AN OVERVIEW OF THE TRANSIMS MICRO-SIMULATION MODEL: APPLICATION POSSIBILITIES FOR SOUTH AFRICA

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ABSTRACT

The Transportation Analysis and Simulation System (TRANSIMS) model was developed as a replacement of the traditional four-step travel demand model. The goal was to provide a simulation model that could analyze many of the issues facing transportation planners such as sustainable development, environmental impacts of proposed projects, and Intelligent Transportation Systems (ITS) deployment. While a simulation approach is powerful and potentially useful, a challenge for transportation modelers is that they will need to fully understand the new modeling paradigm so that the new model is not simply treated as a "black box".

The focus of this paper is on providing on overview of TRANSIMS based on lessons learned from research on real, calibrated transportation networks in Texas. An overview of the TRANSIMS model in terms of its main components along with a brief comparison to the four-step model will be provided. This is followed by an analysis of the highway link supply relationship in the TRANSIMS micro-simulation model with an emphasis on the implications for transportation planning practice. One of the benefits of a micro-simulation model is that the fundamental traffic flow properties are emergent from the model. This appears to eliminate the need for the modeler to assume a prior link flow-density-speed relationship. However, it is shown that the results from the model can be very sensitive to the calibration parameters chosen. Lastly, the paper examines implementation implications from a South African perspective and what transportation planners should be doing in order to prepare for the transition to micro-simulation planning models.

INTRODUCTION

It has long been recognized that the traditional four-step travel demand model is not robust enough to analyze adequately many of the issues facing transportation planners. Sustainable development, environmental impacts of proposed projects, and Intelligent Transportation Systems (ITS) deployment are examples of some current topics of interest. One potential solution has been to adopt stochastic, microscopic based models that can model individual demand responses to changes in supply. The most visible of these models is the Transportation Analysis and Simulation System (TRANSIMS) which was developed as part of the Travel Model Improvement Program

(TMIP) (Weiner and Ducca, 1999). The focus of this paper is on providing some an overview of the TRANSIMS model using insight gained from research on calibrated transportation networks in Texas.

This paper is broken down into three sections. The first section provides an overview of TRANSIMS in terms of its main components along with a brief comparison to the four-step model. Next the TRANSIMS traffic flow theory is described and the challenges for transportation modelers are highlighted using examples from Texas. Lastly, some implementation implications from a South African perspective are provided.

Overview of the Transportation Analysis and Simulation System (TRANSIMS)

Figure 1 provides a conceptualization of the TRANSIMS architecture. It may be seen that the system consists of five modules. The first module, the population synthesizer, is used to create a synthetic population of the households in the study area. It combines aggregate information from the census demographic tables (summarized by census tract or block group) and disaggregate data from the Public Use Microdata Samples (PUMS) census records in order to create a synthetic population base in which each individual is also assigned to a distinct household (Beckman et al. 1996). The aggregate statistics of these households, at the census tract and block group level, mimic the aggregate statistics of the true population contained within the census data. The synthetic household attributes used in the analysis are identified *a priori* and may include anything contained in the census data including gender, age, education, employment, income, vehicle information, etc.

The second module, the household activity generator, identifies the set of "potential" daily activities of each synthetic individual in each of the synthetic households. The number of trips each individual is scheduled to complete can be ascertained by counting the number of location changes in their daily list of activities. In essence, the list of activities defines the daily trip chain(s) desired by each traveler in the population and would be analogous to the information contained in a traditional travel diary. The input to this module is information from household activity surveys, workplace surveys, and land use information. For illustration purposes a distinction is made in Figure 1 between the list of activities and the activity attributes. The attributes of the activities would normally includes such things as activity priority, start time, duration, mode preference, location, et cetera.

The third module, the route planner, identifies the route for each trip output from the second module. Note that the route attributes in the TRANSIMS context includes not only what links a traveler would use but also information such as mode, changes in mode, parking locations, traveling companions, et cetera. The input to the process includes traveler information and activity information from Module 2 as well as network information. Network information would include link location, link travel times for each mode, mode accessibility, et cetera. Note that all of the information associated with each route (i.e. departure time, links used by mode, expected travel time, etc.) for each trip is explicitly enumerated and output.

The fourth module, the micro-simulation uses the route plans from Module 2 as input and simulates the transportation network at a microscopic level of detail – albeit at a lower fidelity than most traffic operations models (LANL 1998). In effect, Module 4 simulates the interaction between demand (the synthetic populations desire to travel between activity locations) and supply (the ability of the transportation system to meet this demand). As would be expected, the network data for each mode is also required. The output of the micro-simulation module can include information on each traveler, information on each mode down to the sub link level, and summary information on the network as a whole.

