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A NEW SIMULATION MODEL FOR EXPRESSWAY WEAVING SECTIONS EVALUATION

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ABSTRACT

Simulation of traffic flow is an effective tool for traffic system management, control and optimization, particularly in congested urban areas. TESS is an object oriented traffic simulation model with detailed representation of vehicles and their interactions. This paper presents the TESS simulator including the car-following model and new lane-changing procedures. Four weaving sections are simulated in TESS platform using field data come from Traffic Information Collecting System in Shanghai China. Compared with the CORSIM model, good results are obtained after using the calibrated TESS model in simulating weaving sections.

1 INTRODUCTION

Simulation models have been widely used in traffic system management, control, evaluation and optimization. They permit the traffic engineer to study and evaluate the performance of transport network systems at the operational level, under various alternative management options. Controversial or new techniques can be tried and tested without any disruption to traffic in a real network.

Tongji transportation nEtwork Simulation System (TESS) is a microscopic time-interval update simulation model being developed at the Tongji University since 1999. TESS simulates the traffic behavior at a microscopic level and with detailed representation of individual vehicles and their interaction with their physical environment and other vehicles. Driver behavior (varying driver types, ranging from passive to aggressive) of individual vehicles (auto, bus or truck) are formulated in the model through interaction with its surrounding environment, which includes the geometry, the traffic control and information devices, incidents and other vehicles. The model concepts and specifications and the first application in the area of intersection control modeling in urban arterial network were described in previous papers (Yang and Zhong, 1999, 2001; Sun, Wu and Yang, 2005).

On the other hand, a major social problem in developing countries is traffic congestion. Expressway weaving sections are typical type to carry out merge and diverge in urban expressways, and usually a traffic congested bottleneck and incident spot and characterized for intense lane-changing and complicated driver behaviors. So analysis on weaving sections can be helpful to verify the capabilities of TESS model. This paper concentrates on the lane changing and merging (as a special case of lane changing) algorithms developed for the TESS model and four weaving sections are simulated in TESS platform.

2 RESEARCH REVIEW

Gipps (1986) proposed a framework for the structure of lane changing decisions in urban driving situations including the influence of traffic signals, obstructions and different vehicle types, such as heavy vehicles. The model concentrates on the decision-making process considering the potentially conflicting goals and assuming a logical driver behavior and was found to be a serious limitation in congested and incident affected conditions (P.Hidas,2002).

In the last decade a number of new microscopic and macroscopic traffic simulation models were developed which incorporated some form of lane changing models. Unfortunately, very little detailed information about these lane changing models are published in the literature (P.Hidas,2002). Most publications mention that the implemented lane changing models are based on a set of rules, but the description of the rules are usually superficial and incomplete. For example, Fritzsche (1994) described a microscopic traffic simulation model to be used for the analysis of bottleneck situations, e.g. when one lane of a multi-lane road is temporarily closed. This is a typical situation where vehicles trapped behind the lane closure during congested. Low conditions can not move into the unblocked lane without the active cooperation of drivers in the unblocked lane. The description of the lane changing rules are very brief in the paper, and cooperative or forced lane changing behavior is not considered. Yousif and Hunt

(1995) developed a microscopic simulation model for the investigation of lane changing behavior on multi-lane unidirectional roadways. The rules pertaining to the desire and the possibility to change lane are based on similar logic to that described by Gipps (1986). Barcelo' et al. (1996) described the AIMSUN2 microscopic traffic simulator developed for modeling real-time traffic management and information systems. The behavior of each single vehicle on the network is continuously modeled throughout the simulation time period, according to several driver behavior models (car following, lane changing, gap acceptance). The lane changing model is based on Gipps' model (1986). Yang and Koutsopoulos (1996) presented his approach for modeling lane-changing behavior using the discrete choice and this model is based on the gap acceptance model. Wagner et al. (1997) described a 'minimal microscopic' traffic model developed to reproduce macroscopic characteristics of traffic flow. The model was found to be able to reproduce satisfactorily the lane usage characteristics on multi-lane roads over a wide range of low levels under normal conditions. All of the vehicles have little direct coordination with surrounding vehicles (P.Hidas,2002).

