A SIMULATION STUDY ON ENVIRONMENTAL IMPACT OF AUTOMATED TRUCK LANE ON INTERCITY EXPRESSWAYS

by Xun SUN**, Tomio MIWA***, Toshiyuki YAMAMOTO**** and Takayuki MORIKAWA*****

1. Introduction

Intercity expressways as major transportation network suffer from increasing congestion with a rapid growth of freight transportation, The percent of truck in expressways will affect traffic flow characteristics, for truck characteristics differ from that of passenger car (e.g. acceleration capabilities, maximum speed, length).As the traffic flow becomes less homogeneous, the probability on a decrease of efficiency and safety becomes larger and also generates a large volume of CO_2 emissions that has a great impact on environment. Given these circumstances and the future prospects of growing transport volumes, major innovations in the present freight transport systems are required. A new concept of freight transportation system named as automated truck lane (ATL) can prevent some of the expected impacts that would be generated by a growing truck use. But to what extent can ATL help, and what are the impacts of the use of ATL on the other traffic, an effective estimate of the operational performance of ATL system is needed to help make informed decisions.

Tomei-Meishin expressway is a main artery of Japan, and connects the three main metropolitan areas (i.e. Tokyo area, Chukyo area and Hanshin area). The majority of goods movements among the three metropolitan areas are transported by Tomei-Meishin expressway. The second expressway (named as New Tomei Meishin Exp.) is assumed to be put into use in 2020. In order to evaluate the impacts of new logistic system ATL to traffic flow and environment, the performance of ATL should be illustrated by simulation. Previous studies[1) - 2)] are focused on examining traffic flow changes on New Tomei-Meishin Exp. by setting one lane for ATL. There are also many literatures on traffic flow evaluation of alternative strategies involving trucks. These studies[3) - 5)] only conduct basic analyses of impacts to the expressway itself and assuming a fixed demand on it. However, ATL should be evaluated under large traffic networks, because the ATL will probably affect not only traffic flow of itself but that of other expressways and surface roads.

This paper aims to introduce an integrated simulator framework which is needed to conduct the simulation studies of ATL under large traffic networks. Another objective is to analyze the fundamental environmental impact characteristic of ATL by comparison of alternative strategies, and then evaluate the environmental performance of ATL on large traffic networks by utilizing the integrated simulator.

2. Integrated simulator

A new simulator is needed to conduct the task of simulating traffic flow on large traffic networks which are affected by New Tomei-Meishin Exp.. Generally, the macroscopic or mesoscopic simulator will be chosen to do the task. However, if we want to evaluate the environmental impact of ATL to itself and other expressways or surface roads, we should analyze the change in speed of passenger car and truck, for the instant speed and acceleration are the main factors in calculating CO_2 emissions of vehicle. The mesoscopic simulator can only provide the average speed of vehicle in each link that can't fully evaluate the environmental impact of ATL. The speed change must be estimated by the microscopic simulation model which can reflect the detailed movement relationship between passenger car and truck. For the simulation of large traffic networks with huge numbers of cars requires considerable run times, we consider that microscopic simulator can't afford the cost of simulating detailed behaviors of the whole traffic networks.

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*Keywords: automated truck lane, CO_2 emissions, integrated simulator, intercity expressways

**Student Member of JSCE, M.E., Graduate School of Environmental Studies., Nagoya University
(Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan, Tel: 52-789-3730, Fax: 52-789-5728 email: sunxun@trans.civil.nagoya-u.ac.jp)

*** Member of JSCE, Dr. Eng., EcoTopia Science Institute, Nagoya University
(Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan, Tel: 52-789-3565, Fax: 52-789-5728 email: miwa@civil.nagoya-u.ac.jp)

****Member of JSCE, Dr. Eng., Graduate School of Engineering., Nagoya University
(Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan, Tel: 52-789-4636, Fax: 52-789-5728 email: yamamoto@civil.nagoya-u.ac.jp)

*****Member of JSCE, Ph.D., Graduate School of Environmental Studies., Nagoya University
(Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan, Tel: 52-789-3564, Fax: 52-789-5728 email: morikawa@nagoya-u.ac.jp)

Moreover, we can't obtain all detailed road information to calibrate the parameters of models which must be required for microscopic simulation on the large traffic networks. An integrated framework of combining microscopic and mesoscopic models will be adopted for the simulation study of ATL. The Framework of simulation system is illustrated in Figure 1.