Once a TRANSIMS simulation is complete the output from the micro-simulation is used to analyze the network. Because the module is micro-simulation based and every traveler and vehicle is modeled explicitly the user has considerable flexibility in which metric(s) to use. It should be noted that while the vehicles are modeled at a microscopic level of detail their emissions are not estimated within the micro-simulation module. They are instead estimated from the aggregate output data as shown in Module 5 in Figure 1. This approach was adopted because the mircosimulation module is based on Cellular Automata (CA) rules and while TRANSIMS has been calibrated to macroscopic flow observations there is no guarantee that the microscopic speed profiles are accurate or even reasonable (Nagel et al. 1997, Williams et al. 1999, Zietsman and Rilett 2001 a).

Because of the inherent complexity associated with demand estimation, TRANSIMS models the traveler's decision making process, which is inherently simultaneous in nature, in a sequential manner with appropriate feedback loops. For example, in order to identify accurately a travelers' activities or plans (i.e. in Module 2) the level of service (LOS) attributes of the different modes by time of day needs to be known – which will clearly not be known until the micro-simulation module (i.e. Module 4) is complete. Therefore, during the first iteration the values are estimated. If the estimated LOS values and the resulting output LOS values do not match then adjustments are made and the process is repeated as shown in Figure 1. That is, the simulated activities as defined by A, the activity attributes (location, time, etc.) as defined by B, and the routes (departure time, links used, etc.) as defined by C may be changed as a result of new level of service attributes estimated in the micro-simulation module. The optimal configuration of the iterations or feedback loops and the conditions, if any, under which this process converges are ongoing research topics (Smith et al., 2000).

Comparison of TRANSIMS with the Four-Step Approach

Because of the long history of the four-step model in transportation planning, there is a natural tendency to attempt to discuss TRANSIMS using traditional terminology. In one sense this is reasonable because the underlying conceptualization of the transportation demand-supply process for both approaches are essentially the same. In addition, while the underlying process is simultaneous in nature both approaches are iterative as evidenced by the feedback steps associated with them. However, a comparison is problematic because TRANSIMS represents a fundamental shift, rather than an incremental change, in the implementation of the underlying conceptualization.

Obviously the key difference between the approaches is that TRANSIMS is micro-simulation based and is therefore capable of modeling the stochastic and dynamic attributes of the transportation system. Each traveler's activities, for example, are considered across the entire day as a single entity or chain. Thus all of the major lifestyle and travel decisions such as what activities to participate in, when to participate in the activities, where to participate, what mode to use, what route to choose, etc. can be made in a consistent manner at the individual traveler level, an ability which is not remotely possible with the macroscopic four-step model. In addition, because TRANSIMS is stochastic the LOS results, for example, can have confidence and/or tolerance intervals associated with them. In contrast, the four-step model tends to have varying levels of detail at each step. For example, traditionally trip distribution is aggregate and mode choice is disaggregate and the four steps are basically treated independently of each other. Therefore, the ability to model decisions consistently and at a disaggregate level across all four steps and to put confidence bounds on the resulting estimates is problematic, at best, for the macroscopic four step model.

While it is impossible to compare directly the five modules of TRANSIMS and the four steps of the traditional model it is potentially useful to compare and contrast them. What would be referred to as trip generation, trip distribution, and, to a certain extent, mode choice in the four-step process essentially occurs in the activity generation and route planner modules as shown in Figure 2. If the trips from each individual's activity chains are aggregated according to activity locations or zones, categorized according to trip purpose and mode preference, and stored in matrix form this would represent the modal origin-destination (OD) matrices that are currently used to represent travel demand in the four-step model.

The actual route that each traveler uses on each trip of her daily itinerary is identified in the route planner module in TRANSIMS. The modeling of the interaction of the demand, as represented by all of the travelers' route plans, and the supply, as represented by the transportation network, takes place in the micro-simulation module in TRANSIMS. In essence, the route plans serve as the desired demand for travel while the micro-simulation is used to identify the effect these demands have on the available transportation supply. Note that this approach is explicitly multi-modal, dynamic, and disaggregate in nature.