Considering the road status, traffic demand and driver behavior have big difference between china and developed countries and most of the simulation models are determined according to the foreign situations and not always suit for China, we need the simulation model adaptability analysis especially in congested situations. But few researches on weaving sections were conducted in China (Sun and Yang, 2004A).

3 THE TESS MODEL

The overall structure of the TESS model is presented in figure 1. The main modules of TESS model are: (1) network building; (2)O/D estimation; (3) vehicle generation; (4) route selection, based on individual driver characteristics and (5) vehicle-progression, based on car following and lane changing theory. These modules are integrated through a flexible High Level Architecture (HLA).

The driver-vehicle objects (DVOs) travel between their user-defined origin and destination, select their routes according to the prevailing traffic conditions and their individual route choice characteristics. The model allows the simulation of six main DVO classes. First, the drivers are classified into two groups: equipped and unequipped drivers. The equipped drivers are assumed to use their In-Vehicle Navigation Systems (IVNS). Second, the IVNS are divided into three types according to the information strategy and driver's response to information: (1) The Boundely Rational (BR) users who take information discounting strategy and follow a boundedly-rational switching rule in response to descriptive information; (2) The SO users who follow prescribed System Optimal paths; (3) The UE users who follow User Equilibrium routes. Finally,

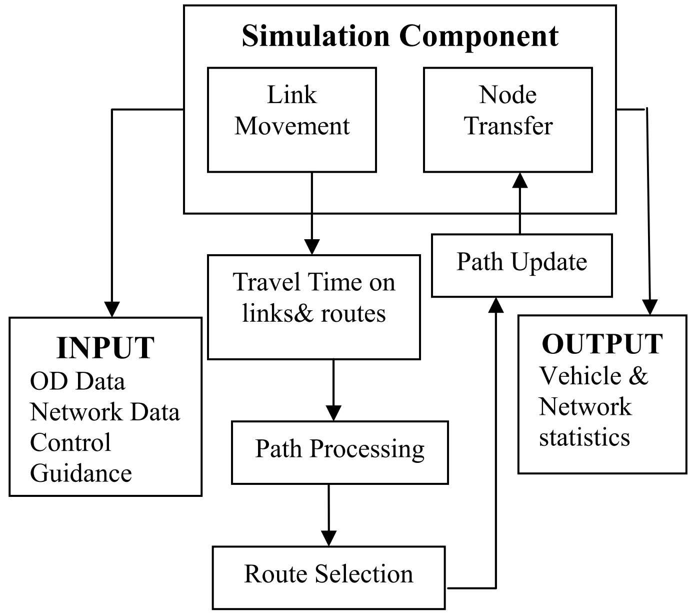

Figure 1: The TESS Model Structure

the non-equipped drivers are divided into three types DVOs: (4) the TRaditional (TR) drivers who do not receive any information and follow historically known routes; (5) the Pre-Specified (PS) drivers who follow externally paths under current shortest path; and (6) the driver who react to Variable Message Signs (VMS). Given the time-dependent O-D desires for users in each of these six classes, the formulation seeks a time-dependent traffic assignment which provides the number of vehicles of each class on the network links and paths satisfying system-wide objectives and respective conditions for each class. TESS can be used to evaluate the effectiveness of Advanced Traveler Information Systems (ATIS) including In-Vehicle Navigation Systems (IVNS), Variable Message signs (VMS), broadcasting and internet (Sun, Wu and Yang, 2005).

