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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

CUMULATIVE IMPACT OF DEVELOPMENTS ON THE SURROUNDING ROADWAYS' TRAFFIC

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16. Abstract: In order to recommend a procedure for cumulative impact study, four different travel demand models were developed, calibrated, and validated. The base year for the models was 2005. Two study areas were used, and the models were run for three periods (AM peak, PM peak, and average daily traffic). The models were developed based on the two regional models of the Baltimore-Washington, D.C. area. The calibrated models were utilized to forecast traffic for the years 2010, 2020, and 2030. The 2010 forecast results were compared to the ground counts. In total, 72 different models were developed and run. It was concluded that the Sub-TAZ model forecasted traffic more realistically and this model was best suited for the cumulative impact study. It was recommended that the base regional model should be zoomed-in by the Sub-TAZ model for the study area, in order to conduct a cumulative impact study. The Sub-TAZ model can also simply be applied to the regional model. The researchers also investigated the feasibility of using TRANSIMS to develop an Activity-Based regional model. The research team developed and calibrated TRANSIMS Trip-Based (Track 1) and Activity-Based (Track 2) for one study area. The research team concluded that the regional Activity-Based model can be developed and calibrated in three steps, transitioning from a Four-Step model to Sub-TAZ, then to TRANSIMS Track 1, and finally to TRANSIMS Track 2.

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EXECUTIVE SUMMARY

In order to recommend a procedure for a cumulative impact study, the research team developed, calibrated, and validated four different travel demand models. The models were developed with 2005 as the base year. The models were run on two study areas for three time periods: AM peak, PM peak, and average daily traffic (ADT). The models were developed based on two regional models of the Baltimore-Washington, D.C. area. The calibrated models were utilized to forecast traffic for the years 2010, 2020, and 2030. The 2010 forecast results were compared to the ground counts. In total, 72 different models were developed and run. It was concluded that the Sub-TAZ model forecasted traffic more realistically and this model was best suited for the cumulative impact study. It was recommended that the base regional model should be zoomed-in by the Sub-TAZ model for the study area, in order to conduct a cumulative impact study. The Sub-TAZ model can also simply be applied to the regional model. The researchers also investigated the feasibility of using TRANSIMS to develop an Activity-Based regional model. The research team developed and calibrated TRANSIMS Trip-Based (Track 1) and Activity-Based (Track 2) for the MD 175 study area. It is concluded that the regional Activity-Based model can be developed and calibrated in three steps, transitioning from a Four-Step model to Sub-TAZ, then to TRANSIMS Track1, and finally to TRANSIMS Track 2.

INTRODUCTION

In order to get permission to obtain access to a state highway facility for their development, developers are required to conduct a traffic impact study (TIS) and submit it to the county in which the development will be located. A TIS reviews the impact of the proposed development on the surrounding roadway system, with consideration given to traffic capacity, signalization, and safety issues. The report identifies necessary improvements off-site and near the site access that are in accordance with county laws and state policies.

Most counties only require developers to include traffic generated by the *approved* development proposals in their TIS. As a result, the traffic impact of many of the pending developments is not considered, and roads become more congested than the individual TIS projected. Unforecasted congestion is also caused by uncaptured regional growth between different phases of developments. Therefore, the assumptions and results of the travel demand modeling (TDM) are also critical in TIS.

This research used TransCAD, the travel demand modeling (TDM) software package, to form two case studies that quantified the problem. The research team compared different transportation models and suggested the best model that SHA staff can use to forecast traffic realistically. The model can also decrease the gap between TDM and TIS. The researchers also used TRANSIMS to develop an Activity-Based model.

Objectives

The objectives of this research project were threefold:

- to form two case studies that examine the cumulative effect of developments on roadways
- to develop different TDM models (including an Activity-Based model) for the two study areas and find the model that gives the most realistic results
- to provide SHA with a model that will best decrease the gap between TDM and TIS

The next phase of this study, if pursued, will use the results of this project to investigate and evaluate the effect of the combined trips generated by the built developments in the two case studies. The researchers expect to provide SHA staff with recommendations that can be used to perform comprehensive TIS.

LITERATURE REVIEW

Land use and transportation are intertwined. Development density and location affect travel patterns, and the transportation system's degree of access affects land use and development trends. Smart growth and sustainable development commonly refer to the integration of land use, transportation planning, and development. These approaches recognize the importance of establishing land use goals to promote alternative transportation modes, including transit and non-motorized transportation. Involving all stakeholders in the coordination of land use, transportation (or other infrastructure), and economic development plans is becoming a common way to address policy issues.

In a search for sustainability in transportation facilities and a reduction in traffic congestion, policy makers and federal and state departments of transportation tend to profile solutions through policies that will significantly improve the coordination between land use development and transportation systems. A TIS plays an important role in this coordination. TIS and traffic impact analysis (TIA) have been used interchangeably and analyze the same thing. This study uses TIS to describe this concept; however, some studies use TIA.

TIS guidelines usually require the developers to calculate the traffic effect of a proposed development and all approved developments on the surrounding area. However, a TIS can also evaluate the combined effect of a proposed project and its surrounding properties. This report refers to this type of evaluation as a cumulative traffic impact study (CTIS).

There is no specific definition for CTIS in the literature. The research team defines it as an analysis of the cumulative effect of a proposed project and all existing, approved, proposed, and potential projects on the study area's transportation system. Cumulative traffic effects can result from individually minor but collectively significant traffic generated by each development in a study area. Different states have different guidelines for TIS. Some states require consideration of all potential projects, and others all proposed projects, while many others only require the approved projects.

As stated earlier, transportation and land use are strongly related. Land developments affect transportation systems by changing traffic patterns. On the other hand, transportation projects are usually done to reduce travel time and to increase development accessibility. However, transportation projects are one of the numerous factors that influence development patterns. The estimation of induced growth effects requires the identification of the project's contribution to changes in development patterns. Once the project's effect on land use has been identified, this information can be used to estimate the traffic impacts attributable to land use changes caused by the project. Methods for analyzing the induced growth effects of transportation projects include quantitative methods (e.g., travel demand models, integrated land use, and transportation models) and qualitative methods (e.g., scenario writing).

In order to have a concise background, the researchers reviewed past research and regulations related to the cumulative impact of development on surrounding roadways' traffic. The literature search covered the development of standards, cumulative assessment, and TIS guidelines across the United States.

TIS Guidelines in the State of Maryland

SHA requires developers to submit a TIS report in order to receive an access permit to the state roads. The report provides the state and local jurisdictions with data on on-site and off-site improvements that should be considered. Traffic capacity, signalization, and safety issues are all considered in the assessment of the report.

A TIS is required for any development that generates more than 50 peak hour trips. For any TIS prepared with a lower threshold, SHA expects the report to conform to the guidelines as if state highways were involved. When an impact study is required, a scoping meeting is held with the developer (or their consultant) and the appropriate representatives from SHA and/or the local jurisdiction. It is the responsibility of the developer to initiate this meeting by working through SHA's Access Management Division. This meeting focuses on site-specific information concerning the development, and copies of the meeting minutes have to be distributed to all interested parties. During this meeting, the study area, which must be in accordance with local public facility guidelines, may be modified in consultation with SHA. In the absence of local guidelines, the study area is the nearest signalized public street intersection in all directions within a one-mile radius from each access point.

The TIS must include traffic counts and analysis; the annual growth in traffic; traffic generated by other approved developments and the proposed development at build out, and/or at any significant stage of development; and traffic analysis for all approved or funded highway projects. The report must also include total traffic analysis with improvements, explanation of the analysis results, and the developer’s reasonable suggestions or recommendations for traffic improvements to mitigate the site’s traffic impact.

SHA’s TIS guideline is intended to be a template for preparing a traffic impact report for developments that affect the state’s highway system. Traffic reports prepared for the counties should include analyses consistent with these guidelines, especially when a state roadway is involved. Some counties have their own guidelines, and the SHA guidelines are not intended to replace them, but supplement them.

Most of Maryland’s 24 counties have specific TIS procedures and policies, but none of them require a CTIS to determine the effect of excessive development on current and future roadway traffic. The extent to which a proposed development will affect existing transportation performance has been the key issue in any intended development proposal. With increased development, local authorities seek better ways to coordinate land use and transportation.

In Carroll County, a TIS is required for any mixed residential or industrial development proposal. Carroll County may consider adding public facilities in the subdivision and site plan approval process, which complies with Article 66B of the Annotated Code of Maryland. The TIS should examine the extent to which the proposed development project will substantially impact the county’s transportation system. At the scope of work meeting, which is held before the TIS is completed, developers are expected to specify the range of the TIS and get approval from county officials. According to the guidelines, all development proposals that produce more than 50 peak hour trips are subject to TIS. Most importantly, every county-approved project that exceeds the specified period of development will require another TIS. However, the developer is allowed to fund the improvement through the county's capital investment fund, especially if the development proposal will have a substantial impact on the county roadways due to inadequate transportation facilities.

In Charles County, developers are required to conduct a TIS if the proposed project generates 100 or more vehicle trips during the peak hour (Charles County, 2006); the proposed development is close to an intersection that currently carries high trips per peak hour; developers request a new traffic signal; or the traffic impact study is not current. However, when a proposed project meets the traffic impact standard, the developers are required to prepare a document that shows why the project does not require a TIS. A traffic specialist from the area that will contain the proposed project reviews the document. This traffic specialist determines how much impact the proposed project will have on the existing roadways.

In Queen Anne's County, developers are required to follow the county's TIA guidelines (Queen Anne's County, 2008). The developer is expected to determine if the proposed development will generate 25 or more trips per peak hour, and that number must include pass-by trips diverted to the site from existing traffic. The developer or applicant is also required to request a meeting with county officials to determine the scope of the study. The developers have to include all approved and funded developments in the study area. The guidelines also require the developers to use the traffic counts that were performed less than a year before the TIS was submitted. As in Charles County, if the traffic count does not meet 25 trips per peak hour, the developer is expected to provide proof that the development will not affect existing transportation performance.

In Washington County, a TIS report is the minimum requirement for the developers of proposed residential or commercial projects (Washington County Policy, 2005). The county established a cumulative database to account for the extent to which previous and pending developments will impact the transportation system.

The Montgomery County TIS guidelines require developers to include traffic of all developments approved but not built as well as all built and occupied developments, before the submission of a development proposal. Besides, "Transportation Planning staff may require that applications in the immediate vicinity of the subject application filed within the same time frame be included in background traffic, even if the Planning Board has not approved them. If an application is approved after a traffic study has been submitted for another project and both require improvements for the same intersection(s), then the traffic study for the pending application must be updated to account for the traffic and improvements from the approved application."[1]

Baltimore City traffic impact guidelines (2007) require applicants to include approved and existing developments. A TIS can be required for any type of development: residential, institutional, commercial, office, industrial, or mixed-use. Developers are required to conduct a

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[1] M-NCPPC, 2011, Page 18

TIS for proposed developments if the gross floor area is greater than 15,000 square feet and any of the following conditions is true:

- The impact area includes an intersection with level of service (LOS) of D[2] or worse.
- The development includes 100 or more dwelling units.
- A gross floor area greater than or equal to 150,000 square feet will be used for warehouse.
- A gross floor area greater than or equal 50,000 square feet will be used for non-warehouse.

The TIS guideline states that trip generation shall be estimated using ITE handbook.

Anne Arundel County (2007) requires TIS to include critical lane volume analysis for the existing traffic, the background traffic (expected traffic from developments under construction), and expected traffic from developments under review. If the critical lane volume exceeds 1,300, the appropriate intersection analysis (according to Highway Capacity Manual) must be included.

Frederick County (2009) requires all proposed developments to perform a TIS, except those expected to generate less than 25 trips during the adjacent street's peak hour and less than 50 trips during the proposed site's peak hour. The growth in traffic should include traffic generated by approved developments in the study area.

Harford County (1996) requires a complete TIS for any residential, industrial, or business development that generates more than 249 daily trips. ITE trip generation rates shall be used. All approved projects in the study area need to be included in the trip generation estimation.

Prince George's County (2002) requires TIS for developments generating 50 or more trips in any peak hour. TIS must include all existing and approved developments in the study area. Similarly, Calvert County requires the inclusion of all existing and approved developments in a TIS. Furthermore, it requires that county roads and intersections within the study area maintain an LOS C after the development is built (but an LOS D is acceptable at town centers).

TIS Guidelines in Other States

Different states have different rules for their TIS. To the best knowledge of the authors, only Virginia and California require CTIS. Below is a brief review of TIS guidelines in five states.

Virginia

In 2006, the state of Virginia transmitted a regulatory and advisory role to its department of transportation, VDOT (VDOT Administrative Guideline, 2008). VDOT's regulation classifies land-use development proposals in these key stages: comprehensive or amendment, rezoning, and subdivision or site plans.

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[2] LOS C and D usually refer to volume over capacity of 0.55 and 0.73, respectively.