(1) Mesoscopic simulator

Mesoscopic simulator will conduct the movement of vehicles on surface road, and provide vehicles which will enter into expressways to microscopic simulator. Mesoscopic simulator will also calculate the link travel time, and provide dynamic route information of total road network using DUO (dynamic user optimum) assignment method. The maximum vehicle number of group is five. The scanning interval is 15 seconds.

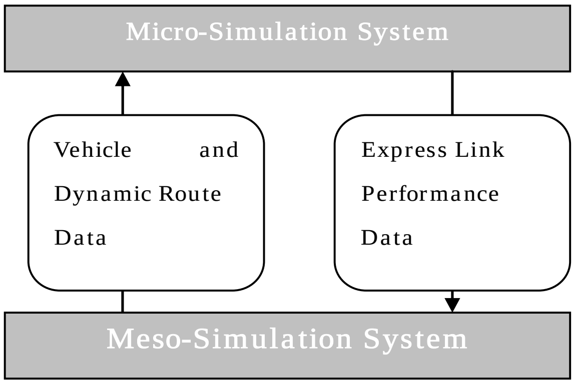

Figure 1: The framework of integrated simulation system for ATL

(2) Microscopic simulator

Microscopic simulator will conduct the movement of vehicles on expressways, and provides the real time results of link performance to mesoscopic simulator. Expressways are the road network at 2020 when New Tomei Meishin Exp. is put into service. The inner 2 lanes of 6 lanes will be dedicatedly used for automated truck lane. The microscopic simulator is designed to update vehicle position every 0.5 second, and two kinds of vehicle i.e. passenger car and truck are simulated in this system. The system is capable of simulating expressways, including car-following, lane changing, on- and off-ramps, merge and diverge sections.

(3)The procedure of data exchange

A procedure of data exchange must be followed to ensure a correct data exchange between two systems, for the basic characteristics of microscopic and mesoscopic simulation are different. The microscopic simulator time step is shorter than that of mesoscopic simulator. Moreover, the unit of microscopic simulator is one vehicle, and for mesoscopic simulator that is one group of vehicles. In the procedure of data exchange, mesoscopic simulator obtains vehicle data for current time segment by reading dynamic OD data, and then randomly assigns the depart vehicles into different simulation steps within the current time segment. One time segment is 30 minutes, hence, one time segment contain 120 mesoscopic simulation steps, and one mesoscopic simulation step equal to 30 microscopic steps. The vehicle update process is presented in Figure 2.

(4) CO_2 emissions models

The models used to determine the CO_2 emissions are associated with the activities of vehicles. In order to make a more detailed evaluation of environmental impact of ATL, we use a microscopic emission model for vehicles to reflect the contribution to the smoother transportation. In this paper, the type of vehicle includes passenger car and truck. All passenger cars are considered as gasoline cars, while all trucks as diesel vehicles.

CO_2 emissions model for truck can be expressed as [7]

$$E_{truck} = 3.50 \cdot v + 2.67 \cdot 10^{-4} \cdot v^3 + 3.64 \cdot a \cdot v + 113.9 \qquad (1)$$

E_{truck}: the amount of CO_2 emissions (g/sec)
v: the speed of vehicle (km/h)
a: the acceleration of vehicle (km/h/sec)

CO_2 emissions model for passenger car can be expressed as [6]

$$E_{car} = K_c \cdot (0.3 \cdot T + 0.028 \cdot D + 0.056 \sum_{k=1}^{K} \delta_k (v_k^2 - v_{k-1}^2)) \qquad (2)$$

E_{car}: the amount of CO_2 emissions (g)
K_c : coefficient of transformation (g- CO_2/cc-gasoline)
T : the vehicle travel time (sec)
D : the vehicle travel distance (m)
δ_k : accelerate 1; otherwise 0

k : the number of measuring period (k = 1,2,……K)
v_k : the vehicle speed for the period of k (m/sec)