The TRANSIMS approach may be contrasted with the four-step model where the aggregate route choice and supply interaction is modeled in the traffic assignment step. Note that traffic assignment in the four-step model also has a type of internal feedback loop where drivers shift their routes in response to changes in supply as evidenced by the logic of the Frank-Wolfe, Incremental and Iterative traffic assignment algorithms. In essence, TRANSIMS models "traffic assignment" using Modules 3 and 4 and a feedback loop as shown in Figure 2. Therefore, the feedback between the "fixed" supply and "fixed" demand, which is essentially endogenous to the traffic assignment step in the four-step model, is modeled exogenously within TRANSIMS.

Note that in the four-step model feedback between supply and demand in the form of changes in trip generation (i.e. activities) is theoretically possible. However, empirical evidence has shown that trip generation is unaffected by the level of service of the network and consequently this feedback is rarely, if ever, performed in practice. It should be noted that work in this area is ongoing (Ortuzar and Willumsen, 1996). In addition, there has been considerable research work performed on incorporating feedback involving trip distribution and mode choice (Boyce et al. 1994).

TRANSIMS SUPPLY RELATIONSHIP

The TRANSIMS highway supply relationship is based on a cellular automata (CA) micro-simulation and as such the traffic properties are derived from individual vehicle trajectories. At a fundamental level the relationships contained in empirical models such as the Highway Capacity Model are based on the same type of data -- aggregated information from individual vehicles. However, because the vehicle trajectories are modeled explicitly in the CA model and may be readily accessed, the modeler has considerable leeway in choosing techniques for identifying the key traffic properties. For example, the modeler can choose the aggregation methods with respect to both space (e.g. one cell to entire link) and time (e.g. one second to one day). Note that in the HCM the fundamental flow parameters are usually based on point observations over a fifteen minute period (TRB, 2000).

The CA model is conceptually quite simple and it is this simplicity that allows it to be used, in a reasonable amount of time, for the simulation of traffic networks down to the local road and driveway level of detail. Each roadway lane is subdivided into cells that are 7.5 meters in length. Each cell can be either occupied by a vehicle or empty. The vehicles are moved through the network by a set of rules and the velocity of a given vehicle is an integer number and ranges from zero to five cells per second. Based a simulation time step of one second each increment in speed corresponds to approximately 27 km/h and therefore, the maximum speed of five cells per time step is equivalent to 135 km/h.

The CA is a time-based, rather than an event-driven, simulation where each time the vehicles follow three steps. In step 1 every vehicle i will change lanes with the externally defined probability p_{lane} given that there is an opening next to them. Note that in order to avoid two vehicles switching into the same cell on highways with more than two lanes, the direction of shift is alternated each time step. In step 2 the velocity of each vehicle i on the roadway is updated according to whether a vehicle needs to decelerate because of a vehicle ahead of it (rule 1), maintain a free flow speed (rule 2) or accelerate (rule 3). The rate that vehicle performs these maneuvers is based on the parameter p_n.

rule 1) Deceleration because of vehicle i ahead

Is the gap between vehicle i and the vehicle ahead less than or equal to five cells?

v_i = gap - 1 (if possible) with probability p_n

v_i = gap with probability $1-p_n$

rule 2) Maintenance of speed

Is the gap between vehicle i and the vehicle ahead greater than five cells *and* is the current speed v_{max} ?

$v_i = v_{max}-1$ with probability p_n

$v_i = v_{max}$ with probability $1-p_n$

rule 3) Acceleration

Is the gap between vehicle i and the vehicle ahead greater than five cells *and* is the current speed less than v_{max} ?

$v_i = v_i$ with probability p_n

$v_i = v_i + 1$ with probability $1-p_n$

In the third step the vehicles' locations are updated based on the speed calculated in Step 2. In essence each vehicle is moved ahead v_i spaces and because of the logic employed there are no conflicts between vehicles wishing to occupy the same space. Note that other issues such as passing and conflicting movements at intersections are not discussed in this paper and the logic of the model can be found elsewhere (LANL, 1998).

The TRANSIMS logic can best be explained by example. Figure 3 shows a vehicle's trajectory from the Dallas network study (FHWA, 1998) when p_n is set to the recommended value of 0.2 (LANL, 1998). The vehicle speed is on the y-axis while the time since departure is shown on the x-axis. As would be expected, given the model's logic, the vehicle speeds are discrete. It may be seen in Figure 3 that the maximum speed is 108 km/h (5 cells/time step) and that the changes in speed are instantaneous. A vehicle can only increase its speed by one cell/s during one time increment as shown by point A. However, the deceleration can be instantaneous (i.e. from v_{max} to 0) as shown by the slope of the trajectory at point b. In addition, a vehicle may shift lanes at any given time step and obviously this behavior is not shown in the time-series diagram.