Fixed-time signal coordination and adaptive control strategies can be programmed into the TESS network model. Incidents of varying severity may be set to occur at any point and any time on the network and for any duration. Within the microscopic model, new positions and states are calculated in each time step by a driver and vehicle model. The combined driver/vehicle model produces the longitudinal new vehicle acceleration, and a decision to change lane or not. In each iteration, the driver model produces the driver actions, consisting of the lane change action and the new pedal and gear positions. Next, the vehicle model calculates the resulting acceleration of the vehicle. During the simulation run, an animation option allows the user to observe current conditions at any part of the network. The model outputs provide various statistics of vehicle and network performance both in numerical and graphical formats.

3.1 The Car-Following Model

The car-following model calculates a vehicle's acceleration rate, considerate its relationship with the leading vehicle. In several circumstances, this model is also used as a sub-model for calculating appropriate acceleration rates: (1) preparing to follow another vehicle if two or more lanes merge into a single downstream lane; and (2) yielding to another vehicle shifting into the same lane. The car-following model used in TESS draws upon previous researches (see, for example Herman et al., 1959, 1963; Yang, 1997).The model is based on the headway and relative speed of the leading and the following vehicles. Depending on the magnitude of headway, a vehicle is classified into one of four regimes: free flowing, car following, event responding and emergency decelerating. For detailed description please see the reference: Sun (2003).

3.2 The Lane Changing Model

3.2.1 The Lane Changing Procedures in TESS

Modeling lane changing behavior is more complex since it actually includes three parts: the need for lane changing, the possibility for lane changing, and the trajectory for lane changing. Each part is important for getting a realistic lane-changing model. Furthermore, the lane-change model is complex itself. It needs to consider not only the vehicle in the front, but also the vehicles nearby, and even the traffic flow information. When drivers make decisions to do lane changing is a complicated thing and depends on travel destination, driver behavior, and traffic flow. Lane changing model in traffic micro simulation can be clarified into two categories: mandatory and discretionary. Mandatory lane changing happens in following situations: (1) the current lane is blocked; (2) the current lane is merging to another lane; (3) the destination requires to change to another lane. Discretionary lane changing happens in following situations: (1) over passing the low speed or heavy vehicle; (2) yielding another merging vehicle. The overall structure of the lane changing model is depicted in Figure 2.

People won't do lane changing without any reason in normal situations. To reach their final destination, drivers will do mandatory lane changing when the current lane is not available. To adjust vehicle speed, drivers will do discretionary lane changing. Note even under mandatory lane changing situation, the driver do not need to do lane changing immediately.

To do the lane changing, the most important thing is to check whether it is safe to do it or not. Most of lane changing models are based on the gap acceptance model. In the gap acceptance model, another gap is always ignored for some reason. It is the front gap, which is the gap between the vehicle doing lane changing to the vehicle ahead it. According to our observations and field test, in most of

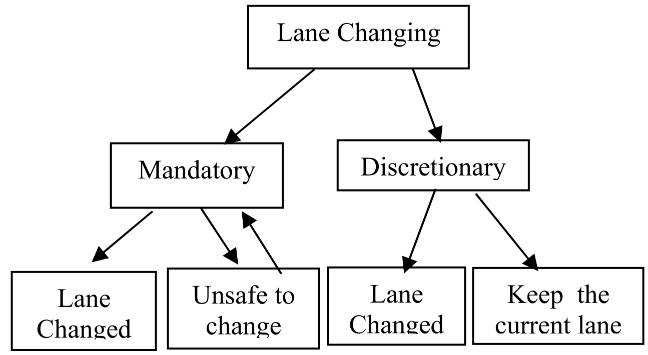

Figure 2: Summary Flowchart of the Lane Changing Process in TESS

situations, the lag gap and lead gap are acceptable for drivers, but they won't do the lane changing when the front gap is too far or too short. The gap as figure3 shows.