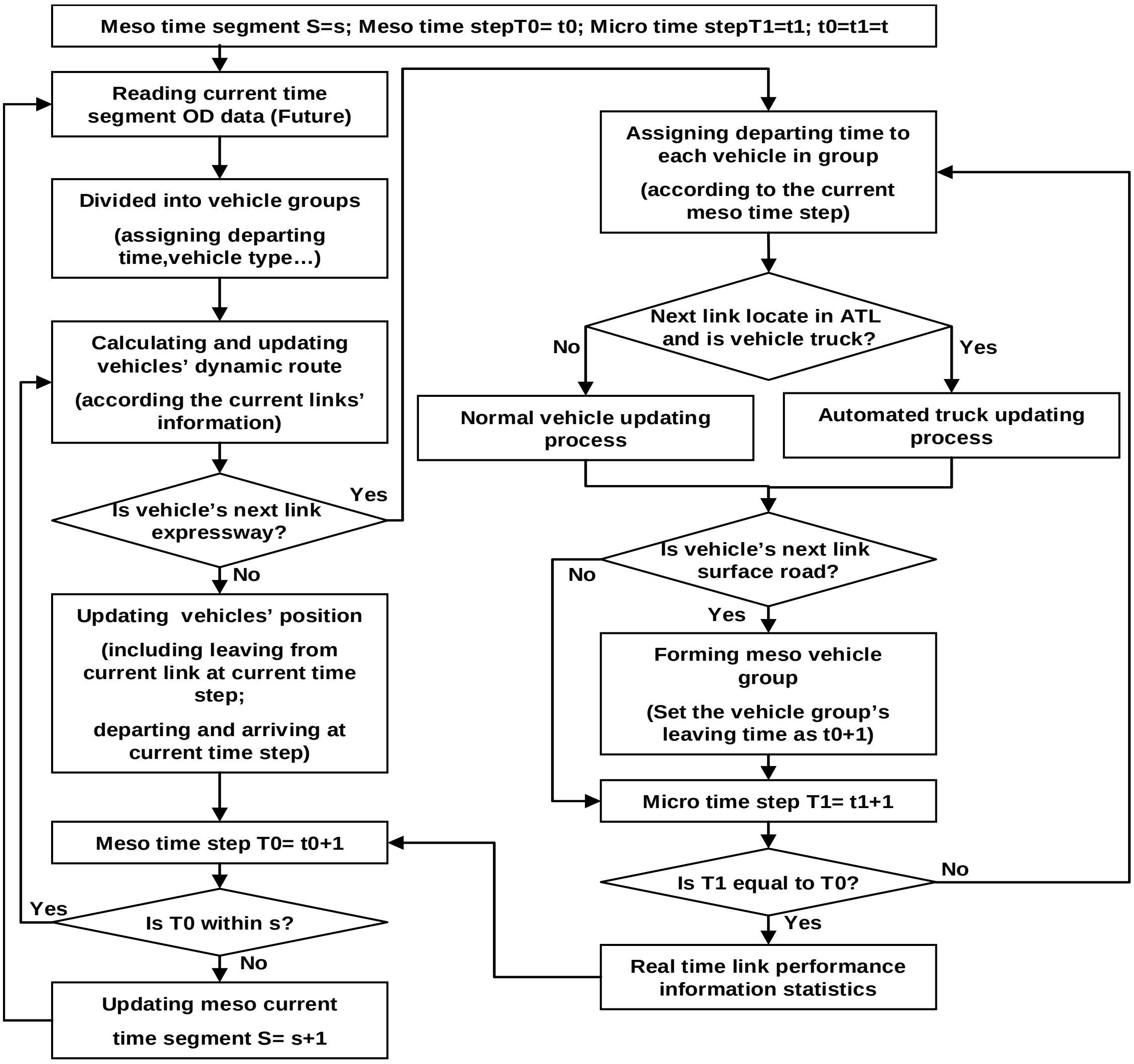

Figure 2: Flow-chart of vehicle update process of integrated simulator.

3. Fundamental experiments

We choose a 6km long link containing 3 lanes from New Tomei-Meishin Exp. for the experiment. Three cases are evaluated.