The important point to note about Figure 3 is that the trajectory of the vehicle is only a representation of the actual vehicle performance as evidenced by the instantaneous changes in velocity. These trajectories need to be smoothed and/or aggregated in order to obtain a more realistic representation of traffic. This was not seen as problematic by the developers because the goal of the model was not to accurately replicate the movement of individual vehicles but rather to model the aggregate traffic behavior (Nagel et. al, 1997). Thus, the model is calibrated to macroscopic traffic measurements and this is why the emissions model does not use the individual vehicle trajectories as input but rather simulation data that has been aggregated over space and time (Williams et. al, 1999).

The speed-density-volume relationship is emergent from the model rather than being defined exogenously. Figure 4 shows a graph of the space mean speed versus flow from a TRANSIMS simulation of the calibrated I-10 network in Houston, Texas. It may be seen that in this situation the capacity of the upstream section, which is represented by the empty squares, is approximately 2100 veh/h. Note that the downstream section does not reach capacity and experiences a significantly lower travel speed. Figure 5 provides a sensitivity analysis of speed-flow relationship on a highway link as a function of different p_n values. For this particular example it was found that as p_n increases both the free flow speed and observed maximum volume decrease. However, under certain situations the opposite affect may be found (Rilett and Raney, 1999).

It is imperative that the model be calibrated correctly. This point cannot be overstated as evidenced by the fact that the recommended parameter for p_n is 0.2 and a value of 0.3 was used in the Dallas case study. Calibration studies on freeway corridors in Houston, Texas indicate that values in the range 0.05 to 0.10 may be most appropriate. It was shown that TRANSIMS, using the calibrated parameters, can replicate observed volumes to within ten percent during congested conditions and within one percent during uncongested conditions (Rilett et al. 2000, Zietsman and Rilett, 2001 a). Of more importance was that a similar analysis using the high fidelity CORSIM traffic operations model found comparable error rates with respect to estimated speeds and travel times. Therefore, while further study on different freeways and operating conditions is required, the preliminary results indicate that TRANSIMS is as accurate as the state of the practice, high fidelity traffic operations models with respect to modeling freeway sections.

A similar study was also performed where the TRANSIMS signalized intersection parameters were calibrated to the observed volume and control delay at a diamond interchange in College Station, Texas (Rilett and Kim, 2001). While modeling signalized intersections is considerably more complex than uninterrupted flow conditions TRANSIMS requires only one additional parameter: dwell time. Full details of the CA logic for intersections can be found elsewhere (LANL 1998, Nagel et al. 1997). It was found that the calibrated p_n parameter was 0.3 and the calibrated dwell time parameter was five seconds which may be contrasted to the default values of 0.2 and two seconds, respectively. As discussed previously, the highway calibrations identified p_n to be 0.1. Because p_n is a global parameter it is hypothesized that the different calibration values may be problematic when trying to calibrate networks that have both urban freeways and traffic signals. A logical solution might be to allow p_n to vary by the type of link although how this concept could be implemented would need further study. More importantly, the TRANSIMS results were compared to results from the macroscopic traffic signal optimization package PASSER III, and results from the micro-simulation traffic operations analysis model CORSIM. For the base case PASSER III, CORSIM and TRANSIMS were able to adequately represent the demand within one percent. PASSER III, CORSIM and TRANSIMS were able to estimate the control delay to within five percent of the observed value. The fact that the TRANSIMS traffic signal logic had the same error range as the high fidelity CORSIM model and the macroscopic PASSER III model gives some credence to the basic low fidelity approach.

There are a number of opportunities and challenges associated with using micro-simulation models in place of traditional macroscopic supply models. One opportunity is that because TRANSIMS is micro-simulation based, there is the potential to define transportation planning concepts of supply in the same manner as in the transportation operations field. For example, capacity (or maximum flow rate) will be a function of geometric conditions (e.g. number of lanes), the volume and movement of traffic (e.g. amount of weaving), and the traffic control conditions (e.g. ramp metering), which is similar to the HCM definition (TRB, 2000). Therefore, while TRANSIMS will require a more thorough understanding of fundamental transportation concepts by transportation planning professionals it should allow more consistent modeling approaches across the different transportation sub-disciplines.

APPLICATION POSSIBILITIES FOR SOUTH AFRICA

A question that can rightfully be asked is whether a highly sophisticated modeling approach such as TRANISMS will have any applicability in a developing nation such as South Africa. The question can be addressed by looking at South Africa's unique transportation challenges, its current modeling approaches, and the possible role that TRANSIMS can play in addressing its challenges.

