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FLOW PROFILE COMPARISON OF A MICROSCOPIC CAR-FOLLOWING MODEL AND A MACROSCOPIC PLATOON DISPERSION MODEL FOR TRAFFIC SIMULATION

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ABSTRACT

Microscopic traffic simulation and macroscopic traffic signal timing/optimization computer programs are used by transportation professionals to evaluate existing and alternative signal timing control and geometric design plans. A comparison of the underlying models of traffic flow in a Federal Highway Administration microscopic traffic simulation program and macroscopic traffic signal optimization program was conducted. The original objective was the parameter calibration of a macroscopic platoon dispersion flow model of a simulated "group" of vehicles discharging from a traffic signal controlled intersection approach. The basis for the calibration was to be the observed platoon dispersion flow resulting from the microscopic simulation of "individual" vehicles departing from a similarly modelled traffic signal controlled intersection approach. In generating the data needed for such a calibration and subsequent comparison, a deficiency in the microscopic traffic simulation program was found that needs to be eliminated before such a calibration can be deemed beneficial.

1. INTRODUCTION AND BACKGROUND

Traffic simulation and signal timing/optimization programs are used by traffic engineers to evaluate existing and alternative signal timing control and geometric improvement plans. One of these programs, TRANSYT-7F, is probably the most widely used traffic signal timing optimization program for arterials and networks. Another program, TRAF-NETSIM®, is the most widely used traffic simulation program for detailed alternative evaluations. It has realistic modelling and detailed performance measures, including the evaluation of signal timing plans generated by TRANSYT-7F and other signal timing programs.

Both of these programs are valuable tools applied by the transportation professional in the quest to provide increased capacity and reduced delays on the urban street network. Often, both of these programs are used during the conduct of an improvement project. TRANSYT-7F is first used to develop an initial signal timing plan and to very quickly evaluate various major geometric improvements, and then TRAF-NETSIM, with its detailed microscopic modelling capabilities, is used to fine-tune the signal timing plan and to more closely evaluate and adjust network geometric improvements.

Because these two programs are often paired together because of their seemingly complementary capabilities, a clear demonstration of the similarity in their modelling of overall traffic flow would provide even greater credence to both their individual and joint usage. One purpose of this paper was to provide such a demonstration by comparing macroscopically predicted and microscopically simulated traffic flows.

This paper documents and compares the microscopically generated Flow Profiles of TRAF-NETSIM with the macroscopically generated Flow Profiles of TRANSYT-7F. The results provide greater incite to both of these models and provide information as to what adjustments may be necessary in either TRANSYT-7F or TRAF-NETSIM so that the underlying Flow Profiles are "equivalent". The documentation of "equivalent" Flow Profiles would establish greater faith in the use of the models in evaluating traffic engineering improvement alternatives.

2. TRANSYT-7F PLATOON DISPERSION MODEL

TRANSYT-7F's signal timing optimization is based on the minimization of a Performance Index composed of user-specified or program defaulted weights of estimated delay, stops, and fuel consumption using a hill-climbing technique. Underlying the calculation of the Performance Index is the fundamental model of traffic flow used by TRANSYT-7F called the "Platoon Dispersion Model". This macroscopic model realistically simulates the dispersion of traffic downstream of a signal controlled intersection approach in its calculation of downstream Flow Profiles, that is, the predicted flow rates over time for any point downstream from an intersection given the upstream Flow Profile.

The Platoon Dispersion Model in TRANSYT-7F is a recurrence equation defined as:

$$q'_{t+T} = F * q_t + [(1-F) * q'_{t+T-1}]$$

where

q'_{t+T} = predicted flow rate at time interval t+T;

q_t = flow rate of the initial platoon as it discharges from the stopline during time step t;

T = 0.8 times the cruise travel time on the link (Cruise travel time is the time to traverse a link assuming no need to slow down or stop for a signal. The value of 0.8 reflects those drivers who travel at a higher speed than the average.);

F = $1/(1 + aT)$, a smoothing factor; and

a = an empirically derived constant called the Platoon Dispersion Factor normally defaulted to a value of 0.35 for typical urban streets in the U.S.