The administrative guidelines for a comprehensive plan require local authorities and developers to submit development proposals to VDOT for review. The proposals determine whether the development will have a substantial impact on a state-controlled highway. A significant impact to transportation performance is defined as a change that will generate an additional 5,000 vehicle trips per day on the state-controlled highway. If this impact occurs, the local authorities and VDOT meet to discuss the issue. The comprehensive or amendment plan should also contain a detailed transportation plan that describes the existing transportation facilities and its future improvements. The plan must be sent to VDOT 100 days prior to its implementation. The comprehensive or amendment plan does not require a TIA.

The regulations for zoning plans require developers to submit proposals with a detailed TIA to local authorities. The local authorities determine whether the development proposal will significantly affect the state-controlled highway. After the local authorities review the completed application package, they send it to VDOT for review. The TIA guidelines also require local authorities or developers to include information on existing traffic data. They need to include approved, pending, and proposed projects that are close to the proposed development, i.e., a CTIS.

According to Chapter 527 of the state law and regulations, developers are required to conduct a TIS if the trip generation on a state-controlled highway or locality-maintained road is more than 100 vehicles per hour, or the proposed development is within 3,000 feet of a state highway. An additional TIA may be required during the development process in order to approve an entrance permit, especially for specific entrance locations. For subdivision or site plans, the regulations require developers to submit a development proposal and application package to the authority in charge of that jurisdiction. The local authorities also review the application before sending it to VDOT.

The TIA presents VDOT, local authorities, and stakeholders with the same view of the transportation development, thus providing a dependable standard and baseline for consistent growth. VDOT introduced a checklist for the required elements of a TIA. Developers need to submit the checklist with their TIA report.

The James City Citizen Coalition performed a TIS for selected corridors within James City County, Virginia (J4C, 2008). New and existing developments at specific locations were creating traffic nightmares. The county’s geographic information system, real estate data, the previous year’s traffic count, and the Institute of Traffic Engineers’ estimates of traffic per day by development type were used to carry out the traffic study. The TIS found that the cumulative effect of proposed, approved, and existing developments posed a threat to the transportation facility along a specific corridor.

New Jersey

Over the last decade, the state of New Jersey has encountered serious congestion problems along Routes 1-29, 31, 38, 57, and 322 (NJDOT, 2004). The New Jersey Department of Transportation (NJDOT) had long relied on the capacity-widening approach to address the corridors’ congestion, but it was not a sustainable solution.

The state adopted New Jersey Future in Transportation (NJFIT)—a long-term, community-driven initiative—to address the congestion problems. NJFIT integrates land use and transportation planning within regional corridor development, with a focus on sustainable land-use policies that complement and support transportation. Some of the initiative's strategies include the following:

- finding the appropriate land use, access management, and community network solutions to supplement and reinforce the first approach of investing in the state highway system
- providing technical assistance and measures to help communities create laws and a shared vision
- helping communities to understand how zoning and statutes can steer development into sustainable patterns

The application for a preliminary major site plan and subdivision approval, which is submitted to NJDOT, must include a TIA. The assessment should reflect the number of peak hour trips that will be generated by the development site. A TIS is required if the department determines that the development will generate 200 or more additional peak hour trips. The TIS should indicate the development's impact on the state highways and include the number of peak hour trips and daily trips that the development will add to the state highways.

The department requires fair-share financial contributions toward the cost of transportation improvements and mitigation measures on the state highway system if the TIS shows that the development will generate 200 new trips during critical peak hours and a 10-percent increase in previous daily trips on the state highway. However, if the developer requests, the department will permit the developer to construct the improvements at the developer's expense and under the department's supervision. The present State Highway Access Management Code applies not only to developments that need direct access to the state highway, but also to developments that have indirect access to the state highway system and will add additional traffic.

Kentucky

The TIS guideline that was created by the Kentucky Transportation Center determines the appropriate location, spacing, and design of access points from developments to state highways. The guideline also determines whether a proposed development's access to the surrounding roadway will necessitate improvements to the roadway system (Kentucky Traffic Impact Study Requirements, 2010).

A TIS is required as a condition of access permit approval. However, the district permit engineer may waive the requirement for a TIS under two conditions: (1) the applicant can provide documentation showing that the access location is necessary because of a pre-existing condition, not because of the proposed development; or (2) there are no reasonable engineering alternatives for site access. A TIS is not a condition of approval for access permits serving single-family dwellings or multiple-family dwellings with three or fewer units and field entrances.

The Kentucky Transportation Center created a database to track each generated trip and its relationship to the peak hours and number of cars on the road. The applicant is also required to create an access plan to assist in any necessary traffic control alterations in the study area. Kentucky's guidelines state that the TIS must address a minimum study area. However, the district permit engineer can adjust the study area as appropriate to the development size, site-specific conditions, and local and regional issues and policies. The applicant can also extend the minimum study area in order to demonstrate how the proposed access plan could benefit the Kentucky Transportation Cabinet and the community.

When the TIS is required because of the development's traffic volumes, the study area must include all proposed access points and extend to the first full median opening or signalized access point within 4,800 feet of all directions along the intersecting roadway. It must also include the first adjacent partial access in both directions.

When the TIS is required because of spacing deviations, the study area must include the proposed access point that does not meet applicable standards and the access point or public streets within a specified distance.

If the proposed development will modify traffic control, the study area for the TIS must include all of the proposed development's access points, the points adjacent to the proposed access points on both sides of the street, and the first controlled access points within 4,800 feet of any direction along the adjacent roadway network. Additionally, the study area should include all affected signals if the staff determines that a modification will affect the coordinated signal system's operation.

When the district permit engineer requires a TIS, the study area must address the specific issues for which the study was required. The TIS will examine the study area's anticipated conditions one year after the proposed development's opening.

Each study area needs to have access points that pertain to the development of a roadway network. The analysis will be completed to a degree sufficient to document the operational and safety impacts of the proposed development and access plan. The analysis scenarios provide feedback before and after completion of the area's development. Each scenario must include the peak hours of operation in the area.

New York

In New York, the TIS preparation and evaluation process varies based on whether the TIS is prepared by a developer or the New York State Department of Transportation. For both scenarios, the regional traffic engineer for the affected area must review and approve the TIS, its proposed construction, and mitigation elements. If the TIS is prepared by a developer, the proposed development's scale, complexity, and setting dictate the requirements for the TIS. A TIS is not required for developments that generate fewer than 100 peak hour trips.

California

The state of California has similar regulations regarding the preparation of a TIA. Caltrans, the California Department of Transportation, takes its procedures from the California Environmental Quality Act. With the aim of maintaining a consistent traffic flow, Caltrans evaluates a development proposal's impact on a state highway facility. Caltrans reviews the development proposals of federal, state, and local agencies. Developers or applicants for any development that is expected to have a significant impact on a state highway's LOS have to conduct a TIA to determine the level of impact. A TIA will be required if the development proposal will generate over 100 peak hour trips on the state highway facility and the facility is currently experiencing a C or D LOS.

Agencies or developers preparing the TIA should include an analysis of all adjacent facilities, driveways, intersections, and interchanges with the state highway. The study should include the existing conditions and the anticipated cumulative condition of trip generation, distribution, and assignment in the year of the project's completion. First, an analysis of the existing traffic condition is performed. Then, all approved and pending projects in the study area (excluding the proposed project) are analyzed. Finally, the cumulative effect of the proposed, approved, and pending projects is analyzed. The developer or agency preparing the TIA is expected to reach a consensus with Caltrans on the data and assumptions necessary to prepare the study. The TIA must include mitigation measures if the development proposal will have a substantial effect on the state highway facility. This enables Caltrans to determine whether the development impact can be eliminated or reduced to a level of insignificance.

Los Angeles County's TIA guidelines list specific requirements for developers (Loc, 1997). According to the guidelines, development proposals are critically examined to determine the cumulative effect of an existing project (project under construction) on the LOS in a specific transportation facility. A development proposal that generates 500 vehicle trips per day requires a traffic report. Before a full review of the proposal is conducted, a county officer uses a county-prepared checklist to establish whether the traffic analysis meets all requirements.

Similarly, the TIA will contain information regarding the proposed project, including factors that quantify traffic generators and a master plan with a detailed map that shows the site and the study area relative to other transportation systems.

In their TIAs, developers are required to show all roadways within a one-mile radius of the proposed development. They must also show all related projects within a one-and-a-half-mile radius of the proposed development. The roadways include arterials, highways, freeways, and intersections. Related projects include those that are pending, approved, recorded, or constructed.

Riverside County's TIS guideline for development proposals requires developers to conduct a detailed study on intersection analysis, average daily traffic (ADT), and all major streets within a five-mile radius of the project site only if the development proposal is expected to add 50 or more peak hour trips to the existing streets (Riverside County Department of Transportation, 2008). In conducting the TIA, the existing traffic count, the county's projection of the future volumes, and the cumulative impact of existing and approved projects must be considered. Projects under review but not yet approved must also be analyzed to determine the roadway's LOS and necessary improvements.

The city of Riverside's TIA guidelines require developers to provide appropriate transportation impact and mitigation information as a separate document (City of Riverside Public Works Department, 2009). City officials use the document to assess the impact of the proposed project. A TIA is required for a general plan amendment proposal, specific or subdivision development proposals or amendments, and any development that will have a significant impact on a transportation facility's LOS. In conducting the TIA, the cumulative impact of related, existing, and approved projects is considered. In addition, the applicant is to solicit Caltrans' input if the project is located within a one-mile radius of a state-controlled highway.

As stated earlier, in many cases there are discrepancies between the forecasted and the actual traffic. This is often because the cumulative effect of all approved, proposed, pending, and potential projects is not captured. In addition, there may be a gap between the TDM and TIS. In order to investigate this gap, the research team used the Activity-Based model, a method that is more detailed than the Four-Step approach.

Travel Demand Forecasting Models

Urban travel demand modeling is potentially useful in the analysis of urban transportation problems. Urban travel demand modeling provides tools to forecast urban travel patterns under various conditions. The predicted travel patterns provide useful information for planning the transportation system. Travel demand models can estimate how capacity will increase or how highway construction will affect congestion. Modeling involves a series of mathematical equations that represent how people make travel choices.

Travel demand forecasting models tell planners about future travel, shape transport plans and investments, and help them to make better decisions. The classical or traditional urban travel demand model is the Four-Step method, which was introduced in 1950s. This model has been used widely in urban transportation planning. Although it is a good practical model, the model has some shortcomings, especially in short-range planning. It has been observed that, instead of having improved traffic flow, existing and newly constructed roads become congested much faster than forecasted. It seems that current models are not forecasting the travel demand accurately. Thus, the efficiency of the Four-Step model is questionable in this context.

In past decades, travel demand forecasting focused on the effect of new transportation infrastructures, especially highways. Now, travel demand forecasting focuses on short-range planning, such as the impact of adding high occupancy vehicle lanes and inserting intelligent transportation system. As the focus has shifted from a capacity expansion mode to a system efficiency mode, models need to be responsive to such policies and sensitive to short-range planning.

The main characteristic of the Four-Step model is its compartmentalization of the various aspects of travel demand. Since travel demand is too complex to model simultaneously, the Four-Step model disaggregates the demand into several factors and then combines them sequentially. The Four-Step model's four procedures are Trip Generation, Trip Distribution, Mode Choice, and Traffic Assignment. The model's inputs are traffic analysis zones (TAZ), travel surveys, socio-economic and demographic data, and transportation network and land use data for the base and future years. The outputs of the Four-Step model are traffic volumes and travel times for each link in the transportation network. Each step of the Four-Step model is explained below.

Trip Generation

Trip Generation is the first phase in the Four-Step model. Trip Generation is the process of determining the number of trip productions and attractions associated with a given set of activities in a zone. With some variations, it is assumed that there are three types of trips or trip purposes: home-based work (HBW), home-based other (HBO), and non-home-based (NHB). Trips are assumed separate. There are two approaches to estimate the travel demand: aggregate level of zones and disaggregate level of households. The aggregate level of zones approach assumes that the number of trips is a function of zonal characteristics. The disaggregate level of households approach assumes that the number of trips is a function of a household's characteristics. Cross-classification techniques or linear regression can be used to generate trips.

The number of trips is assumed dependent on car ownership, household income, household size, residential density, distance from the central business district, and so on. After the trip productions and trip attractions have been estimated, the trips are balanced. The estimated number of trips produced at the household level should be equal to the number of trips attracted to the activity centers. Since there is a greater degree of confidence in the production models than in the attraction models, trip production totals are normally used as controls and attractions are scaled to productions.

Trip Distribution

The next step of travel demand estimation is Trip Distribution, which is the process of determining trip exchanges or the number of trips between each pair of zones. Trip Distribution uses the Trip Generation outputs and the transportation system characteristics to distribute trips among zones. Typically, there is no feedback between Trip Generation and Trip Distribution. Thus, Trip Generation is not affected by the attributes of travel destination, travel modes, or travel routes. Trip Distribution is performed separately for each origin zone.