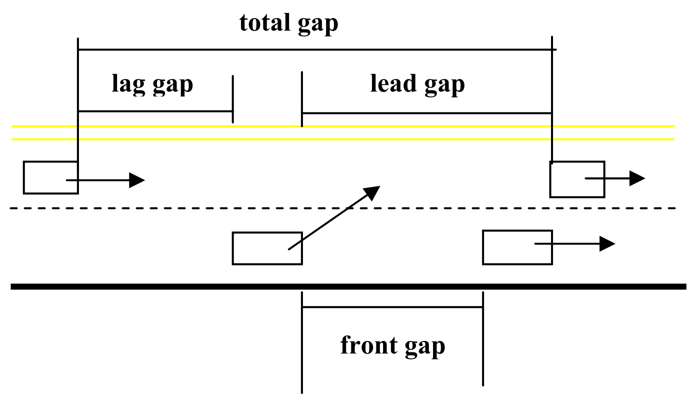

Figure 3: Gap Acceptance Model in TESS

3.2.2 Front Gap

The front gap can be considered as a minimum desired distance to the front car. It is not necessary for drivers to do lane changing at the exact front gap distance. The front gap only tells the normal distance than drivers would accept. Of course, drivers would do lane changing when the distance is farther than the front gap, and even there is no front car. Therefore, this lane changing model only considers the front gap as the minimum lane changing distance. But how to choose suitable front gap for different situations is a higher-level control problem.

In the simulation, the front gap D_{fg} is formulated as a linear function of speed difference V_d. The constant K and offset D vary a little at different leading speeds. The equation is shown as follows:

$$D_{fg} = k * V_d + D \quad (1)$$

These values are obviously not only related with drivers but also vehicle types. Since no enough data about this is available, the simulation will randomly generate K and D in certain ranges for different cars.

3.2.3 Lead Gap and Lag Gap

The lead gap is to keep the car doing lane changing from colliding with the front car. Obviously, the gap is related with V_n and V_a. Assuming a driver will take t_l seconds to finish lane changing and both vehicles keep the current velocities, the minimum distance, $t_l(V_n - V_a)$, is needed. After the car finishes its lane changing, it will change its driving mode to follow the front car. Then the distance will eventually change to desired following distance. So besides the safe distance, an extra space is needed to be comfortable for drivers to change modes. To consider the aggressiveness of drivers while doing lane changing and the figure 4, the discretionary lead gap D_{le}^d is modeling as followings:

$$D_{le}^d = \min(\max(t_l(V_n - V_a) + V_a * 0.58), 1.5 * V_a) \quad (2)$$

the mandatory lead gap D_{le}^m is modeling as followings:

$$D_{le}^m = \min(\max(t_l(V_n - V_a) + V_a * 0.86), 1.1 * V_a) \quad (3)$$

Where the distance is in unit meter, while the velocity is in unit m/sec. The t_l varies with drivers and vehicle types. It is chosen randomly by the simulation program from 2 to 4 seconds.

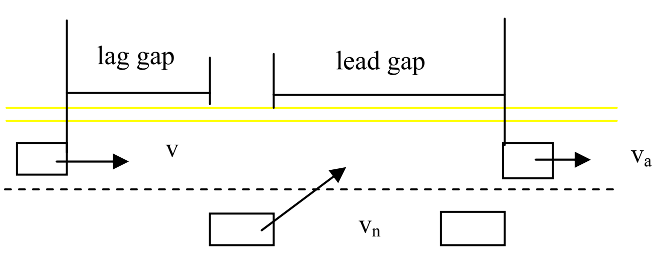

Figure 4: Lead Gap and Lag Gap

The methodology for modeling the lag gap is the same. The difference is that the lane changing car does not want to or is not safe to make the lag car brake. So the lag gap uses some different parameters. the discretionary lead gap D_{la}^d as followings:

$$D_{la}^d = \min(\max(t_l(V_b - V_n) + V_n * 1.08), 1.8 * V_n) \quad (4)$$

the mandatory lead gap D_{la}^m as followings:

$$D_{la}^m = \min(\max(t_l(V_b - V_n) + V_n * 0.87), 1.2 * V_n) \quad (5)$$

The parameters' meanings are the same as in the lead gap model.