In general, this equation estimates the average flow rate over time at which vehicles will arrive at a given point downstream of an intersection. Because drivers are not uniform in their behavior or desires, traffic platoons will disperse. An example of simple platoon dispersion is shown below in Figure 1 for two points on a roadway. The first location is at the stopline and shows the flow rate which would occur as the signal cycles from green to red. The second location is at a point further downstream. The plot of flow rate over time is also known as a "Flow Profile". The downstream Flow Profile is characterized by aggressive (high speed) drivers leading the main body of traffic and slower drivers spreading the platoon to the right (right tail shift).

3. TRAF-NETSIM SIMULATION BASICS

TRAF-NETSIM is a microscopic, one second time-stepping, stochastic simulation model of traffic flow for urban

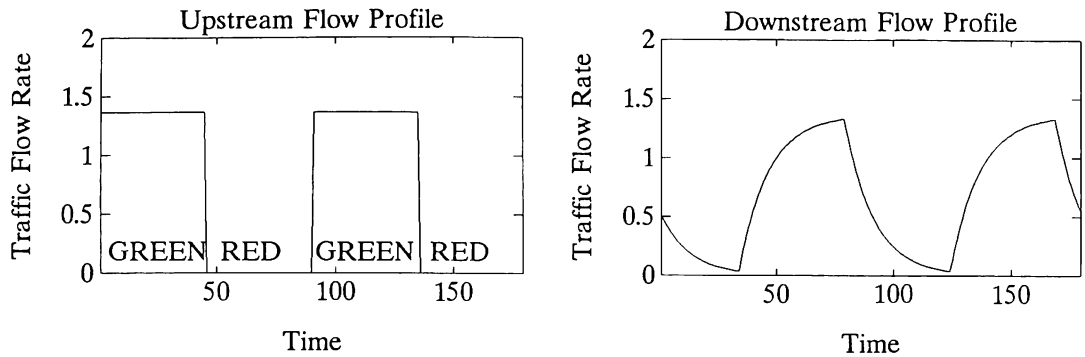

Figure 1. Simple Case of Platoon Dispersion

street networks. Drivers and their vehicles are individually modelled. Modelling details include reactions to other vehicles in the traffic stream and also reactions to traffic control devices such as traffic signals.

The underlying model of traffic flow in TRAF-NETSIM is its microscopic car-following model in which a driver's response, in terms of an acceleration/deceleration rate, is a function of the distance between subject vehicle and leading vehicle, relative speeds, absolute speed, desired speed, vehicle characteristics, and driver characteristics. Driver characteristics are defined by a decile distribution representing a range of driver types between timid and aggressive behavior. The acceleration/deceleration rate of a vehicle is determined every second of the simulation and is used to compute the vehicle state (location and speed) for the next one second time step.

4. COMPARISON BASIS

Simulation models are often compared with each other through comparison of accumulated statistics. The approach taken for this effort was not to compare the models' output statistics but to compare the underlying traffic flow models of these two simulation programs. If the underlying traffic flow models generate very similar behavior, then the performance measures on a relative basis should be the same. Importantly, signal timing produced by TRANSYT-7F could be fairly evaluated in TRAF-NETSIM because the underlying basis of the traffic flow models are comparable. Thus procedures for producing the information needed to compare the Flow Profiles of the respective programs was required.

TRAF-NETSIM, being a microscopic model, does not generate a Flow Profile explicitly as does TRANSYT-7F but it indirectly generates a stochastically noisy Flow Profile in its simulation of individual vehicle movement. Given a sufficiently long simulation time, information about these individual vehicle movements could be accumulated for generation of a smoothed Flow Profile for any location on the roadway.

TRAF-NETSIM optionally outputs data files used in the graphical display of the input data, performance statistics, and in the animation of the vehicles as they travel through the network. The animation file necessarily contains the location of every vehicle on the roadway for every second of simulation. By scanning the animation file, the passage of vehicles past any point can be accumulated. Using this accumulated microscopic data, an average flow rate at any point on the roadway link can be computed. Thus a TRAF-NETSIM generated Flow Profile similar to that of TRANSYT-7F can be constructed. A program was written to access the animation file and output the Flow Profile.