The traditional approach to Trip Distribution is a gravity model that is adapted from Newton's gravitational law of matter. The number of trips produced in zone *i* and attracted to zone *j*, is related to the relative attractiveness of zone *j* to the summation of attractiveness of all zones.

$$T_{ij} = P_i \cdot \frac{K_{ij} A_j f(d_{ij})}{\sum_{all\ zones\ z} K_{iz} A_z f(d_{iz})} \quad \text{(Constrained to productions)}$$

$$T_{ij} = A_j \cdot \frac{K_{ij} P_i \cdot f(d_{ij})}{\sum_{all\ zones\ z} K_{zj} P_z f(d_{zj})} \quad \text{(Constrained to attractions)}$$

Equation 1: Trip Distribution Formulas

where,
T_{ij} = the number of trips produced in zone *i* and attracted to zone *j*

P_i = the number of trips produced by zone *i*

A_j = the number of trips attracted to zone *j*

$f(d_{ij})$ = the friction factor

d_{ij} = the impedance between zone *i* and zone *j*

K_{ij} = a specific zone-to-zone adjustment factor

The above formulas state that the percentage of trips produced by zone *i* and allocated to destination zone *j* is dependent on the production of zone *i*, attractiveness of zone *j*, and the travel time/cost between zone *i* and *j* relative to travel time/cost of zone *i* and other zones and travel time/cost of other zones to zone *j*. Thus, increasing the attractiveness of a zone (e.g., building a new shopping center) increases its relative pull on the trip productions and draws a greater proportion of these productions to itself.

The gravity model is based on the idea that trip end locations that are closer to each other have a stronger attraction than those that are farther apart. This traffic analysis zone (TAZ) proximity is referred to as impedance and can be indicated in terms of travel distance, travel time, or travel cost. This current project uses travel time as the impedance.

Mode Choice

The third stage in the Four-Step approach is called Mode Choice or Modal Split. The origin-destination volumes, T_{ij}, obtained in the Trip Distribution phase are now split into different modes. In studies related to U.S. transportation systems, the term Modal Split is used more often than Mode Choice because usually there is no choice in the decision of which mode to use. For example, those in a household with no car have no choice but to use transit and those in a suburban household may have no other choice than their car. Mode Choice is affected separately for each origin-destination pair. In general, logit models are used for Mode Choice. Mode Choice can be interpreted as the result of individual travelers' utility-maximizing choices.

Mode choice uses the output of Trip Distribution and the characteristics of the trips, the travelers, and the available mode choices, to make trip tables for each trip type and each trip mode. Typically, three major transportation modes (auto, carpool, and transit) are used with further nesting (walk to transit or drive to transit, etc.).

Traffic Assignment

The Four-Step model's last step is Traffic Assignment. Traffic Assignment is the process by which trips are allocated to a network's feasible routes. Traffic Assignment makes a relationship between the demand and supply of traffic. Using origin-destination (OD) matrices by trip type and by trip mode, Traffic Assignment loads the trips (vehicles) on the transportation network. Traffic Assignment is based on the assumption that travelers choose the route with minimum cost. The minimum cost routes are usually considered the ones with the shortest travel times, and the routes are determined by shortest path algorithms. The assignment uses a link performance function to calculate the travel time on each link. A link performance function gives the link travel time as a function of volumes on the link regardless of the time of day. All trips are loaded statically from origins to destinations regardless of the departure time.

There are various link performance functions in the literature: Bureau of Public Roads (BPR) and modified BPR, Davidson's, Chicago Area Transportation Study (CATS), and Toronto. In all of the functions, link travel time is a function of link volumes and, sometimes, link type.

There are different traffic assignment techniques, such as iterative, incremental, user equilibrium, and stochastic user equilibrium. User equilibrium assignment (static user equilibrium) is commonly used in the Four-Step model. A network attains static user equilibrium when no traveler can improve his or her travel time by unilaterally changing routes. User equilibrium relies on the following assumptions: each traveler uses the minimum travel time route, travelers have full information on link travel times, all individuals are identical in their behavior, and travelers consistently make the correct route choices. At user equilibrium, each origin-destination pair's travel time on all used paths is less than or equal to the travel time that would be experienced by a single vehicle on any unused path.

The purposes of traffic assignment are to test alternatives, to establish short-range priority programs for traffic flow improvements, to analyze the location of transportation facilities within a corridor, to provide input for other planning tools (such as air quality studies), and to study the effect of a traffic generator (such as stadium) on traffic flow.

Shortcomings of the Four-Step Model

As stated earlier, although the Four-Step model has been widely used for decades, it presents significant drawbacks. There is no elasticity between demand and supply in the Four-Step model. The model also fails to represent the supply side of transportation. This reduces the efficiency of the model; thus, the forecasting results might not be correct. By not including supply in demand, the model is biased toward the selection of car mode. Observations in the real world verify this shortcoming, because roads become congested much faster than predicted. This problem could be resolved by making the demand model sensitive to transportation supply.

In the Four-Step model, each step is treated serially and independently of the other steps, and the output of each step is passed to the next level. The traditional Four-Step model assumes a hierarchy of travel choices: travelers first decide whether to travel, a destination, a travel mode, and a route. By iterating the revision of the transportation impedance variables, the traditional approach can be modified. Thus, Trip Distribution, Mode Choice, and Traffic Assignment can be applied using consistent estimates of LOS variables. These variables are fed back from Traffic Assignment to the prior steps. The feedback strategy is superior to the sequential process because feedback provides trip-making forecasts and zone-to-zone impedances that are in closer agreement than if only a simple sequential process was used. However, there are some disadvantages to the feedback process. Due to the need for iterations, the models that use the feedback process require significantly more computational time than the traditional Four-Step model. In addition, the iterative strategy must be designed carefully to ensure that the iterations converge toward a stable final forecast.

Due to the lack of a feedback process, inter-relationships among travel decisions at various levels of hierarchy are not represented. Many travelers may consider alternative destinations and alternative modes simultaneously (e.g., use transit to shop in the central business district or drive to a suburban shopping center). Thus, the decision to stop at a store on the way home from work or to make a separate shopping trip later is not considered.

The conventional Four-Step model fails to allow for detailed investigation of policy options such as congestion and parking pricing, vehicle emissions, and time-of-day dimensions (which are needed to estimate congestion and vehicle emissions). Some other disadvantages of the model are discussed separately for each step.

Trip Generation considers individual trips and has no trip chaining. It causes underrepresentation of some types of trips. Trip Generation is performed using liner regression, which is a descriptive technique. Therefore, the complex nature of travelers' behavior is not considered.

One of the shortcomings of trip distribution is that the gravity model is not behavioral. Besides, factors other than travel time could be included in the model to distribute trips. Several researchers suggested utilization of logit models in Trip Distribution to include travelers' behavior. Oppenheim (1995) showed that Trip Distribution models of the gravity formulas are strictly equivalent to behavioral destination choice models.

The most problematic procedure in the Four-Step model is Traffic Assignment. The traditional Four-Step model is static and does not consider time of day. It loads all travelers regardless of their departure time. However, in reality travel rates vary by time of day. Modelers observed that trip rates vary in patterns that are consistently similar in all major urban areas. The Four-Step model assumes that the base year's observed patterns will persist in the future and it classifies trips into three periods: morning (AM) peak, evening (PM) peak, and off-peak periods. Such simplistic assumptions may no longer be adequate for large urban areas with significant traffic congestion.

Time-of-day modeling is an improvement to the traditional Four-Step model. Time-of-day modeling is usually applied after Traffic Assignment. Travel demand for each of the three periods is calculated by multiplying the daily (24-hour period) link volumes by the peak period factors. The peak period factors are obtained from observed traffic. Although time-of-day modeling improves the static problem of the Four-Step model, it does not completely address the problem. Dynamic traffic assignment appears to be one of the solutions for this issue.

In the real world, increasing congestion during the peak period causes peak spreading, which the Four-Step model does not consider. In peak spreading, travelers change their departure time to avoid long trips due to congestion. Because Four-Step models do not use trip departure times, route switching is the only way to avoid congestion in Traffic Assignment. Dynamic traffic assignment and the feedback process allow peak-period factoring.

As mentioned earlier, Traffic Assignment uses a link performance function to calculate link travel time. The link performance function originates from the familiar speed-flow relationship in traffic engineering. This concept was developed originally for long links and tunnels. When flow increases, speed decreases after an initial period of little change; when flow approaches capacity, the rate of deceleration increases. For practical reasons, this type of relationship is considered in terms of travel time per unit distance versus flow in traffic assignment. This travel time-flow or cost-flow relationship is called the link performance function.

The link performance function has disadvantages. The function is not sensitive to intersection delay and assumes that delay occurs on the links. Thus, the model is not reliable for arterial facilities with intersections, especially signalized intersections. The function assumes that the travel time on a link is independent of flows on the network's other links, which is not true for the congested networks. The function also does not consider queued vehicles in the traffic stream. Although the function accurately estimates travel times on non-congested links, it is unable to present a realistic estimation of travel time on links with volume greater than capacity.

A traffic simulator could resolve the aforementioned problems with the link performance function. The deficiencies of the link performance function were long known, but computers were incapable of simulating large-scale transportation networks until recently. Now that computers are more powerful and technologies are more efficient (e.g., parallel processing), it is possible to simulate large-scale networks.

Static assignment models assume that link flows and link trip times remain constant over the planning horizon. Thus, a matrix of steady state, origin-destination (OD) trip rates are assigned to the network links. Although static equilibrium models are adequate for long-range planning analyses, they fail to capture the essential features of short-range planning analysis. Dynamic traffic assignment could be an improvement, but it cannot be applied to the Four-Step model because the model is time invariant and does not have the structure to store trip departure times.

Enhancements to the Four-Step Model

Some researchers have modified the Four-Step model in order to improve its efficiency.

Mann (2001) proposed a small modification to the Four-Step model in order to yield more realistic traffic volumes on roadways adjacent to centroid connectors. The model, which is called b-node, has been utilized by VDOT for its regional, county, corridor, subarea, and intersection studies. It has been stated that the b-node model produces better and smoother traffic volumes than the regular Four-Step model. The b-node model reads a metropolitan planning organization model's zone-level, network trip table and performs a subzone, capacity-restrained traffic assignment. A zone centroid connector can have up to 12 connectors, and each connector's b-node becomes a subzone. The model allocates the zone trip table into subzones by land activity (when there is information on all land uses in the subzone) or equal weights. The network is then restructured (by renumbering zones or subzones and nodes) to prevent the nodes and subzones from overlapping and to justify up to 10,000 subzones.

For example, the b-node subzone level process was implemented for the entire suburban authority of Loudoun County, Virginia: the county was subdivided into 1,500 subzones from 145

MPO zones. The b-node model is useful because the modeler can effortlessly assign subzones by adding centroid connectors to the existing network. The one-square-mile zones are too large to yield accurate traffic assignments on major and collector roadways in urban and suburban areas. The model does not need many manual adjustments to its output.

The sequential approach of traditional Four-Step model suffers from inconsistency among the flow values in each step of the procedure. Recent research has tried to integrate traveler’s choice on the four steps simultaneously. Zhou et al. (2009) developed the combined travel demand model, which can integrate the different four steps using the random utility theory. Their model brings consistency to travel choice and includes some behavioral aspects in traditional Four-Step models. Yang and Chen (2009) developed a model to assess changes in system performance measures due to slight changes in the network.

Festa et al. (2006) enhanced travel demand forecasting with experimental sequential models for the simulation of trip chains to generate tours. They calibrated and validated behavioral random utility models to simulate the traveler decisional process. Kockelman and Krishnamurthy (2004) applied nested behavioral models for cost optimization and used Ray’s Identity for cost value. The resulting travel demand method featured numerous choice dimensions (e.g., trip generation and welfare measures) that considered all facets of traveler choice. They stated that the prediction results from calibrated model showed that the approach was a reliable alternative to the Four-Step model.

Activity-Based Travel Demand Modeling

Activity-Based modeling is a relatively new method that replicates the activity of all individuals in the network for a 24-hour period. The Four-Step model aggregates the trip generation process and finds the total number of trips produced by each development type in each traffic analysis zone. However, the Activity-Based model is disaggregate and finds trips for each traveler.

With microsimulation, the Activity-Based model addresses almost all of the aforementioned shortcomings in the Four-Step model. The Activity-Based model considers the interaction between demand and supply. The model is behavioral and considers individual information and behavior.

Goulias (2007) prepared a feasibility study of a new travel-demand model with a multi-phased, Activity-Based approach for the region covered by the Southern California Association of Governments (SCAG). This study outlined a six-phase model that included a pilot Activity-Based model whose performance would be compared to the current Four-Step model. The goal of this study was to create “a living map in GIS” through microsimulation of every person, household, and network in the SCAG region. It was hoped that the map would address policy issues, future sustainability, applicability of new research and technology methods, and operation of a dynamic planning environment.

According to McNally (2000), the themes that characterize the Activity-Based modeling framework are as follows:

- Travel derives from the demand to participate in an activity. Sequences or patterns of behavior are the basic unit of analysis.
- Household and activities influence travel behavior.
- Spatial, temporal, transportation, and interpersonal interdependencies constrain activity or travel behavior.
- Activity-Based approaches reflect the scheduling of activities in time and space.