The highly populated urban areas in South Africa have recently been organized into new mega cities or metropolitan councils. These metropolitan councils have jurisdiction over a number of conventional cities. The first major transportation challenge facing these metropolitan councils is to provide commuter transportation to previously disadvantaged communities. These communities typically reside in high-density areas located at considerable distances from their work opportunities. The commuter trips of these communities are performed by modes such as commuter rail, minibus-taxis, buses, and private transportation. The second major transportation related challenge facing the metropolitan councils is the high levels of congestion and the inadequate transportation infrastructure to cope with it.

The determination of traffic demand is the common transportation planning strategy that can be used to assist in addressing the above-mentioned challenges. Current and future traffic demand is determined through the use of transportation models. In South Africa the EMME/2 suite of programs, which is based on the four-step process, is frequently used as modeling tool. A more detailed simulation-based model such as SATURN is often used as a supplement to this model.

Due to the aggregate nature of the four-step model and the fact that these models are typically developed with fairly coarse zones, its level of accuracy is at best questionable. Errors in the range of 30% are typically encountered on highways carrying in the order of 20,000 vehicles per day. By using these corridor volumes, as inputs into a more detailed model such as SATURN will serve very little purpose due to the high levels of error associated with the input volumes. The four step model should, therefore, be used for its appropriate purpose, namely as a strategic tool to indicate future demands on existing and planned transportation corridors. This strategic approach is very important for broad level transportation planning and should be encouraged. It should, however, not be used as a tool to indicate detailed traffic flows on individual streets.

Apart from this strategic approach, there is a definite need to obtain more detailed estimates at a more localized level. For example, to be able to model the complex travel patterns of the various communities and to determine the effect of proposed projects, a much more accurate and detailed modeling approach is required. Also, public participation that deals with future transportation networks can only be conducted successfully if the network is addressed at a detailed level. This is the case because the public can only relate to transportation implications that can directly affect them on a localized level.

The TRANSIMS model is designed to replicate models such as EMME/2 and SATURN in a single model. It makes it possible to model the complex travel behaviors of individual commuters and to simulate the resulting demand on a very detailed transportation network. The problem with this approach, however, is that it is very data and computing intensive. For example, a twenty-kilometer section of freeway takes forty-five minutes to run on a Sun computer using the Unix operating system. At its most detailed level of output it produces ten million lines of data, occupying 400 mega bites of memory.

The high level of data requirements is mostly a concern in developing nations where detailed databases are typically not used or kept current. For South Africa, the databases used for its existing transportation models along with other sources such as census data, and ITS data can be used as an excellent starting point. The highly labor-intensive nature of data collection can also create an opportunity for very needed job creation.

Although the data needs and computing requirements are daunting, the benefits of this type of model cannot be under estimated. Apart from the modeling benefits discussed above, a detailed database of travel behavior within a region can be considered as a tremendous asset. Additionally, it should be noted that the simulated household data has wider applicability than only for traditional transportation planning. Because the model is household based it can be used to test various economic, environmental and sustainability policies (Zietsman and Rilett 2001 b).

The rate at which computing power is increasing can also make this type of approach very attractive in the medium to long term. Metropolitan councils within South Africa could, therefore, seriously consider incorporating an approach such as TRANSIMS. Implementation does not have to happen immediately but can be phased in over a number of years. For example, the TRANSIMS model can initially be used to model only specific high profile corridors. As data and additional computing power becomes available the study area can be gradually increased until the whole metropolitan area is covered.

The decision whether to move to TRANSIMS is obviously up to the South African modeling community. However, whether the decision is to go with TRANSIMS or not, it should be realized that there is a definite trend to move towards micro-simulation based approaches. Modelers will, therefore, have to be at least knowledgeable about such models, particularly when setting up data collection and data archiving exercises. This will make the transition a lot smoother when it occurs. Although TRANSIMS can be considered as new and daunting, there appears to be enough valid reasons for the South African modeling community to at least consider it. Additionally, South Africa can be used as test bed for applying TRANSIMS in a developing nation. Initial work in this regard is underway where existing models that are used to model the Mabopane-Centurion corridor will be converted to TRANSIMS. Such a conversion requires additional data and various refinements, but is perhaps not as cumbersome as it might appear. A successful application in this regard has been achieved in Houston, Texas (Rilett and Kim 2001).