The process of generating the TRANSYT-7F Flow Profile is relatively simple. A short program based on the TRANSYT-7F Platoon Dispersion Model was written from which the resulting Flow Profile at any point downstream of an upstream Flow Profile source can be determined. A traffic signal is simulated at the upstream end by simply turning the traffic flow on and off in a cyclical manner. The Platoon Dispersion Model's only inputs are the upstream Flow Profile, the average "cruise time" to the downstream point, and the Platoon Dispersion Factor "a".

With the capability to generate Flow Profiles from either model, it was possible to perform a comparison analysis of the Flow Profiles and use this analysis to determine what could be adjusted in either or both models to make them more similar.

5. DATA GENERATION

For TRAF-NETSIM, over six hours of simulation was performed in which over 13,000 vehicles were simulated traversing a single 4,000 foot roadway link consisting of three through-movement-only lanes. This 4,000 foot link was fed by an external vehicle source link controlled by a traffic signal. The downstream end of the link was uncontrolled. With a traffic demand volume greater than the capacity of the intersection, the generated Flow Profile resembled a simple square wave. The upstream traffic flow is easily replicated in the TRANSYT-7F Platoon Dispersion Model. A large number of vehicles was required for a sufficiently large passage of vehicles at a point on the link. At selected points on the link the arrival times of vehicles were recorded modulo a 90 second cycle. Thus for the six hours of simulation and a 90 second cycle, there were 240 occurrences of each "second" in the cycle. At a point in the link the passage of each car occurs during some "second" in the 90 second cycle. The passage of vehicles was recorded at points positioned at 500 foot increments between 0 and 4,000 feet for a total of nine locations.

The short TRANSYT-7F Platoon Dispersion Model program written to generate Flow Profiles was executed with the same stopline output flow rate as TRAF-NETSIM with a cruise travel time "T" taken from the TRAF-NETSIM output. The TRANSYT-7F default Platoon Dispersion Factor of 0.35 was also used. Flow Profiles were computed for the same link locations as those recorded for TRAF-NETSIM.

6. DATA ANALYSIS

The Flow Profiles resulting from the two computational procedures above were imported into a spreadsheet program. All of data was duplicated into a second identical cycle solely for the purpose of continuity of the Flow Profile in any graphical display. A review of the TRAF-NETSIM Flow Profile indicated that some stochastic noise was still present and therefore a three point moving average was applied to the TRAF-NETSIM generated Flow Profiles.

Shown in Figures 2 and 3 are the Flow Profiles for TRANSYT-7F and TRAF-NETSIM at distances of 0, 1,500, 3,000, and 4,000 feet from the upstream end of the link. In Figure 4 are shown overlays of the TRANSYT-7F and TRAF-NETSIM Flow Profiles for points along the 4,000 foot link.