Davidson et al. (2007) identified three distinct features that are not in the Four-Step model. First, the tour-based approach analyzes travel patterns in sets called tours. Tours are chain of trips that start and end at the base location (home or workplace). Second, the Activity-Based approach suggests that travel derives from the need to participate in an activity. This approach provides a list of activities pursued, available travel modes, and other activity analyses. Third, microsimulation techniques are applied at the disaggregate level of persons and households using socioeconomic and demographic information. This technique allows for a more realistic model outcome, and the output files resemble real travel/activity survey data.

TRB Special Report (2007) recommended that metropolitan planning organizations develop and implement new travel demand forecasting models, such as the Activity-Based model, that are more responsive to current issues. These issues included estimation of vehicle emissions; travel generated by new capacity, freight movement, and non-motorized trips; and assessment of alternative land use policies. This report also noted that the Four-Step model is not “behavioral in nature.” As a result, the Four-Step model is unable to represent the time chosen for travel, travelers’ responses to demand polices (e.g., toll roads, road pricing, and transit vouchers), non-motorized travel, time-specific traffic volumes and speeds, and freight and commercial vehicle movement. Each of the aforementioned items would benefit from the Activity-Based modeling approach.

VDOT (2009) documented that Activity-Based models require custom-made software (written in C, C++, Java, or Delphi) that can link to a conventional model application. The three major travel-demand modeling software vendors are Caliper (TransCAD), Citilabs (Cube), and PTV (VISUM). Caliper is developing a “complete suite” of advanced Activity-Based programs. However, the latest version of TransCAD (version 5.0) has two common components of Activity-Based models: a population synthesizer and a dynamic assignment routine. PTV has an aggregate tour-based model, but all advanced models in the United States use disaggregate Activity-Based models. Citilabs has developed an Activity-Based model in Cube Voyager, which can be applied to small and mid-sized cities.

Hobeika (2010) outlined the development of Transportation Analysis and Simulation System (TRANSIMS), an integrated travel demand modeling system. The Los Alamos National Laboratory developed the system, and the U.S. Department of Transportation and Environmental Protection Agency funded the effort. TRANSIMS was developed to replace the Four-Step travel demand model. TRANSIMS was designed to provide a microsimulation model that addressed legislative policy issues facing transportation planners, including sustainable development, the environmental impacts of proposed projects, and the emergence of intelligent transportation systems. TRANSIMS consists of a series of modules that produce synthetic households. The modules are the Population Synthesizer, the Activity Generator, the Route Planner, the Microsimulator, the Emission Estimator, and the Feedback module.

The principal investigator for the current study reviewed the dynamic traffic assignment models in some well-known computer packages. She described demand estimation, supply presentation, methods for computing dynamic user equilibria, and convergence among these packages with a concentration on TRANSIMS (Jeihani, 2007).

According to VDOT (2009), Activity-Based models are currently used by the New Hampshire Department of Transportation (since 1998), San Francisco County Transportation Authority (since 2001), Mid-Ohio Regional Planning Commission (since 2005), New York Metro Transportation Commission (since 2005), Tahoe Regional Planning Agency (since 2007), and Sacramento Area Council of Governments (since 2007). The Atlanta Regional Commission, Denver Regional Council of Governments, Portland Metro, Ohio Department of Transportation, Metropolitan Transportation Commission, and the Puget Sound Regional Council have Activity-Based models in development.

In a case study of El Paso, Texas, the TRANSIMS model was used to model the interaction between the demand and supply sides of transportation, with primary focus on Microsimulation and Emission modules (Rilett et al., 2003). Rilett et al. imported the OD matrix and network data from the Four-Step model and found that TRANSIMS essentially needs more input data and more sophisticated troubleshooting than the Four-Step model.

Kikuchi and Pilko (2004) studied the feasibility of applying TRANSIMS in Delaware and evaluated its performance. Lawe et al. (2009) documented the first implementation and calibration of the TRANSIMS model in a medium-sized MPO in Vermont. The current base travel-planning model was a Four-Step platform that had been calibrated for AM and PM peak hours separately. The model was a Track-1 implementation of TRANSIMS that used a standard trip table and took advantage of the Router and Microsimulator modules. The TransimsNet program was utilized to convert the initial PARAMICS network for use in TRANSIMS, but some enhancement was performed manually during the calibration process.

Sharif-Ullah et al. (2011) developed a TRANSIMS travel demand model for a small MPO in Illinois to investigate the functional requirements of this approach. The model, which was mainly a Track 1 implementation of TRANSIMS, included three basic steps, network conversion, trip table conversion, and feedback. The results were calibrated and validated. Network files were exported from the existing CUBE model package, and ArcGIS was employed to convert the coordination system and measurement units. TransimsNet, IntControl, and ArcNet utility programs were utilized to synthesize the network, create sign and signal control files, and create ArcView shape files, respectively. The outputs were edited to ensure the consistency of the TRANSIMS network. The six different auto trip tables used in the Four-Step model were utilized in the TRANSIMS Track 1 model.

The Activity Generator module of TRANSIMS requires the collection of household travel survey data to generalize the activity pattern to the population. One of the reasons that MPOs often do not use the TRANSIMS model is that travel surveys are expensive, time-consuming, and plagued by low response rates. Zhang and Mohammadian (2008) developed a methodology to facilitate household travel data transferability for local areas. Since their approach uses a data simulation tool, MPOs can avoid the high costs associated with data collection. The authors estimated that it costs $300,000 and $700,000 to survey a small and large MPO, respectively. The transportation planning community believed that trip rates are transferrable but trip lengths are not. The results of the Zhang and Mohammadian's investigation demonstrated that both trip rate and trip length are transferrable.

The PI of the current study made some enhancements to TRANSIMS. She developed a new heuristic algorithm to determine dynamic user equilibria, implemented the method into TRANSIMS, and applied the model to networks in Blacksburg, Virginia, and Portland, Oregon (Jeihani, 2004; Jeihani et al., 2006). Dixon et al. (2007) compared TRANSIMS estimates of intersection delay to the field data, and the study concluded that TRANSIMS delay estimates for signalized intersections are very close to the real-world observations, but overestimate unsignalized intersection delays. Hobeika and Paradkar (2004) researched the use of travel time pattern (rather than activity time pattern) to match the survey data with the synthetic population data. Their approach was based on the assumption that people of similar demographics are more likely to have similar travel times than similar activity-time styles. They believed that activity time patterns are almost the same for all households, and that the patterns do not have enough variation to make a perfect classification and regression tree. Therefore, they used a travel time pattern to make the classification and regression tree.

METHODOLOGY

SHA staff selected the two study areas. The research team developed four models in order to find the best Four-Step TDM model, to analyze the differences between TIS and TDM models, and to conduct a CTIS. The four models were developed, calibrated, and validated for the year 2005. The models were run for three periods, average daily traffic (ADT), AM peak, and PM peak. Then, the calibrated models were used to forecast traffic in the years 2010, 2020, and 2030. In total, the research team developed and ran the models 72 times.

The 2010 traffic counts from the SHA website were compared to the four models' forecast results. The best model was the one whose forecasted 2010 link volumes were closest to the ground counts. The best model was used for the CTIS study.

The research team also developed an Activity-Based model for one of the study areas in order to learn the feasibility of applying it to regional or statewide models. The Activity-Based model was developed in TRANSIMS.

Forming Case Studies

The selected case studies were Maryland Route 175 (MD 175) and Maryland Route 202 (MD 202) located in central Maryland. Maps of the corridors are shown in Figures 1-6. MD 175 and MD 202 were selected by SHA because of the many developments that have been constructed, approved, or proposed in the study area recently. The case studies will identify and quantify the cumulative effect of these developments.

Figure 1: MD 175 Corridor

MD 175 is a 17-mile, east-west road. It begins in Anne Arundel County at MD 3 (Annapolis Road in Millersville), goes westward as a two-lane highway, becomes a four-lane highway in Odenton, continues into Howard County, and ends in Columbia at the US 29 interchange. Due to the increasing development in the Fort Meade area, there are plans to widen the road between MD 170 in Odenton and the Baltimore-Washington Parkway (MD 295) in Jessup by the year 2020.

The MD 175 study area includes MD 175 from Odenton to Race Road (Figure 2). Figure 3 presents the major developments (Fort Meade, Odenton Town Center, and Enhanced Use Leasing (EUL) Program site) in the study area.

Figure 2: MD 175 Study Area

Figure 3: Major Developments in the MD 175 Study Area

MD 202 is a north-south highway in Prince George's County. It begins (as two-lane Largo Road) at an intersection with MD 725 in Upper Marlboro. Figure 4 presents the corridor, and Figures 5 and 6 detail the study area. The boundary is specified in Figure 5.

Figure 4: MD 202 Corridor

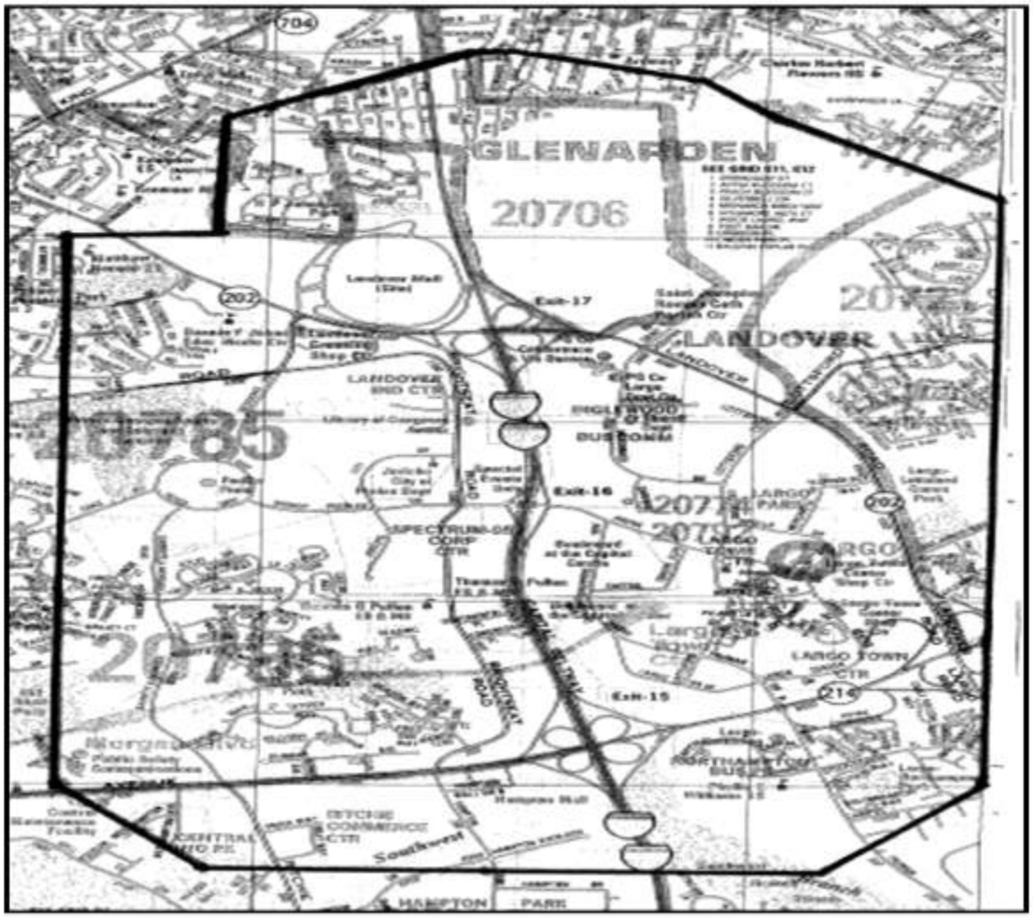

Figure 5: The Boundary of MD 202 Study Area

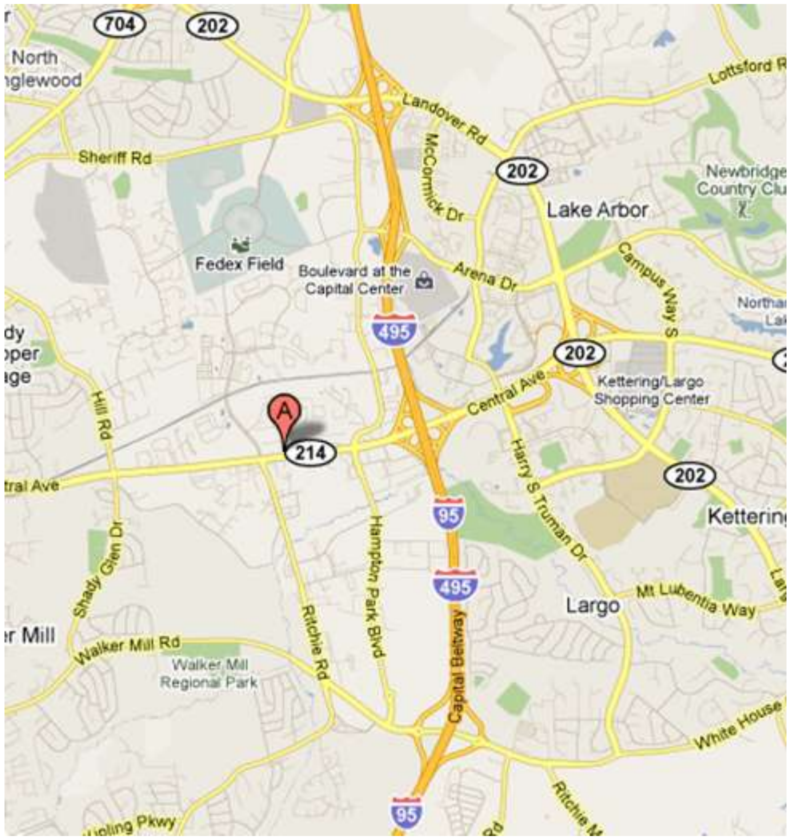

Figure 6: MD 202 Study Area

The five developed models are explained next.