3.2.4 Lane Changing Trajectory

The trajectory used in this study is a Sinusoid trajectory. Sinusoid trajectory provides the continuous curvature and accommodates changing velocity. It is also reasonable for the simulation results. Assuming the vehicle's velocity is v and the time to finish lane changing is t_l. y_d is the desired y position after lane changing.

The equations of Sinusoid trajectory are as follows:

$$x = x_0 + v * t \quad (6)$$

$$y = y_0 + \sin(\frac{t}{t_1} * \pi - \frac{\pi}{2}) * \frac{y_d}{2} + \frac{y_d}{2} \quad (7)$$

The figure 5 shows the lane changing trajectory with v= 20m/s and t_l=3 seconds.

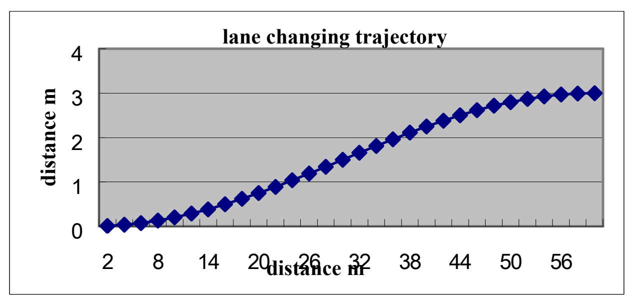

Figure 5: Lane Changing Trajectory

As seen in the figure 5, the simulation result is very good. The curve of trajectory is smooth and the derivatives at both ends are 0. This method is also simple and efficient. Not many calculations are needed to design the trajectory.

3.3 The Merging Model

When two or more upstream lanes are connected to a single downstream lane, a merging area is defined (see figure 6). In the merging area, additional constraints are considered in calculating acceleration rate because vehicles from adjacent upstream lanes may need to coordinate with each other. For the convenience of modeling, merging is classified into: (1) priority merging; and (2) non-priority merging. priority merging includes merging from ramps to freeways, and from minor streets to major streets. Non - priority merging occurs at the drops on freeways.

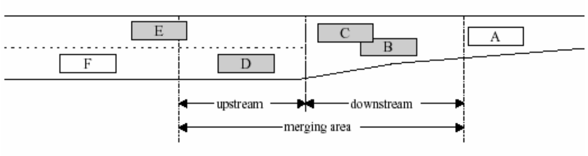

Figure 6: Merging Area

For priority merging, a vehicle without right-of-way must check whether there is any vehicle from the competing upstream lanes. The vehicle executes merging only if the projected headway gap is acceptable.

For non-priority merging, a "first come, first serve" principle determines right-of-way. In other words, among all the vehicles coming from competing upstream lanes, the one closest to downstream lane is chosen as the first vehicle to merge. Other vehicles will either follow appropriate leaders or prepare to stop at the end of their current lanes.

A merging area consists of an upstream area and a downstream area. The downstream area is also characterized by the maximum number of vehicles allowed in. An upstream merging area vehicle (i.e. vehicles D or E) is tagged as a merging vehicle if it has yet to be tagged and the number of downstream merging area vehicles have not reached the maximum. All vehicles in the downstream merging area (i.e. vehicles B or C) are tagged as merging vechicles. The acceleration rates for merging vehicles is calculated by relaxing the car-following constraint and incorporating a merging constraint (Sun, 2003).

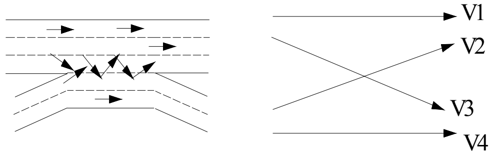

Figure 7: A Typical Weaving Section in Shanghai

4 SIMULATION OF WEAVING SECTIONS

Weaving is defined as the crossing of two or more traffic streams traveling in the same general direction along a significant length of the roadway, without the aid of traffic control devices. Figure 7 is a typical weaving section in shanghai.