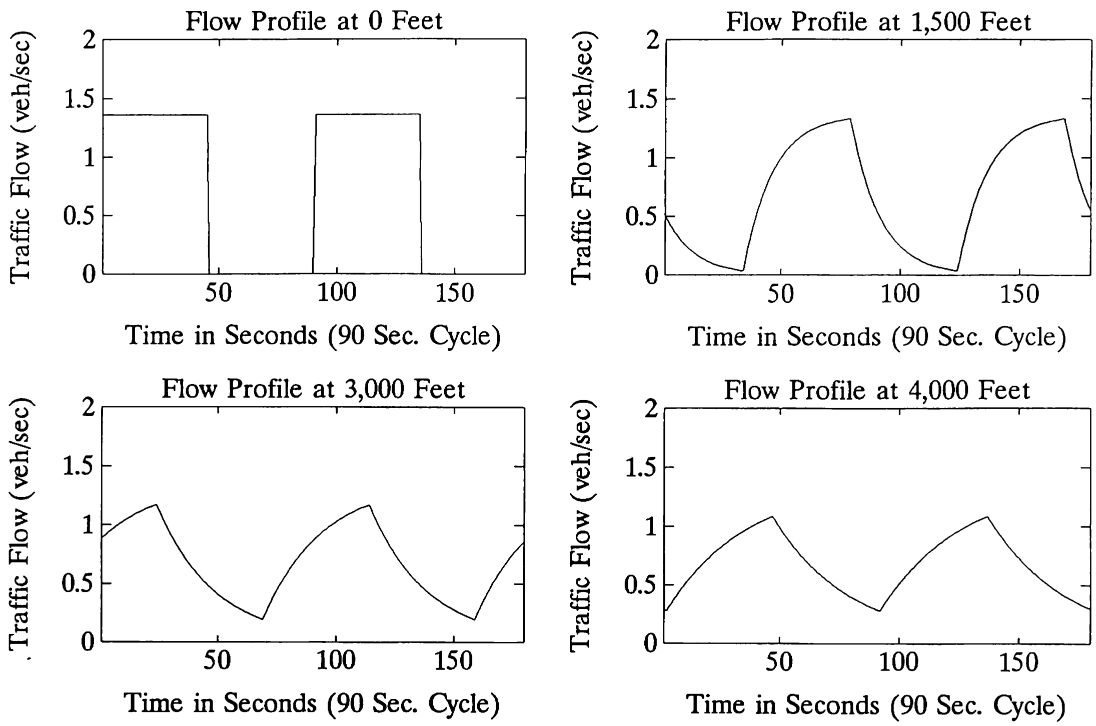

Figure 2. Flow Profiles for TRANSYT-7F

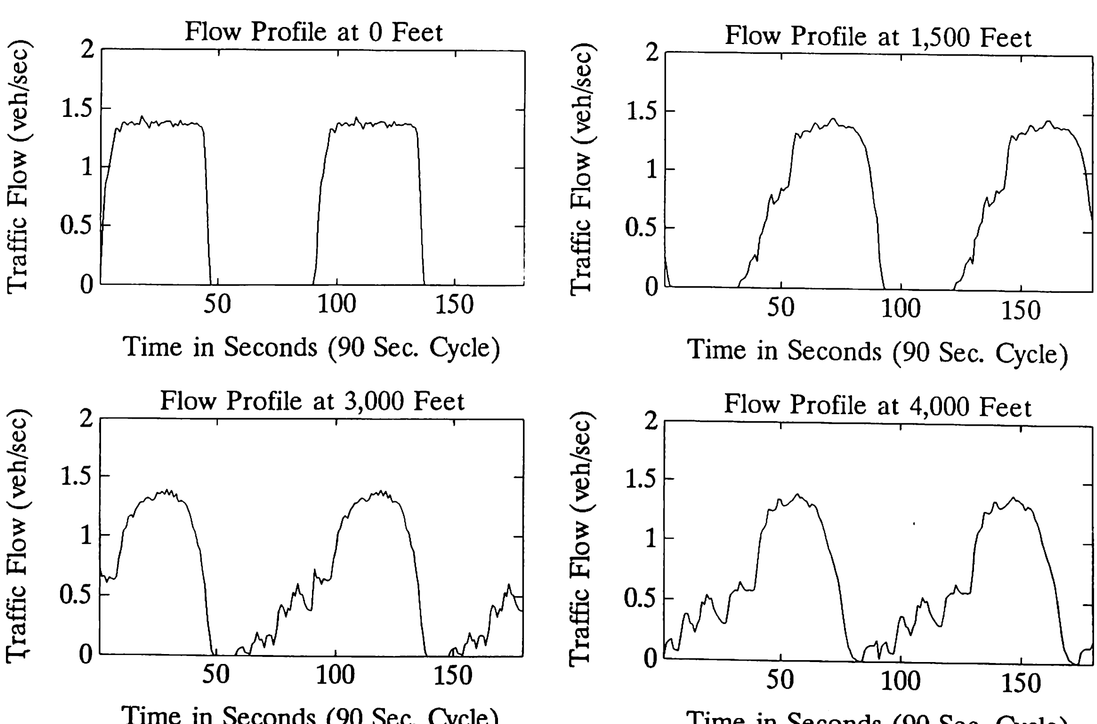

Figure 3. Flow Profiles for TRAF-NETSIM

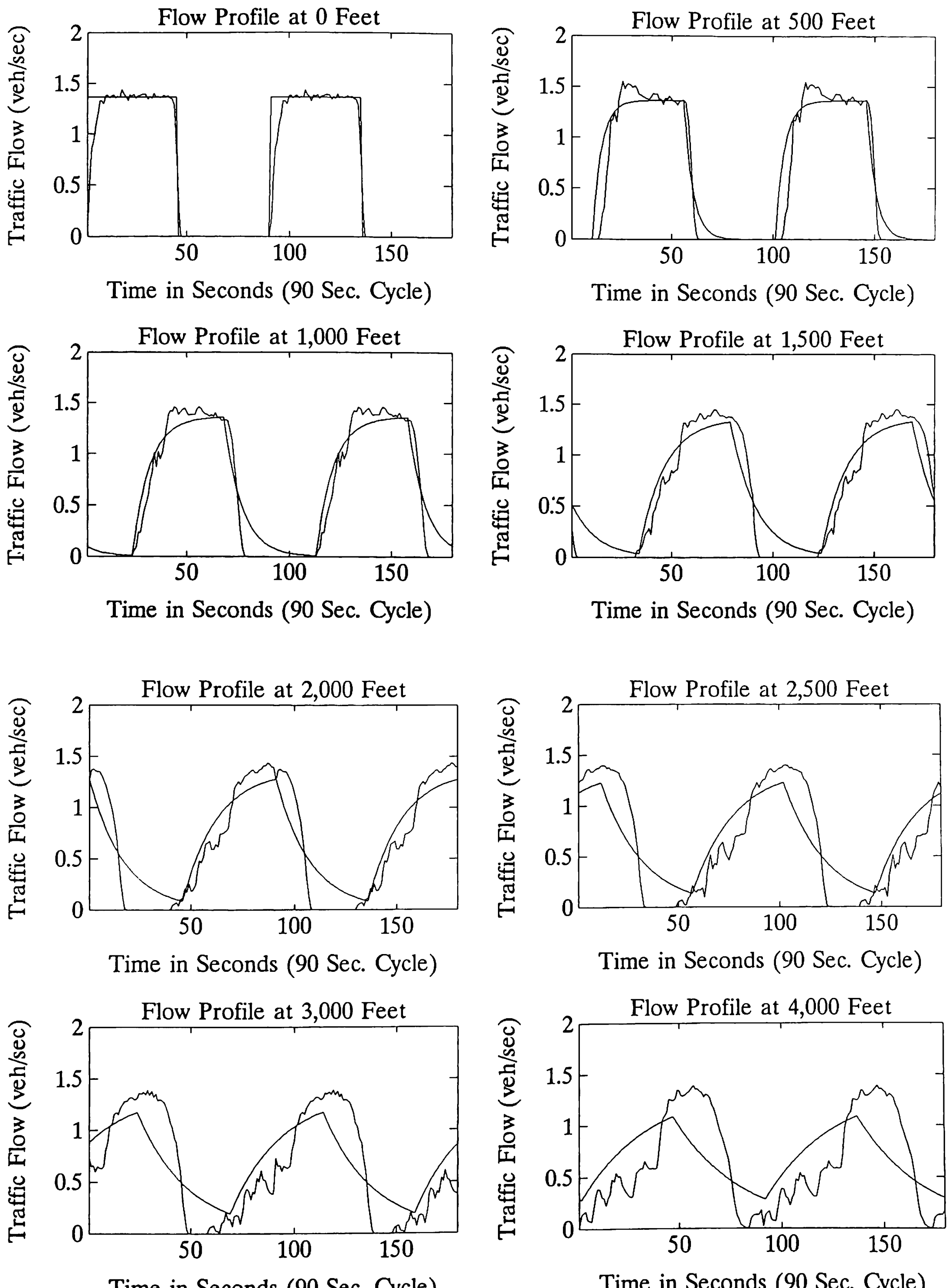

Figure 4. Overlay of TRANSYT-7F and TRAF-NETSIM Flow Profiles

In looking at the graphs, it can be seen that the TRAF-NETSIM Flow Profile does exhibit the characteristic left tail shift caused by aggressive drivers leading the main body of the platoon just as in the TRANSYT-7F model. Without looking at the rest of the graph, it would appear that there is more modelling of aggressive, higher speed drivers in TRAF-NETSIM than in TRANSYT-7F. When compared to the TRANSYT-7F Flow Profile, the TRAF-NETSIM Flow Profile does not show to the same degree the highly distinctive right tail shift caused by slower speed, non-aggressive drivers trailing the platoon as seen in the TRANSYT-7F graphs. In fact, the high drop off in the flow rate for TRAF-NETSIM is itself quite distinctive. Where TRANSYT-7F has a distinctive "right tail shift", TRAF-NETSIM has a distinctive "left tail shift". This result was unexpected.