The Base Model

The base model's development for the MD 175 study area was based on the Baltimore Metropolitan Council (BMC) model. The Metropolitan Washington Council of Governments (MWCOG) model was used for the MD 202 study area. The research team created the modified Four-Step model for the two study areas for ADT and AM and PM peak hours. The model was calibrated and validated using the 2005 traffic counts.

The MD 175 and MD 202 models, which were created with TransCAD software, were based on the Four-Step, transportation-planning model. Since the study concentrates on automobile trips, the research team did not use the Mode Choice module. Therefore, the model uses only three steps: Trip Generation, Trip Distribution, and Traffic Assignment.

Trip Generation uses socioeconomic data to calculate trip ends at the TAZ level. These trip ends are then paired to origins and destinations in the distribution module. Vehicle trips are assigned to the highway network in the Assignment module. The model includes a feedback loop between assignment and Trip Distribution in order to reach a convergent solution. The model structure is presented in Figure 7.

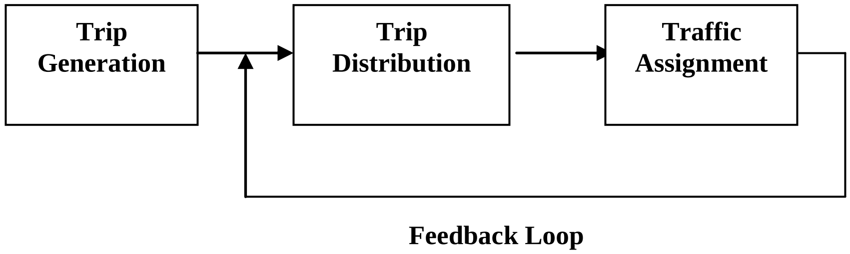

Figure 7: Model Structure

MD 175 Base Model

The BMC regional highway network, which includes 2,928 TAZs, was used to create the MD 175 network. As presented in Figure 8, there are 28 TAZs and 263 links in the MD 175 study area. Thirteen of the 28 TAZs are external (i.e., outside the study area). All of the trips outside the study area are assumed to traverse one of these TAZs to enter the study area.

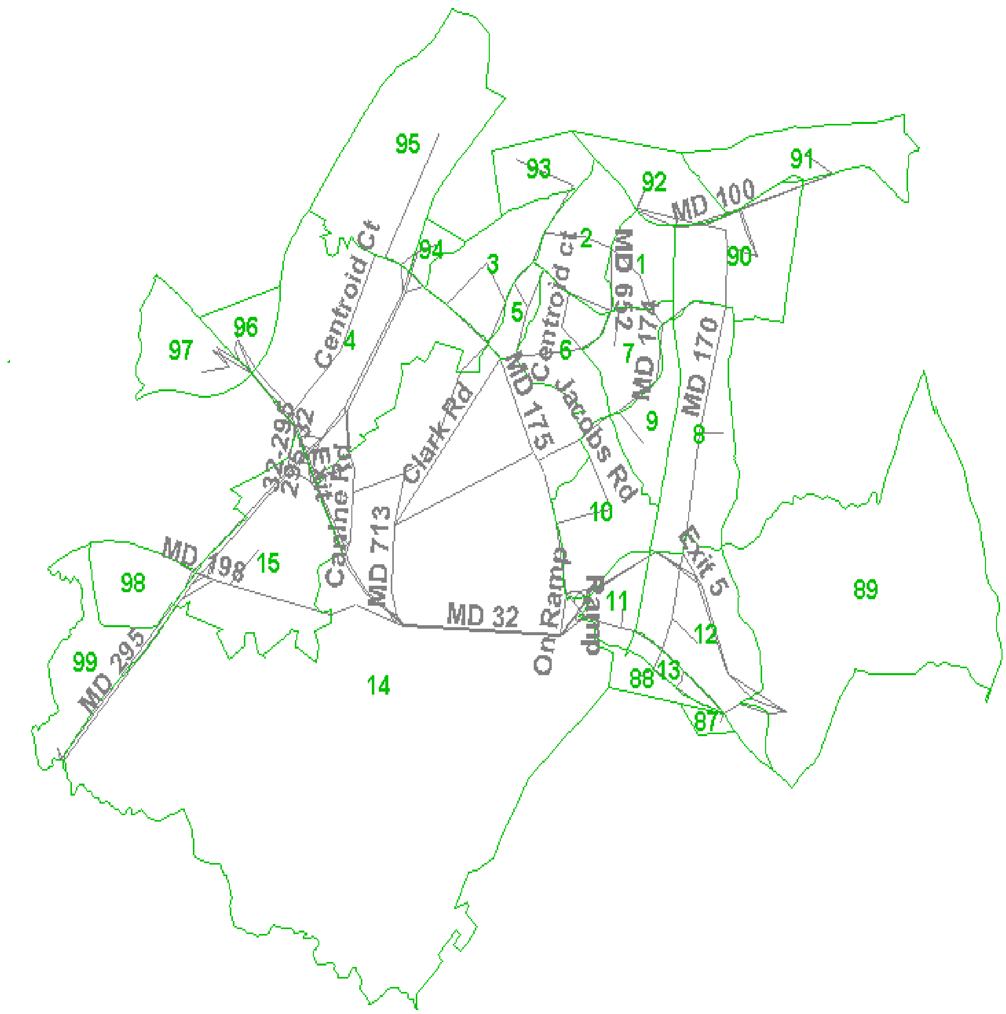

Figure 8: TAZs and Links in MD 175 Study Area

MD 202 Base Model

The loaded MWCOG model, with its 2,191 TAZs, provided the basis for the MD 202 model. As presented in Figure 9, the MD 202 study area includes 24 TAZs (nine internal and 15 external; TAZ=70-84) and 193 links.

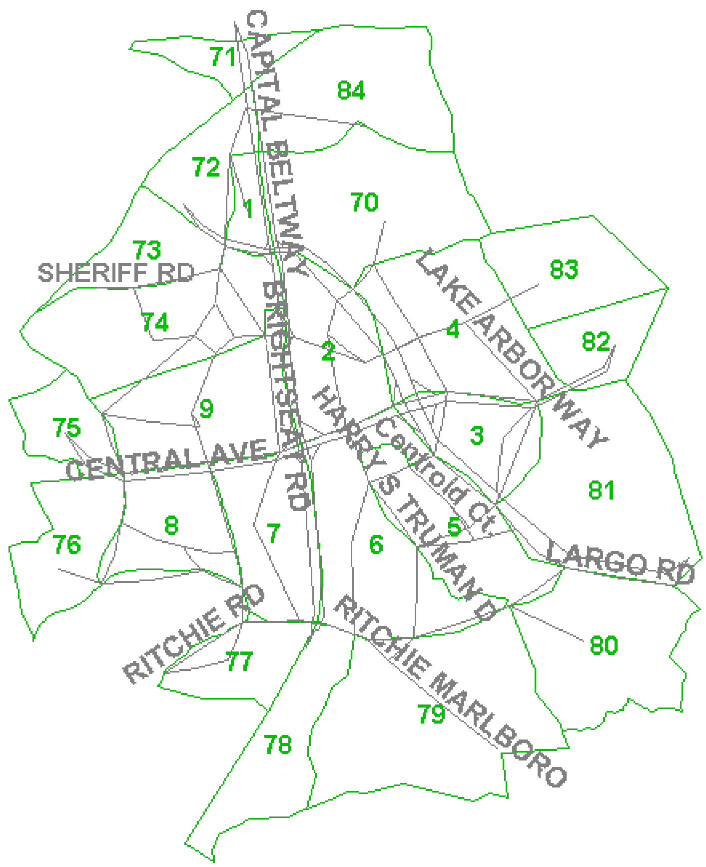

Figure 9: TAZs and Links in the MD 202 Study Area

Trip Generation

The Trip Generation module estimates person trips originating from and destined for each TAZ in the model. These estimates result from the TransCAD Quick Response Method (QRM) Trip Generation procedure. The procedure inputs the socioeconomic data, network, and TAZ structures into production and attraction models. Trip productions are estimated using cross-classification methods, with the classification based on household characteristics. Trip attractions are estimated from a regression equation based on retail employment, non-retail employment, and dwelling units.

The socio-economic data includes population, employment, retail employment, non-retail employment, and households for each TAZ. The research team retrieved the 2005 socio-economic data from the BMC and MWCOG models. The procedure's output is a binary file containing the trip productions and attractions for each TAZ by trip purpose. Tables 1 and 2 summarize the estimated person trips for the MD 175 and MD 202 study areas by trip purpose.

Trip Purpose	Productions	Attractions
HBW	884467	884467
HBNW	129297	129297
NHB	52172	52172

Table 1: The Estimated Number of Trips by Trip Purpose for MD 175 Base Model

Trip Type	Productions	Attractions
HBW	414,731	414,731
HBNW	55,039	55,039
NHB	21,404	21.404

Table 2: The Estimated Number of Trips by Trip Purpose for MD 202 Base Model

Trip Distribution

The Trip Distribution module uses the doubly constrained gravity model with K-factors to predict the number of trips between each TAZ pair for each trip purpose.

The Trip Distribution module's input is the production-attraction (PA) table and an impedance matrix. The PA table is the Trip Generation output (as explained above). The impedance matrix includes auto travel times between zones, intrazonal times, and terminal times. Travel time is free-flow travel time in the first iteration and is the travel time estimated by Traffic Assignment in other iterations. Intrazonal time is a direct input per zone, and terminal time is the time assumed between leaving the location and starting the trip. Terminal time was assumed two minutes for internal trips and ten minutes for external trips. The following formula was used to create a friction factor matrix for each trip purpose. The coefficients are different for each trip purpose.

$$f(d_{ij}) = e^{(C_1 + C_2 . d_{ij} + C_3 . \ln(d_{ij}))}$$

Equation 2: Friction Factor

where,
$f(d_{ij})$ = the friction factor between zone i and zone j
d_{ij} = the impedance between zone i and zone j
C_{1-3} = constants calibrated for each trip type

The module's output was zone-to-zone person trips by trip purpose. The Trip Distribution's output was three matrices of the number of trips between zones for each trip purpose.

Traffic Assignment

The Traffic Assignment module estimates traffic flow on each of the network's roads (links). The module's input is a flow matrix that indicates the traffic volume between each origin and destination (OD) zone. The OD flow matrix is calculated by changing person trips to vehicle trips for each trip purpose, converting daily trips to peak hour trips, and aggregating zone-to-zone person trips by trip purpose (the three Trip Distribution output matrices). In other words, Traffic Assignment makes three OD matrices: ADT, AM peak, and PM peak hour. To calculate the AM and PM peak hour, the research team multiplied the AM peak period (6:00 to 9:00) and PM peak period (16:00 to19:00) by 0.4 and 0.38, respectively.

Each OD flow is loaded into the network links based on each route's travel cost. The travel cost is a combination of travel time and distance, and each route is a set of links that connects the origin and destination. The user equilibrium model, which assigns the calculated OD flow matrix to the network, uses an iterative process to achieve a convergent solution in which no travelers can improve their travel times by switching to another route. In the first iteration, the network is empty and link travel times are free-flow travel times. Link volumes are updated in each iteration, and link travel times are re-calculated based on the following Bureau of Public Roads (BPR) volume delay function.

$$t = t_f [1 + \alpha (\frac{V}{C})^{\beta}]$$

Equation 3: BPR Volume Delay Function

where,
t= congested link travel time
t_f= link free-flow travel time
V= link volume
C= link capacity
α, β= calibration parameters

The default value for α, β parameters are 0.15 and 4, respectively. The Traffic Assignment module's outputs are the link volumes, link travel times, and link speeds.

Feedback Loop, Calibration, and Validation

The Traffic Assignment module's outputs become the inputs for the Trip Distribution module, and a new pairing of origin and destination zones is performed for each trip type. This iteration was performed three times in this project. The first iteration used free-flow travel time for each link, assuming that there were no cars on the link; other iterations used the congested travel time obtained from the Traffic Assignment module. Therefore, the origin-destination paring in Trip Distribution was more realistic.