4.1 Test Bed

Four major expressway weaving sections named BJWH, HHXJH, MMHS and JSKX were chosen for the application of the model. The BJWH and HHXJH are located in "N-S" elevated road; the other two are located in "Yan'an" elevated road, they all belong to the "shen" expressway systems in Shanghai. We consider that these weaving sections can embody the typical traffic flow operating character in china.

4.2 Data Collection

Now ITS in Shanghai is under constructing and deploying. Through the ICICS(Inner City Information Collecting Systems) we can get the "Yan'an" elevated road real-time data including volume, speed, vehicle type, occupancy and headway for every lane at 20 seconds interval. We extracted one week data for this research. Meanwhile we saved one week peak time video information about "N-S" elevated road. Through the TJVICS (TongJi Video Information Collecting Systems) we also can get the needed traffic information such as traffic volume, vehicle type, headway, speed etc, al (Zhu,2001). Table 1 shows the key geometric and traffic data for each testing site. For the intention of calibration we extracted the speed of every lane. Near the road sideline lane is No 1.

Table 1: Simulation Areas Key Parameters

WS	N	L	V1	V2	V3	V4	SL1	SL2	SL3
MM HS	4	2354	958	515	401	92	42.4	45.2	45.9
			3849	927	1805	164	34.7	34.3	32.8
			3710	410	1320	73	38.2	39.8	41.7
			1953	867	861	153	34.1	37.0	36.9
			2474	991	1106	175	34.1	36.2	32.2
J S KX	3	1216	783	582	276	103	39.5	40.1	44.8
			2867	1527	790	270	18.9	15.2	14.9
			2383	1624	812	287	16.5	15.5	16.7
			2020	1319	566	233	31.5	32.9	36.8
			1653	964	497	170	36.9	37.2	40.6
BJ WH	6	550	4458	1360	1900	80	25.6	23.4	24.5
			6600	1100	900	100	18.6	15.3	16.9
HH XJH	4	2420	3199	941	2072	167	35.4	38.6	40.3
			5237	1045	2026	185	13.4	12.1	17.9

WS: Weaving Sites; N: Number of lanes in weaving section; L: length of weaving section (ft); V1: expressway-to-expressway volume (pce/h); V2: expressway-to-ramp volume (pce/h); V3: ramp-to-expressway volume (pce/h); V4: ramp-to-ramp volume (pce/h); SL1: average speed of lane 1 (mph); SL2: average speed of lane 2 (mph); SL3: average speed of lane 3 (mph). (From outerside to innerside the lane number increase).

4.3 Model Application

Each test site was coded into the TESS model. It is critical in the coding to correctly designate the mainline auxiliary lanes and the ramp lane drop. In China there is lack of consideration of lane matching. We must ensure that the model interprets correctly the input design configuration.

On the other hand, microscopic simulation models are not amenable to calibration and validation at the microscopic level, due to the random fluctuations in individual behavioral parameters. Instead, the objective of calibration and validation is to demonstrate that the overall/average performance of the model is in acceptable agreement with observed data and thus it is suitable for the intended purpose. Validation of a complex traffic simulation model is a complex process in which components of the model can be validated separately. We developed a heuristic method-simulated annealing algorithm to calibrate and validate the TESS model which has been described in a previous paper (Sun, Yang, Zhang B. and Zhang C., 2004B). A snapshot of the simulation is depicted in figure 8.