CONCLUDING REMARKS

Transportation planners have been faced with a number of new issues such as the long term effects of ITS and sustainable growth patterns that the four step planning process was not designed to address. One potential solution is to use micro-simulation based planning models that are more robust in capturing individual demand changes for different supply scenarios. The most comprehensive of these models is the TRANSIMS model that has been developed at Los Alamos National Laboratory. The main objective of this paper has been to illustrate the general layout of TRANSIMS with specific emphasis on the highway micro-simulation module. In addition, implementation of these new models was discussed from a South African perspective.

It was shown that TRANSIMS represents a fundamental shift in forecasting theory that will require transportation planners to develop a comprehensive understanding of the differences between the four-step model and the TRANSIMS model. This will occur not only on the demand side, where activities are defined for each individual over an entire day, but also on the supply side where the relationships used are markedly more sophisticated than what has been used in the past.

The advantages to using traffic micro-simulation models, such as TRANSIMS in planning applications, are threefold. First the stochastic and dynamic nature of traffic flow is modeled explicitly. More importantly, the speed-volume-density relationship is emergent and does not have to be identified *a priori*. Secondly, the supply relationship is a function of the roadway geometrics and the traffic demand and behavior (i.e. merges, weaving, etc.). Therefore, the emergent properties are more realistic as compared to current techniques and are similar to the approach adopted in traffic operations. Thirdly, there is an opportunity for traffic operations modeling and transportation planning modeling to become seamless with respect to theory, concepts and description of transportation supply components. For transportation planners the important point to realize is that the nature of micro-simulation model will require them to change fundamentally the way they approach supply relationships in their analyses. However, because these models are more comprehensive, transportation planners will have to develop a good understanding of how these models work in order to avoid treating them like “black boxes”. This is particularly important because much of the underlying approach is markedly different from that of the four-step model.

The metropolitan councils in South Africa can benefit greatly from a more detailed and accurate modeling approach such as TRANSIMS. It is suggested that such an approach be phased in over time.

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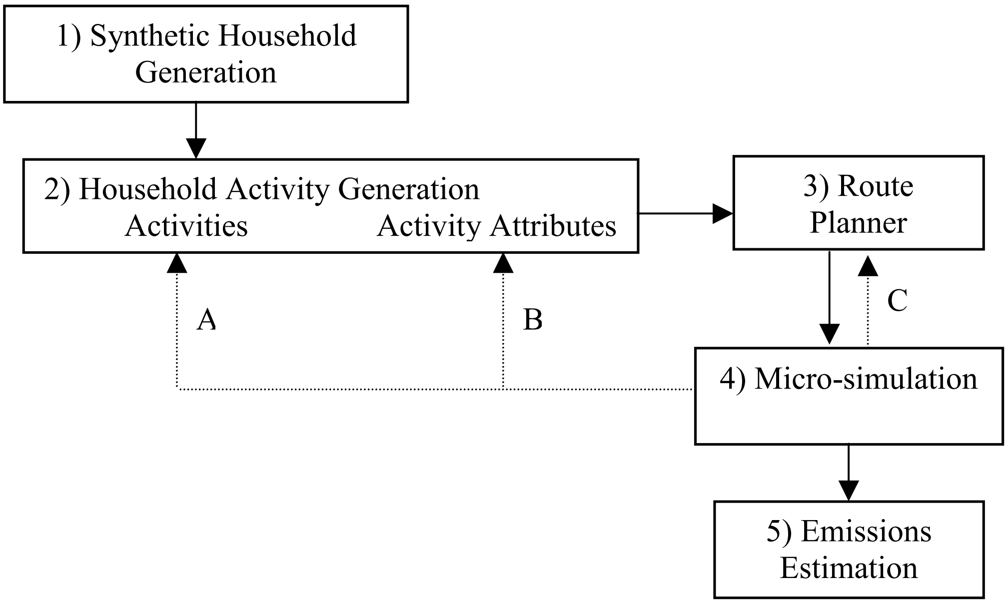

