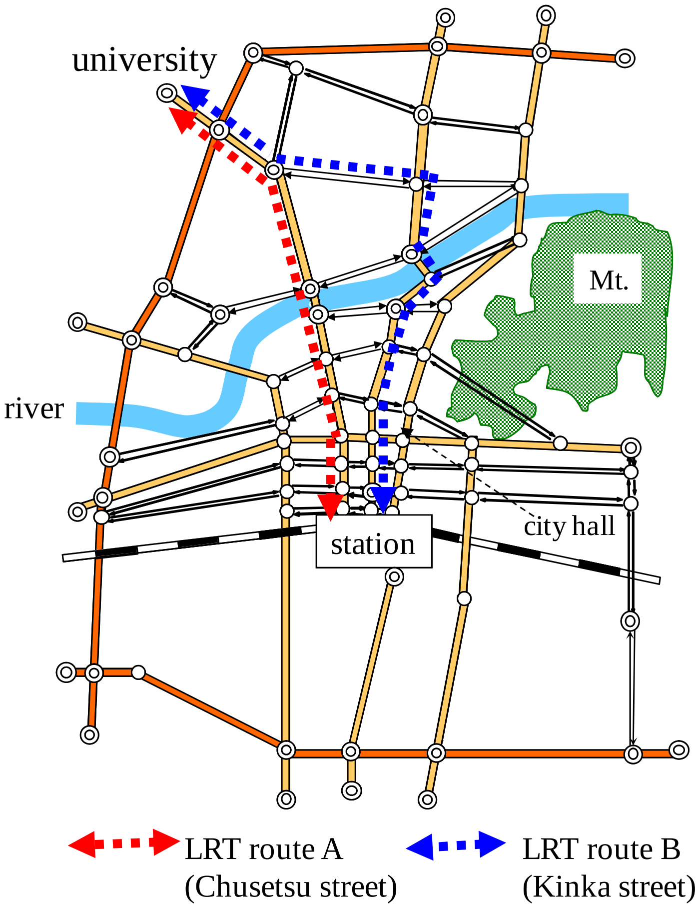


Figure 5 – Location of selected routes for LRT policy for target network

The route A has 4,700 meters length with 10 links. Otherwise, the route B has 6,300 meters length with 13 links. The fare structure has been formulated for route A and route B separately. However, the same fare structure has been assumed for at-grade and grade-separated LRT types. The maximum fare on both routes is assumed as 300 yens. Otherwise, the minimum fare for one link is 170 yens. The fare structure is formulated mainly considering ranges of distance travelled and the increments vary from 20 to 30 yens as the distance increase.

Estimation Result with the Proposed Fuzzy Microscopic Simulation

After assuming the fare structure and route scheduling, the evaluation results have been estimated with the proposed microscopic simulation model. The estimated result on mode change patterns for different options has been shown in Figure 6.

The variations in number of mode changed users across the different options are about 2000 to 4000. The number of trip makers changed mode in the case of route B is more than in the case of route A, because the number of trip maker generated on the route A are more than the route B. The number of mode changed trips with the at-grade LRT policy is almost same as with the grade-separated LRT policy. It means the at-grade LRT system is significantly affecting road traffic with priority lanes and signal priority at signals.

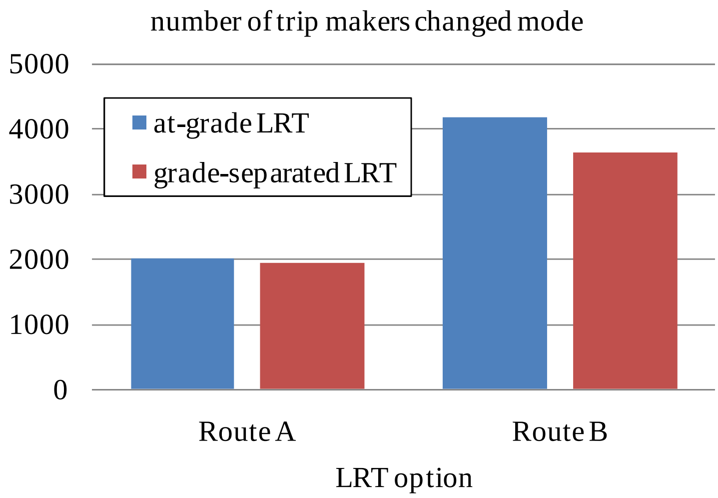


Figure 6 – Mode change behaviour for different options of LRT

As the implementation of LRT system would influence not only on selected route but also on other parts of the network, total travel time on the network has also been considered as an important evaluation index. The results of total travel time have been presented in Figure 7.