Mixed Lanes: this strategy allows truck on all lanes which can increase the number of car-truck interaction.

Dedicated Truck Lane: the inner-most lane is dedicated for truck in this strategy. It can reduce the number of car-truck interactions.

Automated Truck Lane: this strategy will use the inner-most lane as automated truck lane which will be efficiently used by platoon.

(1)Simulation parameters

Traffic demand: Different traffic demands are used to test the performance of cases studied. The amount of traffic demand will vary from 500 vph to 2000 vph for a single lane.

Truck percentage in demand: The truck percentage can vary from 10% to 50% during peak periods. Hence, five truck percentages (10%, 20%, 30%, 40% and 50%) are considered for analysis.

(2)Vehicle Parameters:

Driver type: DSF (driver sensitivity factor) is a FRESIM parameter that reflects driver aggressiveness. The value of DSF ranges from 0.6 to 1.5. The car-following and lane-changing logics in the FRESIM freeway simulator are chosen as the base model based on the insights from a previous study[8)], and we also use a truck-following model which is based on and extended from the FRESIM car-following model to reflect the car-truck interaction.

Preferred speed: a preferred speed under free flow conditions is assigned to each vehicle in the simulator. The preferred speed is normal distributed from 85kmph to 125kmph for passenger car and 75kmph to 115kmph for truck. This represents the speed differences among vehicle types. The ATL expressway link has a speed limit of 100kmph.

(3)Data statistics

The freeway link has a 90min demand generation period. The simulation begins when the first vehicle is generated and ends when the last vehicle leaves the link. Hence, the start-up and end-time effects can affect the performance measures. We will choose the middle 30min simulation result for the performance measures to eliminate the statistics for these periods.

(4)Cases comparison

The performance data for analyzing alternative scenarios is CO_2 emissions ratio of per vehicle kilometers. Experiment data are obtained using 5 simulation runs for the cases comparison. Here, we summarize the fundamental experiment by using the aggregated results presented by Figure 3 under traffic demand of 5000 vph which nearly reach the capacity of expressway considering the 25 percent of truck in total traffic flow. Figure 3 shows that the ratio of CO_2 emissions of ATL is the lowest among the three cases for almost all the situations of different truck percentage except for the situation of a relatively low truck percentage (lower than 10%). The simulation results under other traffic demands also have the similar pattern.

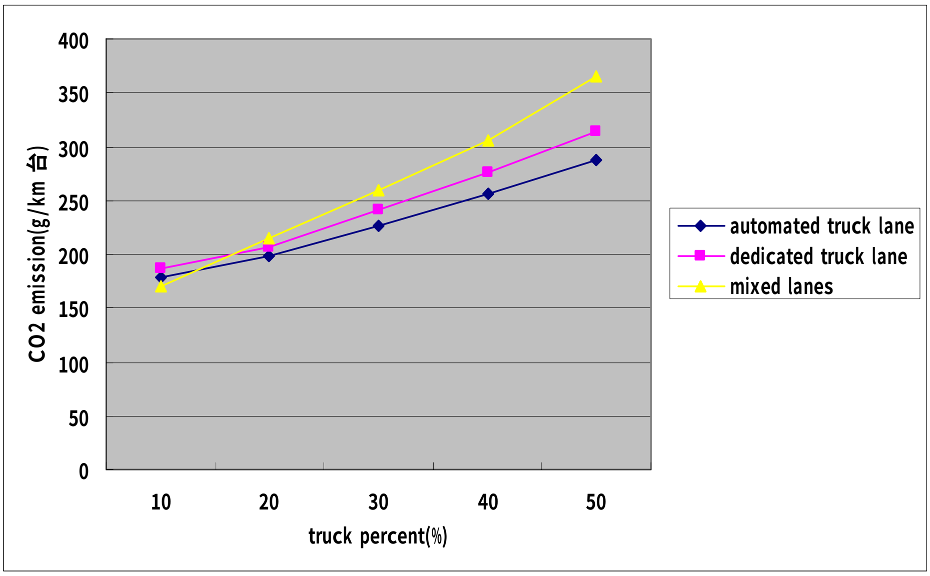

Figure 3: Overview of CO_2 emissions ratio of different scenarios of utilizing lanes at traffic load 5000 vph