Figure 1: Schematic Diagram of TRANSIMS Architecture

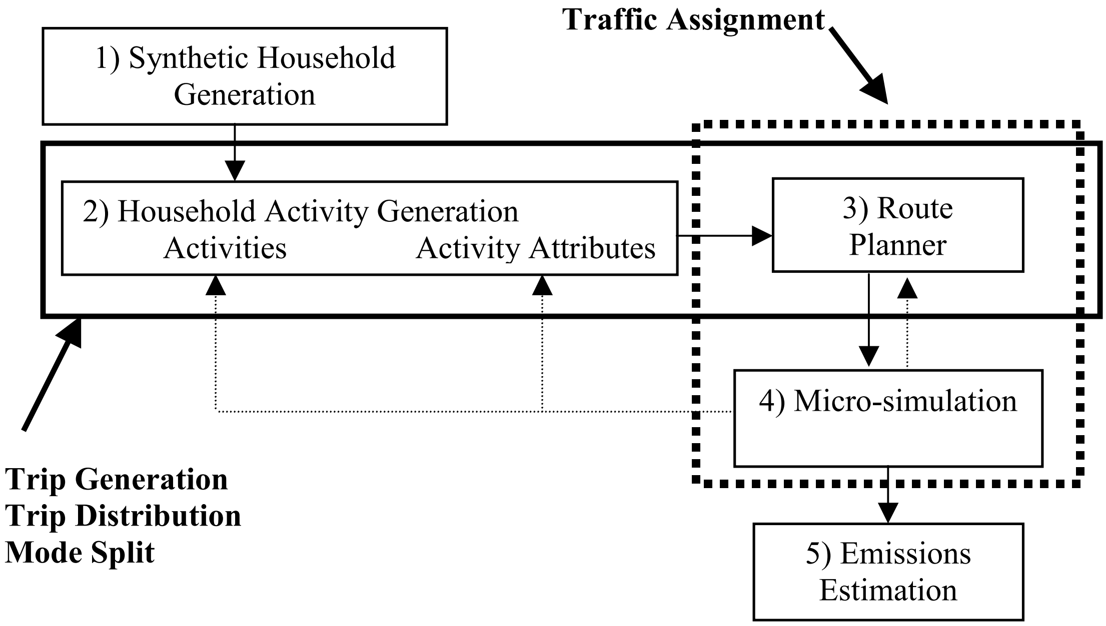

Figure 2: Comparison Between TRANSIMS and Four-Step Architecture

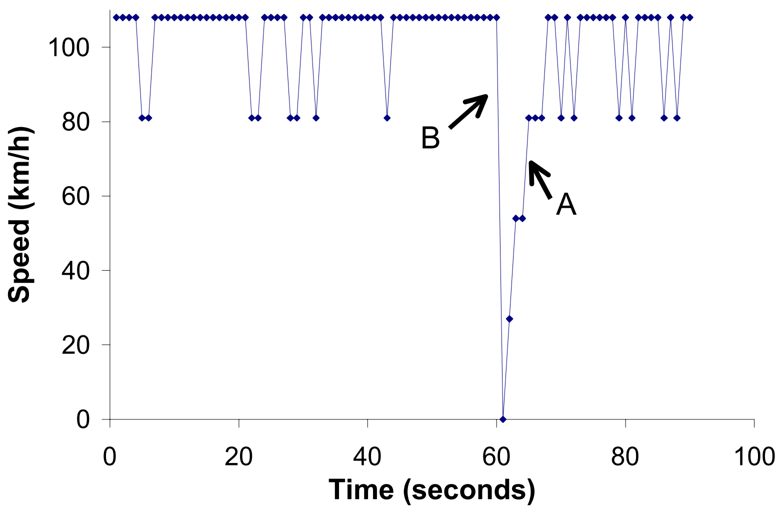

Figure 3: Typical Vehicle Trajectory (p_n = 0.2)