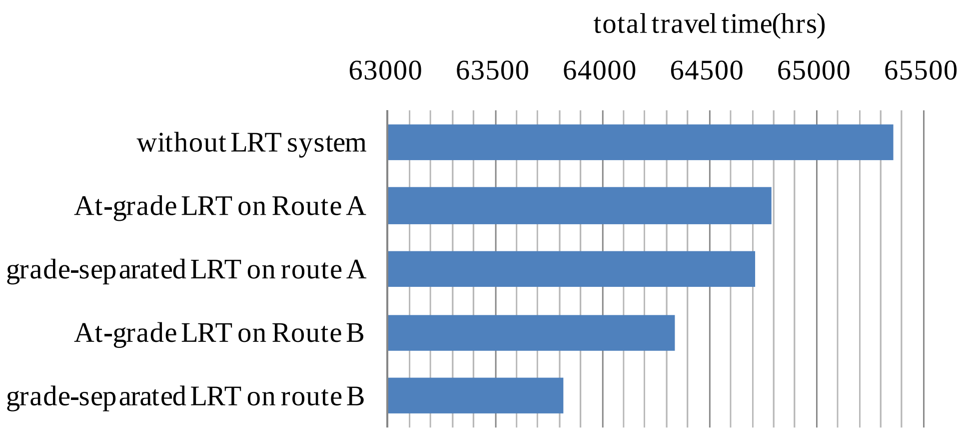


Figure 7 – Total travel time for different LRT options

Implementation of LRT has influenced overall network condition. The all options have reduced the total travel time. The grade-separated LRT options have reduced more compared to the at-grade LRT options. As the at-grade LRT options involve priority lanes and signal priority at signals, the travel time of car user on the route cross to the route of LRT is increasing. On the other hands, as the number of trip makers changed mode in the case of route B is more than in the case of route A, the reduction of total travel time in case of route B is more than in the case of route A.

The effect of implementation of the LRT system to individual vehicles is discussed in terms of OD travel time. The travel time for the particular OD pair to the central station is shown in Figure 8.

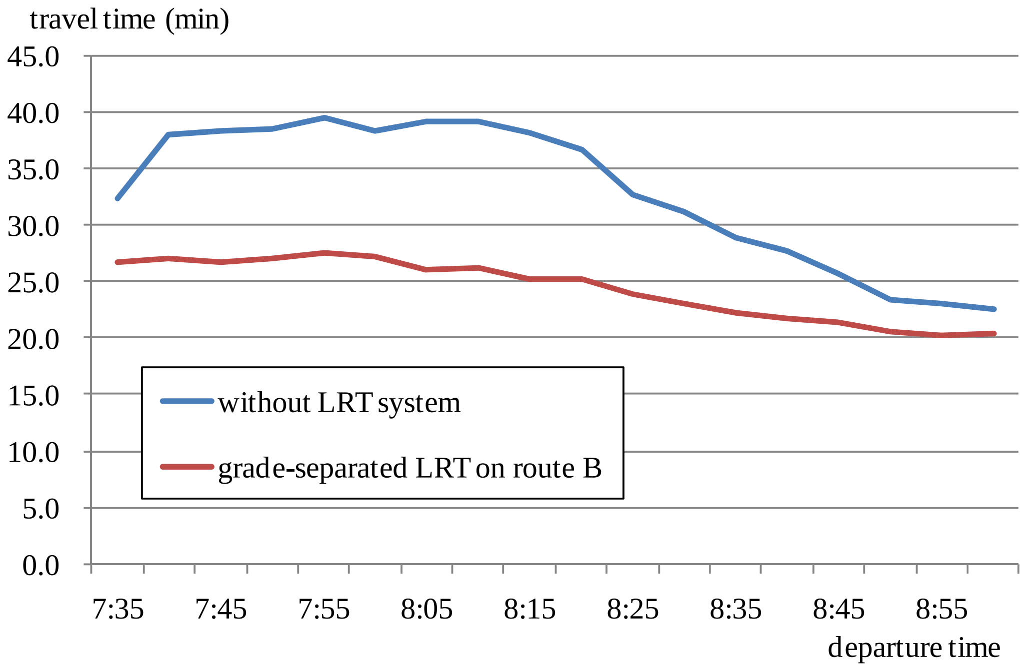


Figure 8 – Time series OD travel time by car

The OD travel time is about 40 minutes at the maximum in the case without LRT system. On the other hand, the maximum travel time in the case of the at-grade LRT on route B can be decreased to about 27 minutes. Therefore, reliability of road network can be improved with implementation of LRT system.

To visualize the impact of this LRT system on the implemented stretch and other parts of the network, congestion on the network has been estimated. The links have been further divided into 100 meter sections in each lane. A section can be marked as congested if the density of vehicles is more than the critical density (50 veh/ lane/ km). As it can be observed that the implementation of at-grade LRT system on route B is expected to give many mode changed trips, the congestion level at 8:00 for without LRT system condition and at-grade LRT system on route B conditions have been compared graphically in Figure 9.