4. Simulation experiments on intercity expressways

In this experiment, our analysis focuses on the environmental impact of ATL on intercity expressways. The experiment of simulation will compare three different scenarios of New Tomei-Meishin Exp.. Base Case is the initial designing case which has 4~6-lane double way, and Case 1 has 6-lane double way. Both Base Case and Case 1 allow truck and car on all lanes, and the maximum speed of expressway is 100 kmph. Case 2 allows automated truck to run on the inner 2 lanes of 6 lanes, and normal trucks and cars on the other 4 lanes. The main task will compare the amount of CO_2 emissions of three Cases and find the change mode of CO_2 emissions on intercity expressways by introducing ATL.

The simulation results on intercity expressways presented in Table 1 show that the introduction of ATL into New Tomei-Meishin Exp. leads to the decrease of CO_2 emissions not only within itself, but also cause the decrease of expressway networks and total road networks, compared with base case and case 1.

Table 1: CO_2 emissions of different cases of utilizing New Tomei-Meishin Exp.

	Total road networks		Total expressways		New Tomei-Meishin Exp.	
Base Case(4-6 lanes 100km/h)	90.3	--	33.7	--	11.7	--
Case1 (6 lanes 100km/h)	88.5	-1.8	32.5	-1.2	12.6	+0.9
Case 2 (4 lanes + 2 truck automated lanes)	86.7	-3.6	31.1	-2.6	11.2	-0.5

Units: 1000t- CO_2

We compare the CO_2 emissions ratio of New Tomei-Meishin Exp. of three cases by calculating the CO_2 emissions of per vehicle travel distance presented by table 2. The CO_2 emissions ratio of ATL is 313.94(g- CO_2/km･vehicle) which is approximately 80% of Base Case, and 89% of Case 1. We contribute the decrease of environmental impact of ATL to the steady traveling of automated truck platoon. The platoon travel would utilize fuel more efficiently than the normal truck traveling.

Table 2: CO_2 emissions ratio of different cases in New Tomei-Meishin Exp.

	Vehicle distance (km･vehicle)	Truck travel distance percent (%)	CO_2 emissions (kg)	CO_2 emissions ratio (g- CO_2/km･vehicle)
Base Case	29,748,025	0.7007	11,722,821	394.07
Case 1	35,689,631	0.7036	12,573,077	352.29
Case 2 (ATL)	35,806,337	0.7001	11,240,934	313.94

We also find a change in CO_2 emissions happens in large area by introduction of ATL. Figure 4 and Figure 5 show that the distinct decrease of CO_2 emissions also happen in the alternative routes to the New Tomei-Meishin Exp. (i.e. Tomei Exp. and Chuou Exp.). The smoother transportation of New Tomei-Meishin Exp. induces traffic flow from Chuou Exp. and Tomei Exp. which are colored by blue. We also find that the amount of CO_2 emissions increase in the segment of main confluence of expressways which are presented in the green circle in Figure 6. The reason is that there is more traffic flow exchange happen among alternative expressways in Case 2 than the other cases. The result indicates that the expressway of setting ATL will affect environmental performance of itself also that of other expressways. In order to make a more precise evaluation, ATL system should be analyzed under large traffic networks.