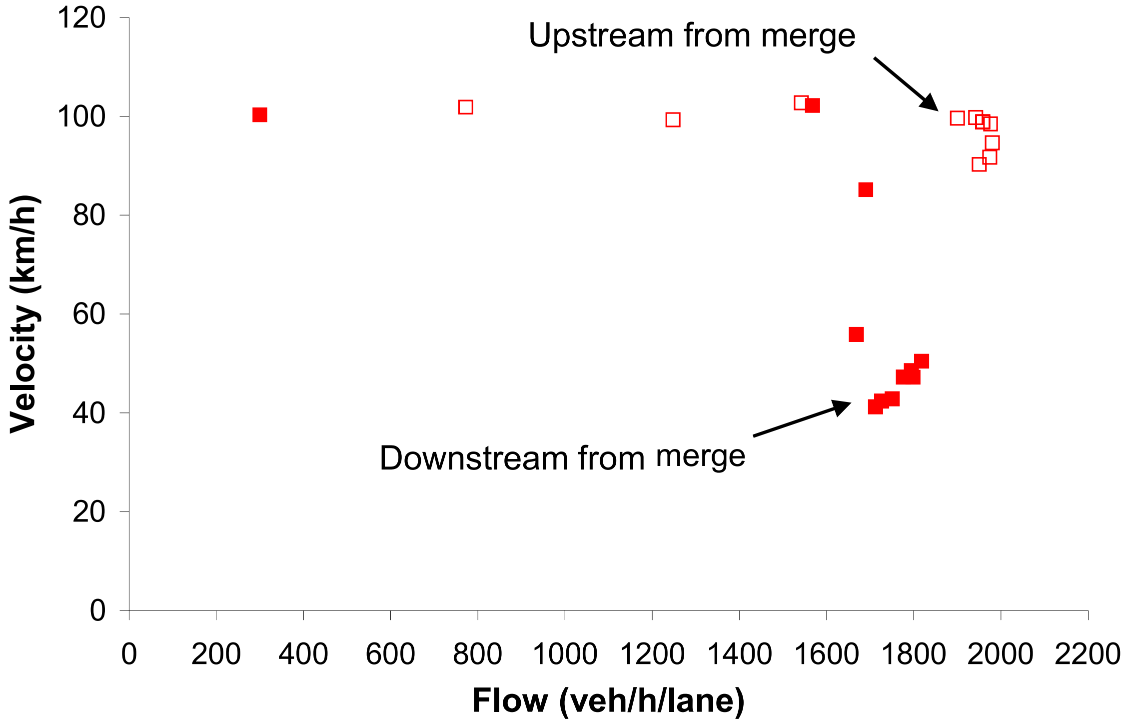

Figure 4: Speed-Flow Graph for I-10 Corridor in Houston, Texas

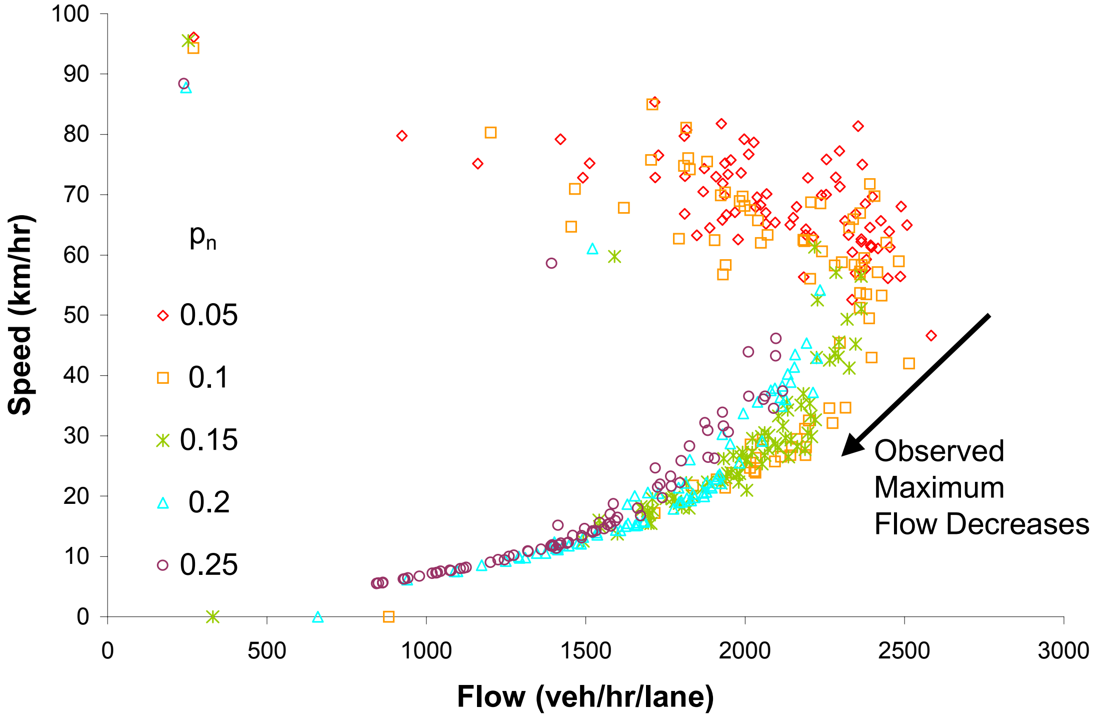

Figure 5: Speed versus Flow for Different p_n values

AN OVERVIEW OF THE TRANSIMS MICRO-SIMULATION MODEL: APPLICATION POSSIBILITIES FOR SOUTH AFRICA

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