The at-grade LRT system on route B has reduced congestion slightly by 2% on the total network. The total congested blocks on the route B have significantly reduced. On the other hands, it can also be observed that the option has also increased congestion on other links, because the signal phasing has been adjusted to optimize the flow on the concerned intersections and concerned stretch i.e. route B at the present case. However, the delays have increased for other intersections located far from the route B.

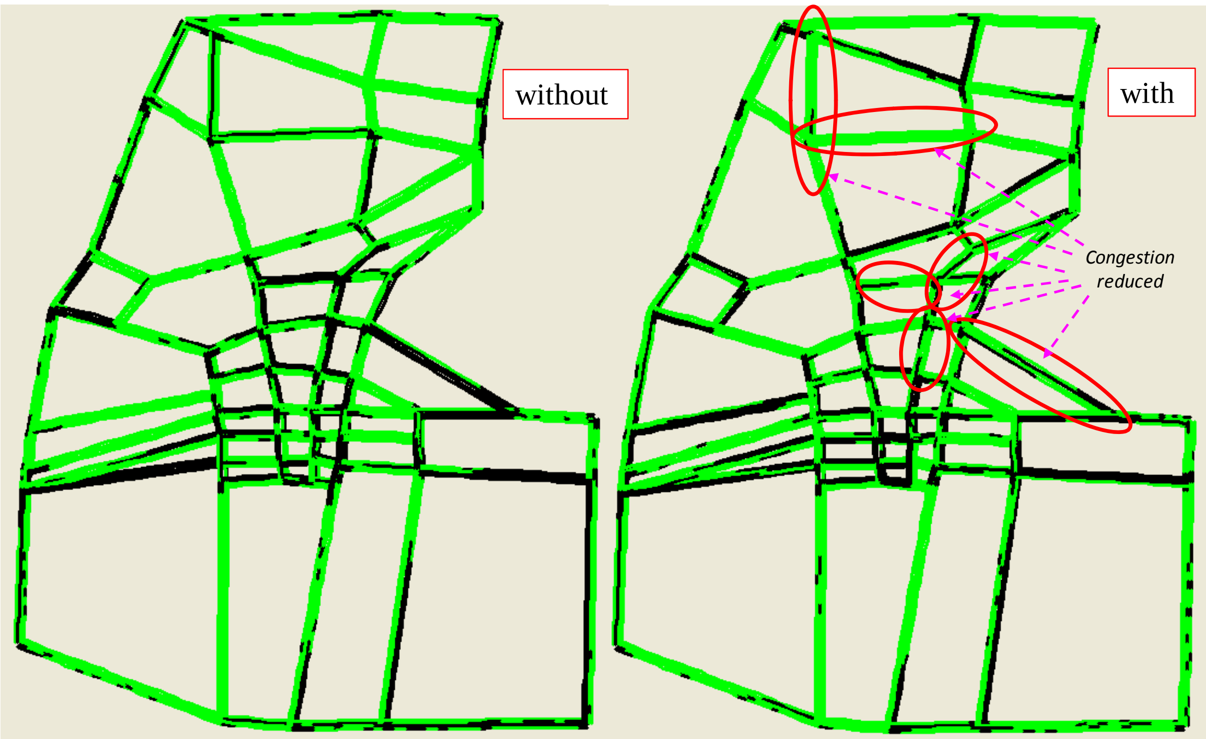


Figure 9 – Congestion on the network

CONCLUDING REMARKS

In the present study, it has been proposed to integrate mode choice model with FLoMiTSiM to enable to simulate driver behaviour from mode choice stage to reaching destination at every possible situation and evaluate wide range of transport policies. The summary of findings from the development of combined model has been given below:

1. As mode choice also involves uncertainty and approximations in human decisions and implementation of fuzzy logic is found to be most suitable and it has also been evident from the results that fuzzy logic model improved accuracy and eliminated partiality factor towards car compared logit model. As proposed model has used utility function with appropriate variables (such as travel time, cost and comfort) applying fuzzy logic, it is possible to extend for multi-modal situations with minimum calibration efforts.

2. It has been found that the integrated model with mode choice and FLoMiTSiM simultaneously simulates vehicular behaviour on network and individual microscopic mode choice decisions with fair amount of accuracy. The proposed fuzzy microscopic simulation model can be applied to describe mode choice decisions and vehicular movements on the road microscopically under different transport polices.

3. The proposed simulation model is applied to the evaluation of implementation of LRT system for the demonstration of the applicability and suitability. It may also help in understanding the procedure to evaluate typical public transport policies and the importance of various evaluation parameters.

It can be concluded that the proposed fuzzy microscopic simulation model can be used to evaluate of wide range of transport polices.
In future scope of the study, it is proposed to consider mode choice behaviour explicitly with socio-economic parameters in the model. Furthermore, the proposed model should be applied to evaluation of environment policies such as carbon tax etc.

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