Model calibration is the process of developing mathematical functions and the associated coefficients or parameters. Model validation is the process of comparing model output with observed data to assess the model's performance. If the analyst finds that the model output and the observed data agree, the model is validated. Validation is an iterative process. The research team repeated the calibration several times before an acceptable validation was achieved. Ground counts were obtained for approximately 50 percent of the links in the MD 175 study area (158 counts out of 327 links) and for approximately 30 percent of the links in the MD 202 study area (59 counts out of 193 links). Individual link errors were calculated by subtracting the estimated model volume from the link's ground count.

The model was calibrated and validated according to the Federal Highway Administration's standards in order to reasonably represent reality (Ismart, 1990).The following statistics were used to measure the calibration.

$$r = \frac{\sum (x.y) - n\bar{x}\bar{y}}{\sqrt{(\sum (x^2) - n\bar{x}^2)(\sum (y^2) - n\bar{y}^2)}}$$

$$RMSE = \frac{\sqrt{\frac{\sum [(x-y)^2]}{n}}}{\frac{\sum x}{n}} ee$$

$$AE = \frac{\sum |y - x|}{\sum x} \times 100\%$$

Equation 4: Calibration Formulas

where,
r= correlation coefficient
RMSE= root mean square error
X= ground count
Y= calibration volume
N= number of observations
AE= Absolute Error

Tables 3-8 compare the FHWA guidelines and the calibrated AM, PM, and ADT models.

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.95
Percent error regionwide	5%	-4.8%
Sum of differences by functional class		
Freeway	7%	-2.8%
Principal Arterial	10%	-6.7%
Minor Arterial	15%	-13.47%
Collector	25%	

Vehicle miles travelled (VMT): 189660.7
Vehicle hours travelled (VHT): 4706

Table 3: AM Peak Hour Calibration for MD 175

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.92
Percent error regionwide	5%	-2.3%
Sum of differences by functional class		
Freeway	7%	-3.6%
Principal Arterial	10%	2.9%
Minor Arterial	15%	-9.8%
Collector	25%	

VMT: 198279
VHT: 4965.9

Table 4: PM Peak Hour Calibration for MD 175

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.93
Percent error regionwide	5%	-4.4%
Sum of differences by functional class		
Freeway	7%	-5.5%
Principal Arterial	10%	-11.4%
Minor Arterial	15%	12.7%
Collector	25%	

VMT: 2067222.9
VHT: 46159.1

Table 5: Calibration for MD 175 ADT Model

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.98
Percent error regionwide	5%	3.98%
Sum of differences by functional class		
Freeway	7%	-2.6%
Principal Arterial	10%	4.9%
Minor Arterial	15%	-.44%
Collector	25%	.16%

VMT: 191063
VHT: 6694.8

Table 6: AM Peak Hour Calibration for MD 202

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.95
Percent error regionwide	5%	3.08%
Sum of differences by functional class		
Freeway	7%	3.5%
Principal Arterial	10%	-1.4%
Minor Arterial	15%	-11.6%
Collector	25%	-11.7%

VMT: 190949
VHT: 6693

Table 7: PM Peak Hour Calibration for MD 202

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.97
Percent error regionwide	5%	1.14%
Sum of differences by functional class		
Freeway	7%	-1.5%
Principal Arterial	10%	-18.1%
Minor Arterial	15%	62.5%
Collector	25%	30.7%

VMT: 1899783
VHT: 43820.9

Table 8: Calibration for MD 202 ADT Model

The Detailed Network

The detailed network model includes all local streets and development driveways in order to represent realistic traffic patterns. The research team added centroid connectors for each TAZ. The Four-Step model assumes that all vehicles originate from the zone centroids and use imaginary links (centroid connectors) to connect to the highway network. The detailed network model shares the assumption; however, it includes the local roads and distributes vehicles among them.

The research team applied the calibrated base model parameters to the detailed network for both case studies. Many local roads had zero volume because other routes were shorter than the ones using the local roads from each zone's centroid. The detailed network model might be more suitable for the b-node and Sub-TAZ models because each group of local roads added in the detailed network could connect to a local centroid constructed in b-node. Figures 10 and 11 present the detailed networks for MD 175 and MD 202.

Figure 10: The Detailed Network for MD 175 Study Area

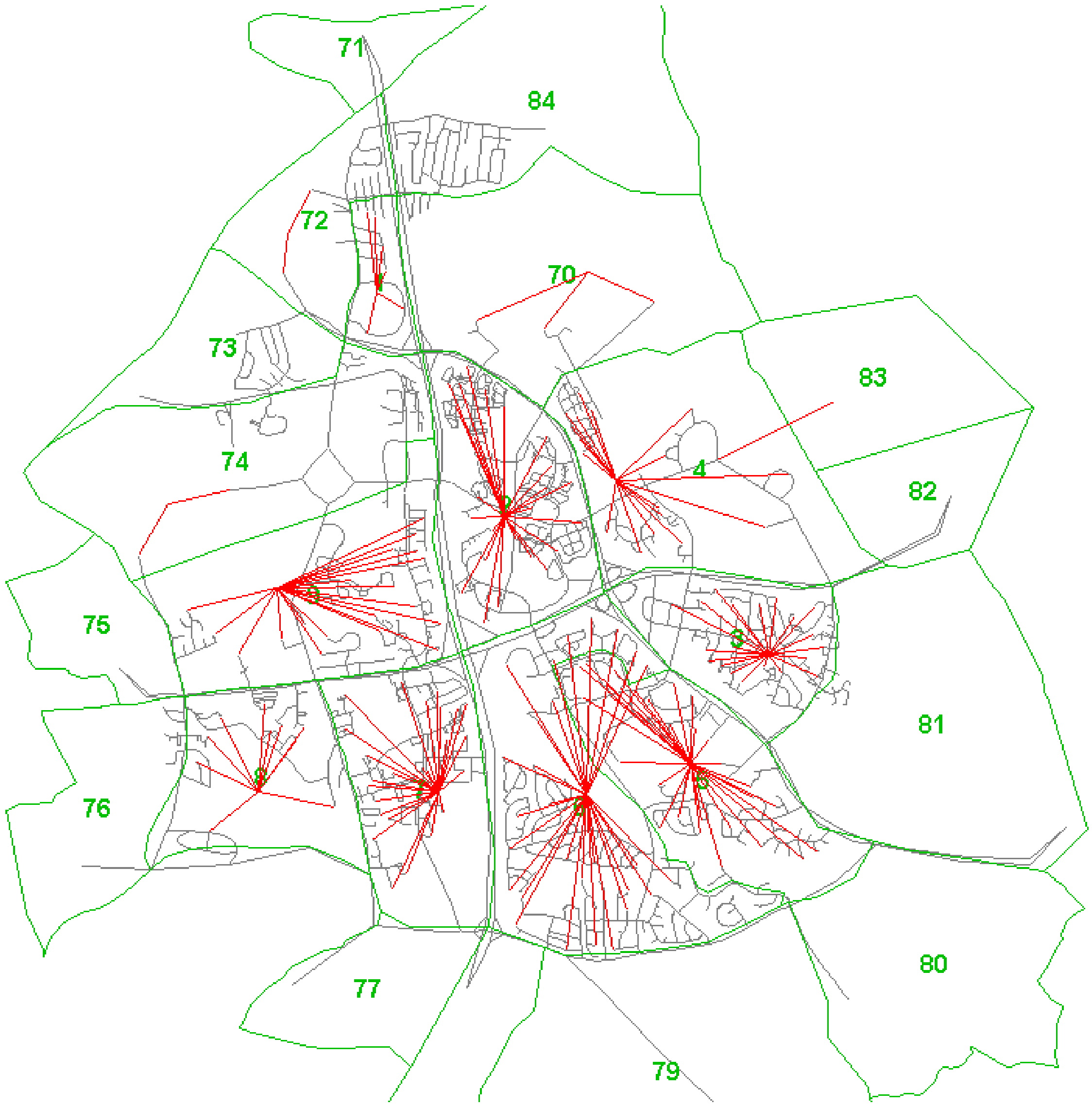

Figure 11: The Detailed Network for MD 202 Study Area

The B-Node Model

The b-node model was based on the VDOT model that was explained on page 16. The b-node model divides the TAZs into several subzones only in the Traffic Assignment step. The model distributes vehicles from and to each Sub-TAZ (rather than each TAZ) in order to reduce congestion on the centroid connectors and on the network's main roads. The b-node was applied to the base and detailed networks for the case studies. Figures 12-14 demonstrate the b-node networks.