In the combined Flow Profile graphs, the differences described above in the Flow Profiles for the two programs are quite apparent. The peak flow rates also differ by a significant amount. The Platoon Dispersion Factor "a" could be decreased in order to decrease the dispersion and raise the peak flow rate in the TRANSYT-7F Flow Profile. However this would cause even a greater difference when compared to the TRAF-NETSIM Flow Profile relative to when the main body of the platoon passes. Another interpretation of the combined Flow Profile graph is that the main body of the TRAF-NETSIM platoon is moving slower than expected.

TRAF-NETSIM uses a decile distribution of desired free flow speeds which range from 75 to 127 percent of the link's desired free flow speed. Thus for a desired link free flow speed of 30 mph (44 fps), stochastically assigned desired free flow speeds for individual vehicles will range from 22.5 mph (33 fps) to 38.1 mph (56 fps). This information along with the knowledge that TRAF-NETSIM currently does not contain a generalized discretionary lane change logic, that is, vehicle lane changing to allow movement around a slower moving vehicle, identifies what may be the primary cause of the Flow Profile differences. It was believed that vehicles in the nine higher speeds were bunching up behind the slowest tenth vehicle. The only place where TRAF-NETSIM currently performs a discretionary lane change is where there is a queue of stopped vehicles.

A review of the graphics animation did confirm the bunching of vehicles behind slower vehicles even though large gaps may exist in adjacent lanes. The largest possible gap that could occur over a 4,000 foot link is easily computed.

$$\text{Largest Possible Gap} = \text{Link Length} * (1 - \text{Lowest Speed \%} / \text{Highest Speed \%})$$

For the simulated case this would be:

$$\text{Largest Possible Gap} = 4{,}000\ (1 - 75 / 127) = 1{,}638 \text{ feet.}$$

Obviously, gaps of this size in the real world would be utilized by traffic in adjacent lanes. On average the gaps would be smaller than the largest possible but would still be of significant length and impact.

7. IMPLICATIONS OF RESULTS ON THE USAGE OF TRAF-NETSIM

The impact of the above described deficiency in TRAF-NETSIM is not as great as the above may imply even though it is significant. Traffic on a busy arterial is characterized not only by the traffic which travels down the arterial from one end to another but it is also characterized by the traffic entering from and leaving to the side streets. Traffic signals that are more typically spaced much closer together than the 4,000 feet used as the last data collection point of this study. Thus there are many other sources of additional stochastic noise which can interfere with platoon flow. However, it is evident that TRAF-NETSIM would underestimate the benefits of progression timing of the traffic signals because the main body of flow would be traveling at a speed slower than the design progression speed and therefore a greater proportion of traffic would encounter red signal indications and thus experience delay.

8. RECOMMENDATIONS

It would appear that the addition of discretionary lane change logic would be very beneficial to TRAF-NETSIM. This is, in fact, an enhancement that FHWA is currently having implemented. The procedures developed for this paper could be used to evaluate the enhanced TRAF-NETSIM program and then be used to determine what Platoon Dispersion Factor "a" in TRANSYT-7F would result in the most comparable Flow Profile.

9. SUMMARY AND CONCLUSION

A major objective of this study was to determine how closely the underlying traffic flow models of a macroscopic and microscopic traffic simulation programs compare in terms of their traffic Flow Profiles, and what aspects of the respective programs may need to be changed or calibrated such that these two programs generate similar Flow Profiles. Having similar Flow Profiles would provide further credence to the use of these programs in working to reduce traffic congestion on urban streets. Computational procedures required to perform such a comparitive analysis of the two flow profiles were developed. In performing the analysis for this paper, it was discovered that the lack of discretionary lane change logic in TRAF-NETSIM lessens it effectiveness in evaluating traffic signal timing plans for providing progressive flow along an arterial.

REFERENCES

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U.S. Department of Transportation, Federal Highway Administration (1989), *TRAF-NETSIM User's Manual*, U.S. Department of Transportation, Federal Highway Administration.