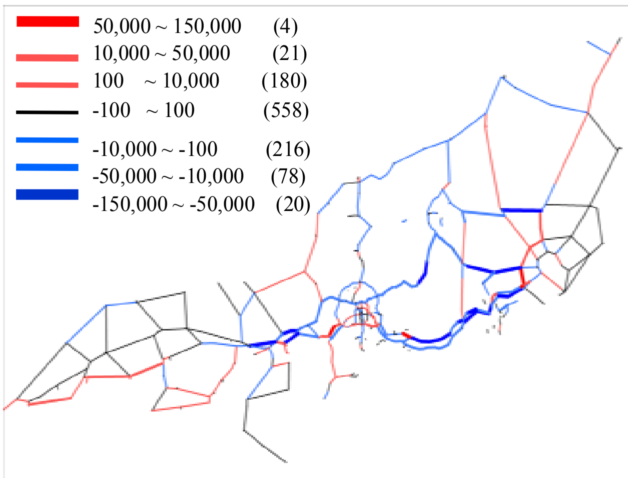

Figure 4: CO_2 emissions difference between case 2 and base case

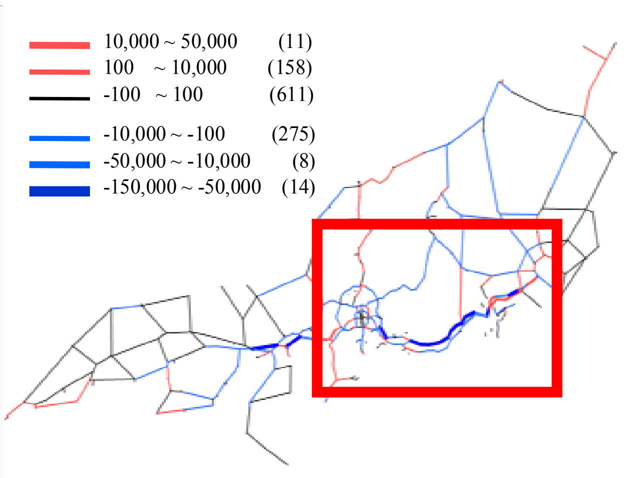

Figure 5: CO_2 emissions difference between case 2 and case 1

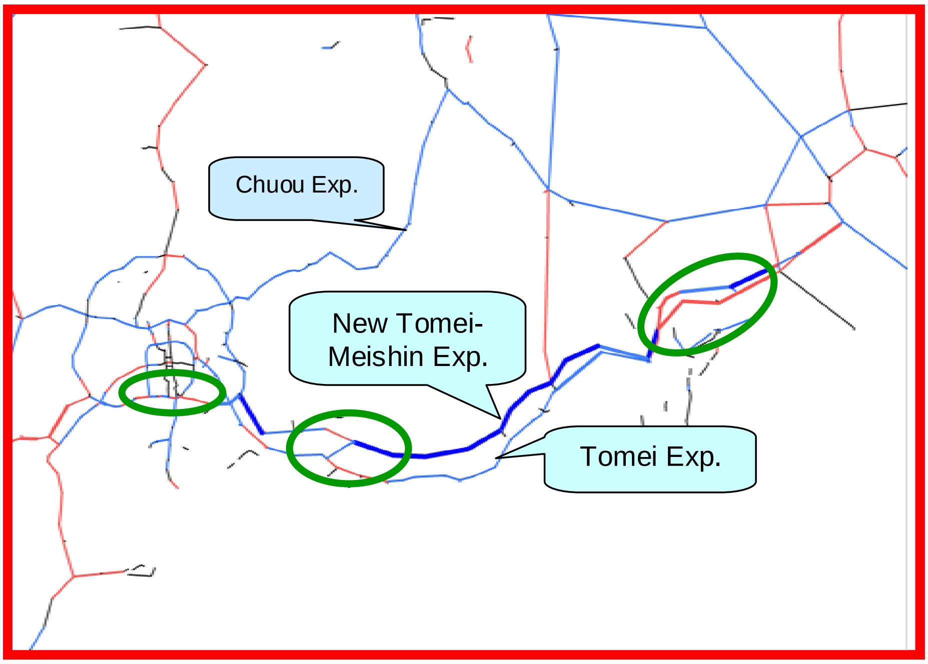

Figure 6: The detailed expressway networks in Figure 5

5. Conclusion

This paper uses an integrated simulation framework for the simulation study of ATL on intercity expressways. We conduct the fundamental experiments of comparison of alternative strategies to show the basic characteristic of environmental impact of ATL. The result indicates that the performance of ATL is the best among the three cases for almost all the situations of different traffic demand and truck percentage.

The findings from the simulation study on intercity expressways are that the environmental impact of ATL is the lowest among three cases, and lead to not only decrease in CO_2 emissions of itself, but also that in expressway networks and total road networks. This paper also shows the change in CO_2 emissions on large traffic networks by introduction of ATL. The distinct changes happen in the alternative routes to the New Tomei-Meishin Exp. (i.e. Tomei Exp. and Chuou Exp.).

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