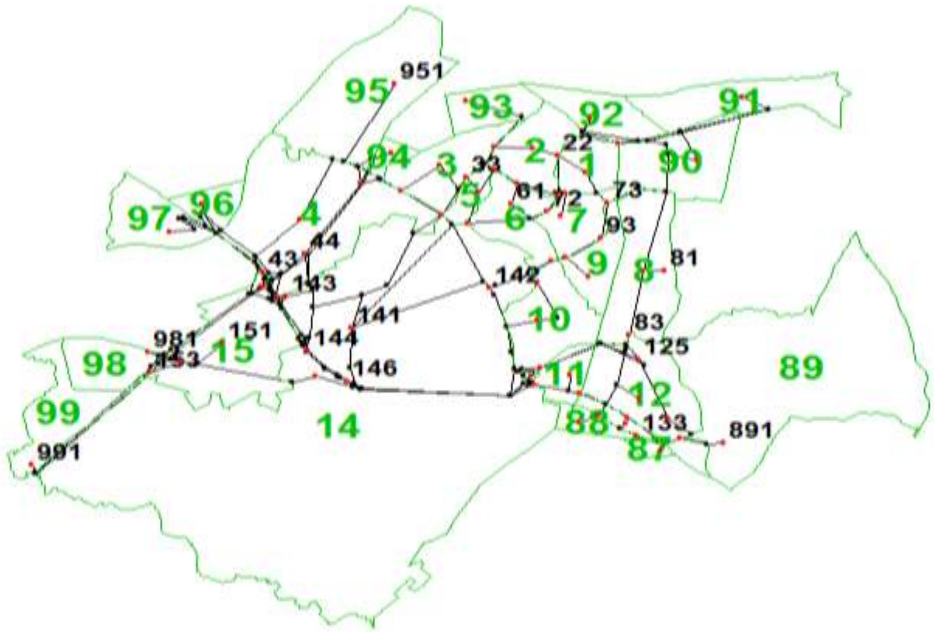

Figure 12: The B-Node for MD 175 Base Network

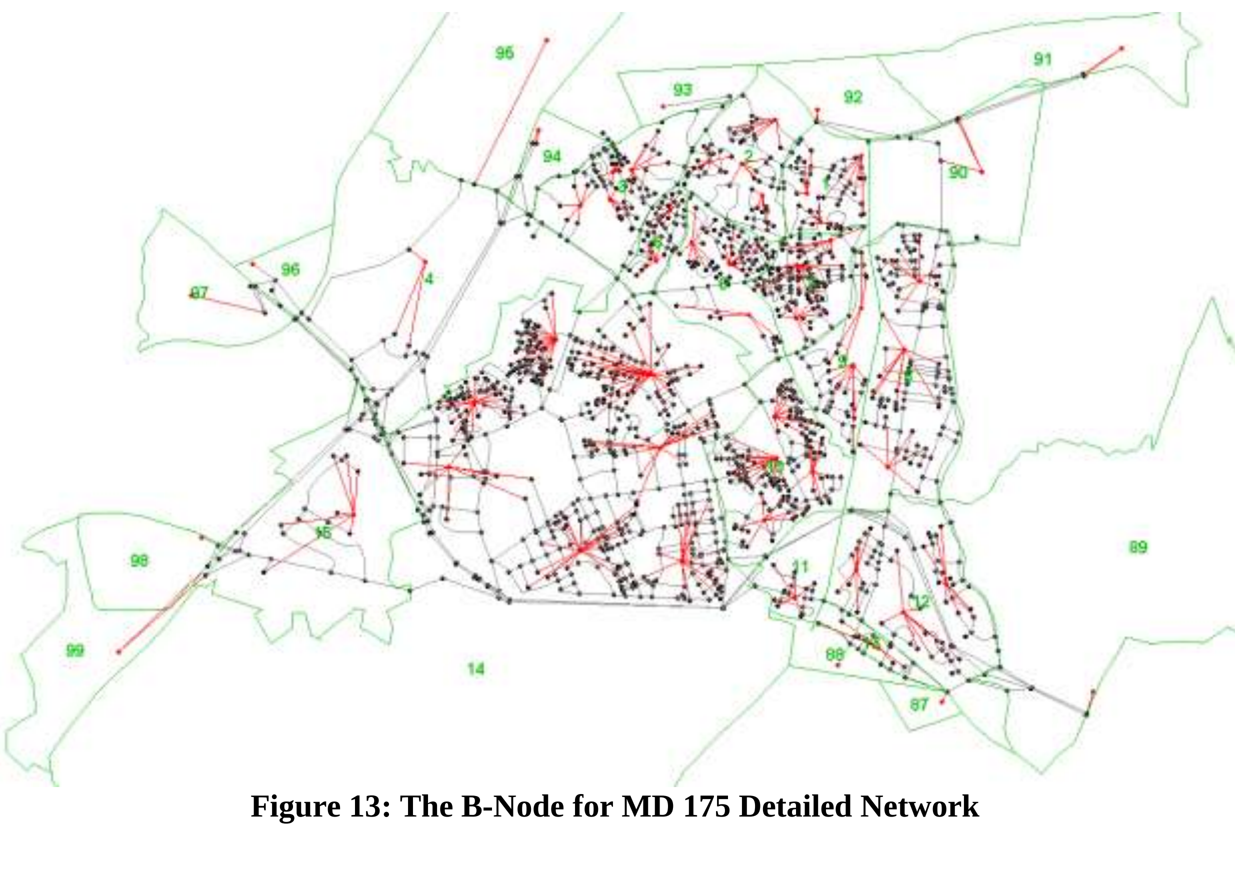

Figure 13: The B-Node for MD 175 Detailed Network

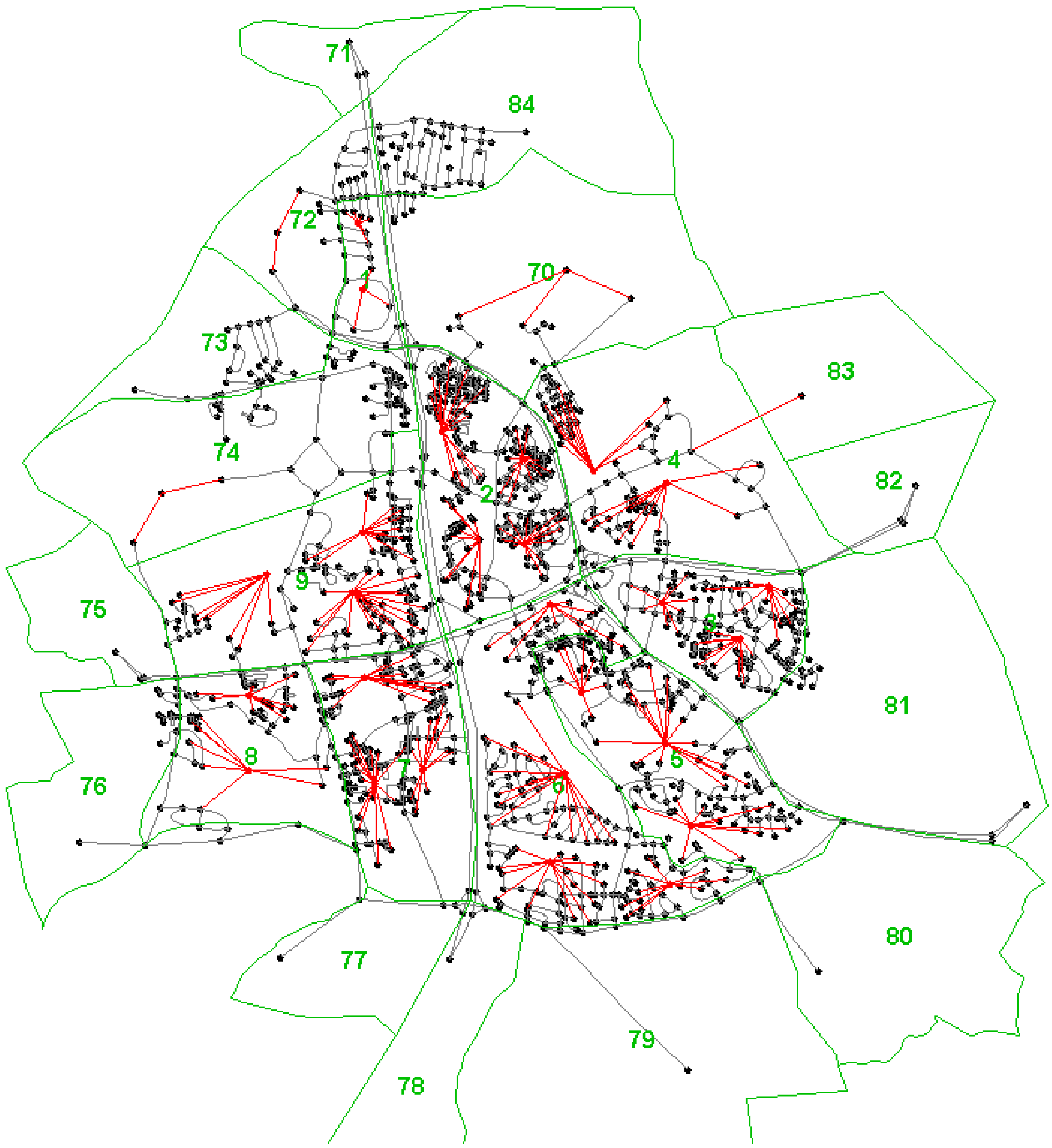

Figure 14: The B-Node for MD 202 Detailed Network

The Sub-TAZ Model

The Sub-TAZ model divides each TAZ into several subzones to capture more internal trips. It is very similar to the b-node model, which divides the OD trips and assumes that zones are divided into smaller zones in the last step of the Four-Step model. However, the Sub-TAZ model divides the zones into smaller zones (called subzones) at the beginning of the process. Therefore, the output of the Trip Generation procedure is divided into the number of subzones in each zone and the rest of the steps use the extended matrices. There are 28 zones in the MD 175 Base model and 55 zones in the Sub-TAZ model. Figures 15 and 16 present the Sub-TAZ networks for MD

175 and MD 202, respectively. For example, zone 2 in MD 175 was divided into four zones: 21, 22, 23, and 24. Table 9 compares the TAZ numbers in the Base and the Sub-TAZ models. As presented in Tables 10-12, the Sub-TAZ model was developed, calibrated, and validated for AM peak, PM peak, and ADT.

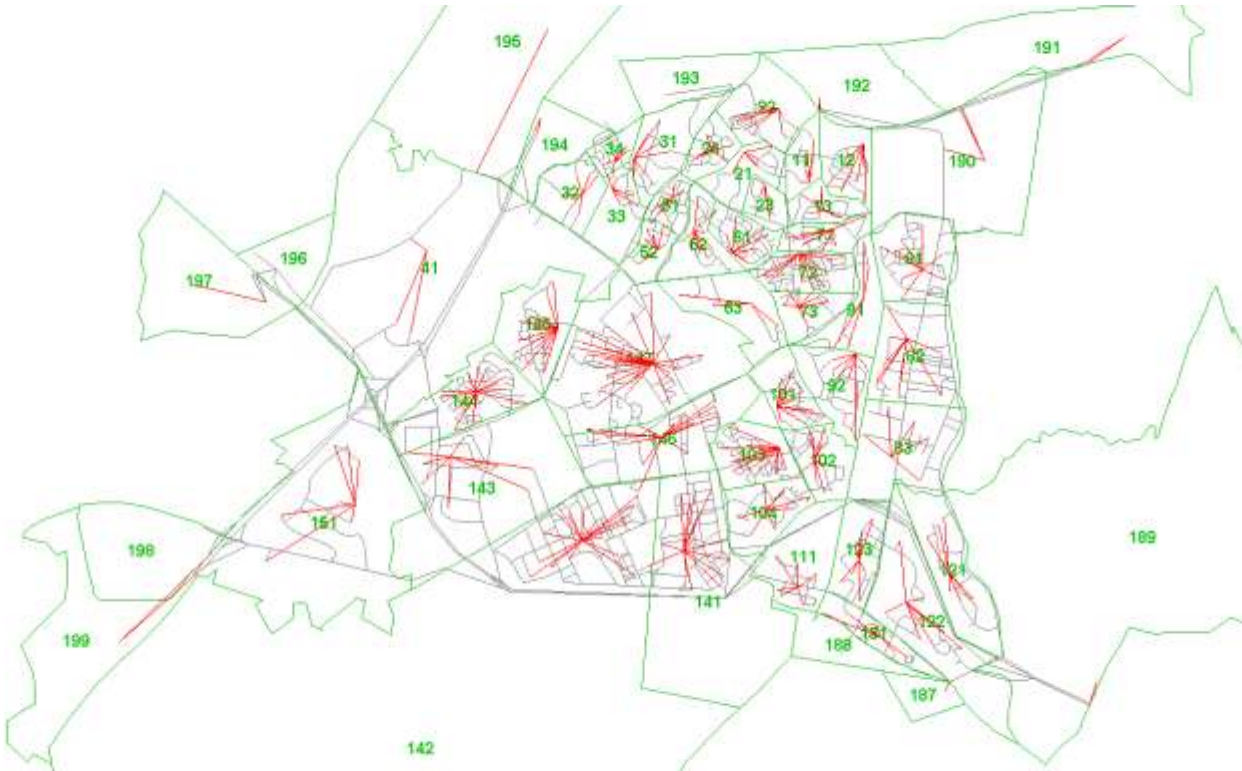

Figure 15: The Sub-TAZ Network for MD 175

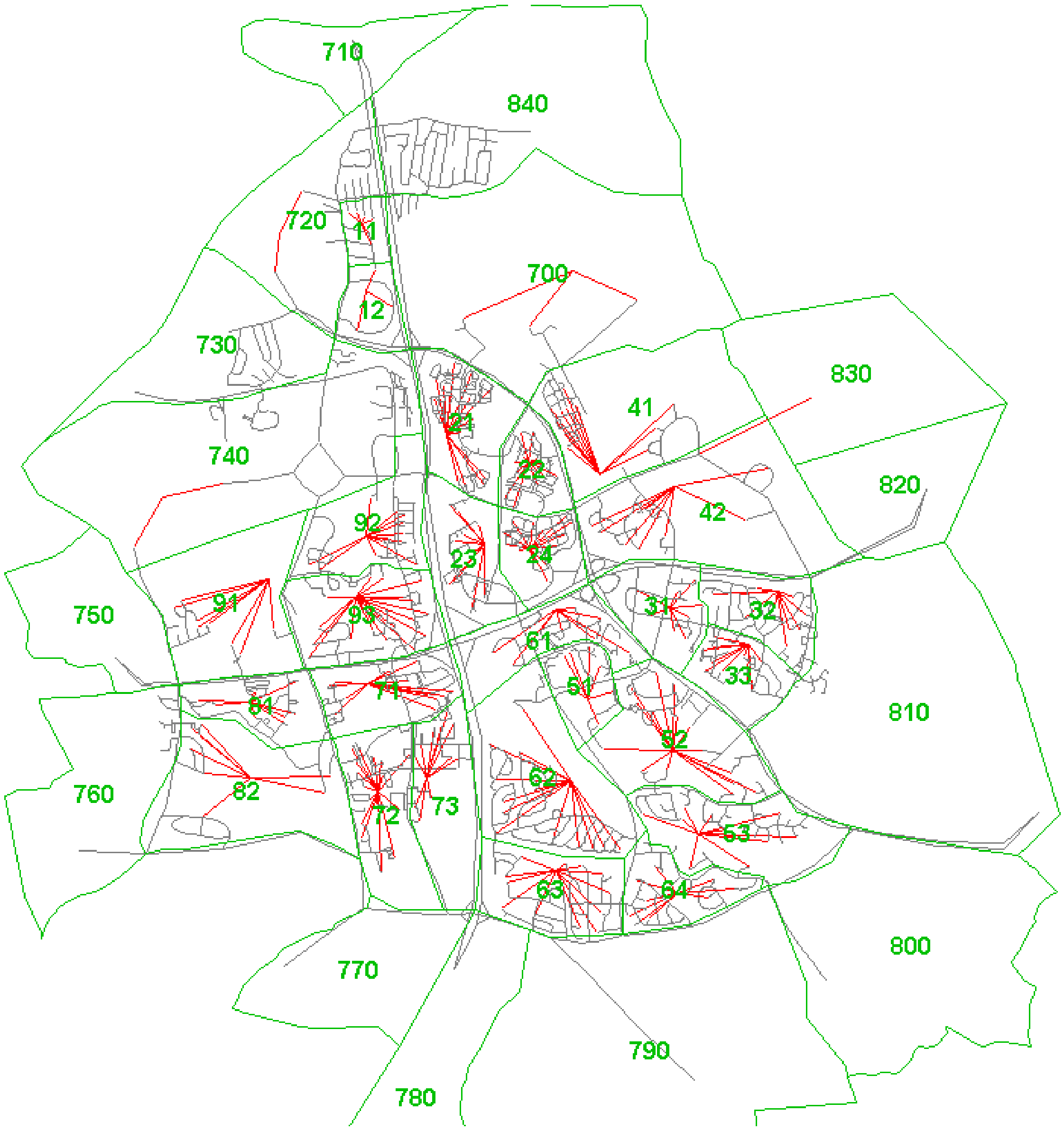

Figure 16: The Sub-TAZ Network for MD 202

Base	Sub-TAZ
1	11
	12
	13
2	21
	22
	23
	24
3	31
	32
	33
	34
4	41
5	51
	52
6	61
	62
	63
7	71
	72
	73
8	81
	82
	83
9	91
	92
10	101
	102
	103
	104
11	111
12	121
	122
	123
13	131
14	141
	142
	143
	144
	145
	146
	147
15	151
87	187
88	188
89	189
90	190
91	191
92	192
93	193
94	194
95	195
96	196
97	197
98	198
99	199

Table 9: A Comparison of the TAZ Numbers in the Base and Sub-TAZ Models

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.96
Percent error regionwide	5%	7.4%
Sum of differences by functional class		
Freeway	7%	0.91%
Principal Arterial	10%	19.7%
Minor Arterial	15%	16.0%
Collector	25%	19.8%

VMT: 206520.8
VHT: 7706

Table 10: AM Peak Hour Calibration for Sub-TAZ Model, MD 175

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.96
Percent error regionwide	5%	4.8%
Sum of differences by functional class		
Freeway	7%	4.4%
Principal Arterial	10%	
Minor Arterial	15%	11.0%
Collector	25%	16.0%

VMT: 205404.6
VHT: 6118.4

Table 11: PM Peak Hour Calibration for Sub-TAZ Model, MD 175

	FHWA Guideline	Model
Correlation Coefficient	0.88	0.92
Percent error regionwide	5%	5.8%
Sum of differences by functional class		
Freeway	7%	-1.7%
Principal Arterial	10%	0.2%
Minor Arterial	15%	24.4%
Collector	25%	-5.4%

VMT: 205404.6
VHT: 6118.4

Table 12: Calibration for Sub-TAZ Model, MD 175 ADT Model

The Activity-Based Model

The Activity-Based model, which is based on travelers' activities and includes all local roads and driveways, was created in TRANSIMS. The Activity-Based model developed by the research team is based on the results of national and regional activity surveys.