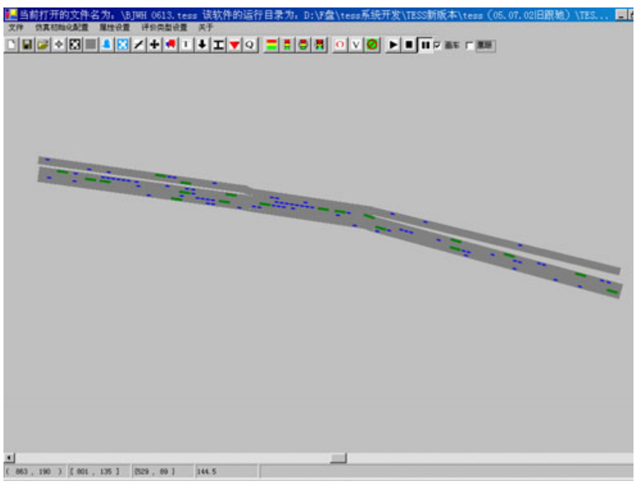

Figure 8: A Simulated Weaving Section (BJWH) in TESS

Meanwhile, The CORSIM model is also modeled using the same input. CORSIM is a very powerful microscopic simulation model designed to simulate traffic flow on freeways and surface streets, and it has been widely used for decades all of the world (Gene Daigle, Michelle Thomas and Meenakshy Vasudevan,1997). All test sites were simulated using calibrated parameters at peak and off-peak time. Figure 9 shows the measured versus CORSIM and TESS output speeds in each weaving lane at peak time (17:00~18:00) in JSKX. Figure 10 shows the measured versus CORSIM and TESS output speeds in each weaving lane and on-ramp lane at off-peak time (11:00~12:00) in MMHS.

From the figure we can see both TESS and CORSIM predicted average speeds are in close agreement with field measurements. In figure 9 the TESS and CORSIM absolute average difference between measured and simulated

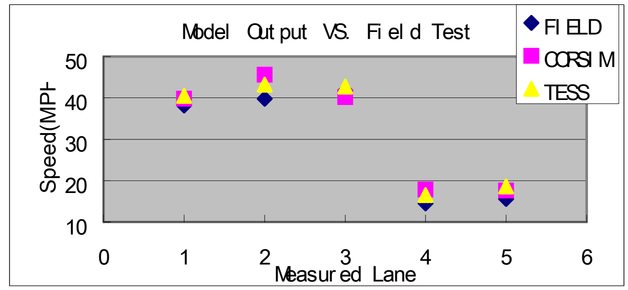

Figure 9: Model and Field Test Speed output at Peak Time in JSKX.

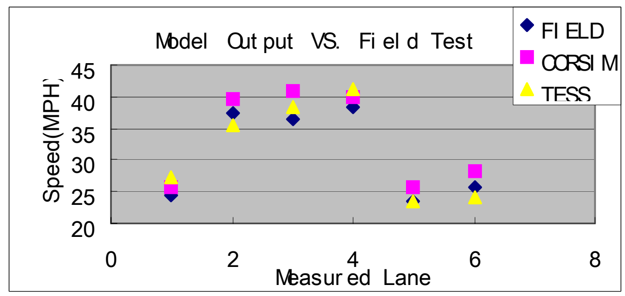

Figure 10: Model and Field Test Speed output at Off-peak Time in MMHS

speeds are 3.83 and 4.35 percent, with a root mean square error (RMS) value of 1.72 and 2.93. In figure 10 the absolute average difference between measured and simulated speeds are 5.10 and 6.35 percent, with a root mean square error (RMS) value of 6.48 and 9.63.

5 SUMMARY AND CONCLUSIONS

This paper has introduced TESS, a microscopic traffic network simulation model and presented the details of lane changing models including both discretionary and mandatory lane changing and merging issues. The major findings from the application of the TESS and CORSIM microscopic simulation model on four real-world expressway weaving sections can be summarized as follows:

1. Preliminary results show TESS is suit for the model of the Chinese traffic situations and have the superiority than the CORSIM model.
2. In the lane changing model, we should pay more attention to the front gap and the DVO directly contact with surrounding DVOs.
3. There are lack of the study of the DVO's perception and recognition of traffic situations. Ulterior researches are going on.

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