TRANSIMS is based on individual behavior and interactions. It traces and simulates the movements of each individual in a fully described network as he or she accomplishes tasks in a 24-hour period. TRANSIMS also collects statistics on traffic, congestion, and pollution. Figure 17 presents a schematic view of TRANSIMS (Hobeika, 2010).

TRANSIMS is more data intensive than TransCAD TDM. Therefore, only the MD 175 study area was coded in TRANSIMS. The research team developed three different models in TRANSIMS: Activity-Based, Trip-Based, and Hybrid.

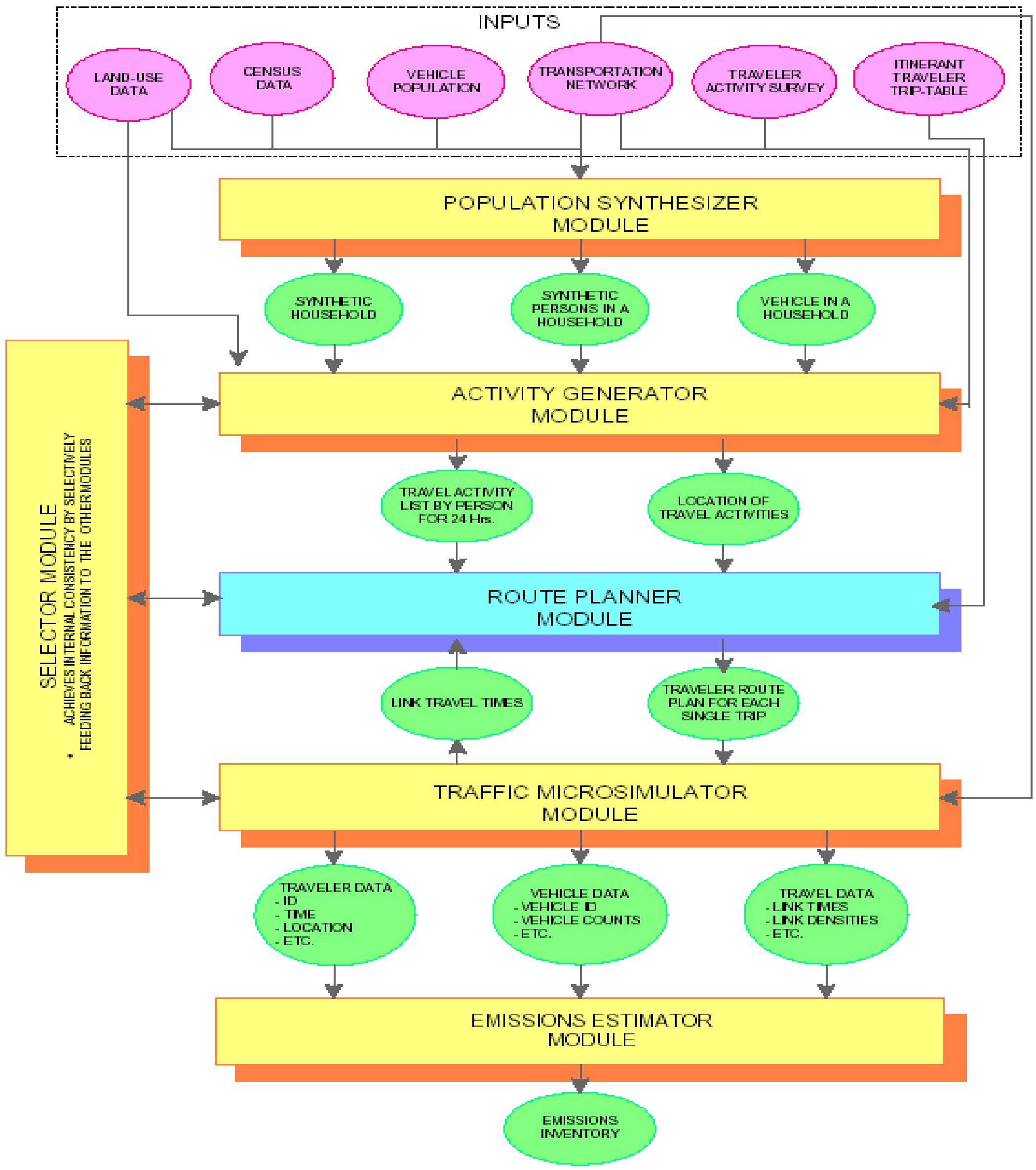

Figure 17: TRANSIMS Framework

The household activity survey was adopted from the national household activity survey. The land use data was acquired from the Four-Step model (TransCAD). Because the Activity-Based model does not replicate external trips, the link volumes only represent internal trips. The research team applied the Activity-Based model to only the MD 175 study area. Since the study area was small and external trips were the major source of traffic volumes, this model underestimated the link volumes.

Trip-Based Model

The Trip-Based model was based on OD trips, not individual activities. The OD matrices from the base model were utilized to make this model. TRANSIMS' Trip-Based model has been used by several researchers and practitioners and is called Track 1. Although this model is not Activity-Based, it can be considered a dynamic Four-Step model. The Trip-Based model breaks the OD trip matrices into different times of day, and uses the time-dependent shortest path (Route Planner) to load the trips on the network. It also simulates network traffic. Since the Trip-Based model is dynamic and uses a Microsimulator, it addresses the problems in the Four-Step model's Assignment step (page 14).

The Trip-Based model does not use the Population Synthesizer or the Activity Generator. The OD matrices are converted and used as an input to the Route Planner. Diurnal distribution and ConvertTrip were conducted to distribute the OD matrices into different times of day (e.g., one-hour periods). Diurnal distribution is a table that specifies the percentage of trips in each period. The ConvertTrip module randomly assigns an exact start time to all trips within each period defined in the diurnal distribution, and allocates activity locations within the corresponding zones.

Hybrid Model

The Hybrid model combines the Trip-Based and Activity-Based models. The Activity-Based model is suitable for internal trips and the Trip-Based model is suitable for external trips. Therefore, the Hybrid model has the advantages of the Activity-Based model and calculates the external trips with the external zones' OD matrices. This model has yet to be adopted by any researcher or practitioner. In all three models, the interaction between demand and supply occurs in the Microsimulator.

Implementation of the Different Models in TRANSIMS

In order to implement the Activity-Based and Trip-Based models for the MD 175 study area in TRANSIMS, the research team wrote scripts to prepare the data and to run different modules.

Network Preparation and Conversion

The network is TRANSIMS' major input. As in the Four-Step model, nodes and links are the major network data. However, TRANSIMS requires the following study area details:

- number of lanes
- turn pockets and merge lanes
- lane-use restrictions
- high-occupancy-vehicle lanes
- turn prohibitions
- speed limits on each link of the network
- location and type of signalized intersections

The research team converted the TransCAD network for use in TRANSIMS. Because data entry for TRANSIMS can be very time consuming, TRANSIMS' developers generated utility programs.

The research team exported three layers of highway (link), endpoint (node), and TAZ from TRANSCAD to shape files. The conversion was performed in the appropriate coordinate system for the study area, which is UTM_Zone_18N (GRS 1980). TRANSIMS measures link length in meters and speed in meters per second, but TransCAD uses miles and miles per hour. Therefore, the research team performed a unit conversion. The shape files of the TransCAD network were converted to TRANSIMS format using GISNet and TRANSIMSNet. GISNet is a useful control key that exports shape files to the appropriate text files. The TRANSIMSNet utility program was then utilized to synthesize the TRANSIMS network and to generate other network files, such as activity locations. The log file was checked for warning messages after TRANSIMSNet was run, and corrections were made when necessary. The following files were generated as TRANSIMS network files: link, node, process link, signal, transit, activity location, parking, shape, and zone.

The research team only coded the MD 175 area in TRANSIMS. Figure 18 shows the links, nodes, and zones of the TRANSIMS converted network. The MD 175 detailed network contains 1,782 links and 1,461 nodes in both TransCAD and TRANSIMS. Figure 19 presents the activity locations on the TRANSIMS network.

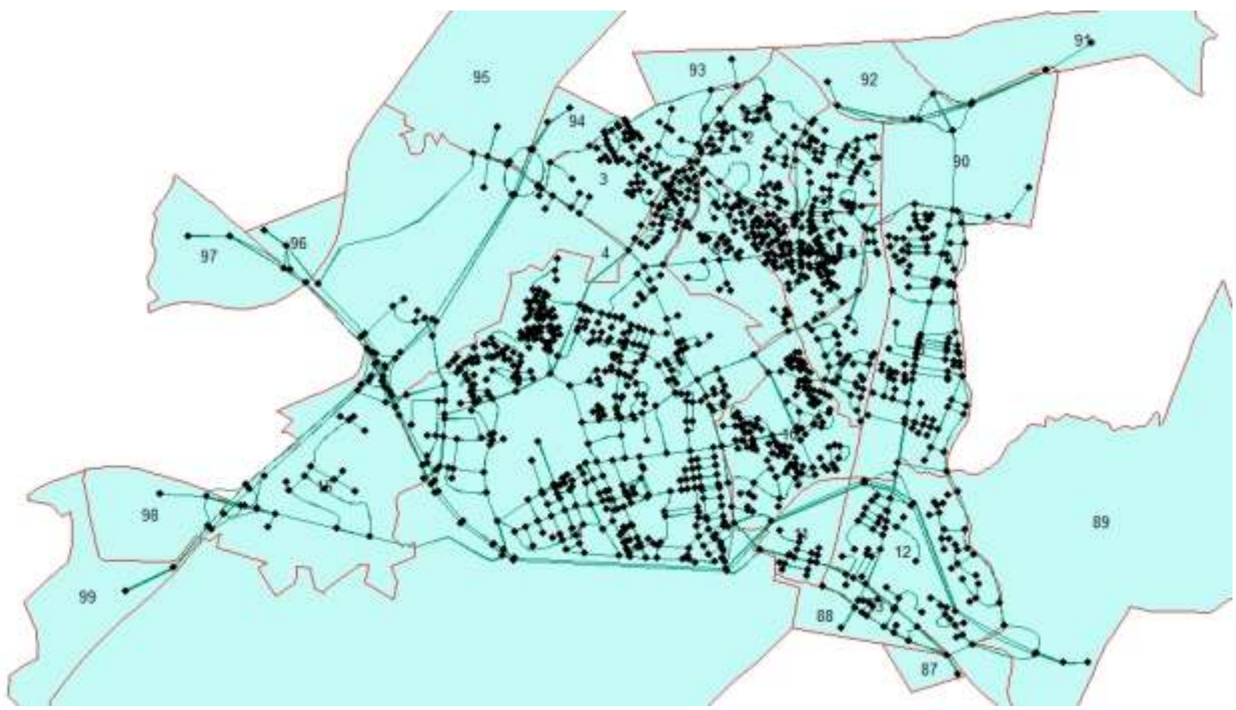

Figure 18: Links, Nodes, and Zones for the TRANSIMS-Converted Network (MD 175 Study Area)

Figure 19: Activity Locations for the MD 175 Study Area in TRANSIMS

Population Synthesizer

Population Synthesizer is the first module in TRANSIMS. The Population Synthesizer uses census, survey, land use, and network data to imitate the study area's real population. It synthesizes the entire population in the study area with the household characteristics from the census data. It specifies household locations, number of people in each household, and demographic and socioeconomic characteristics of all household members. The synthetic population's demographics form the basis of individual and household activities that require travel. Figure 20 presents a sample output file for a synthetic household.

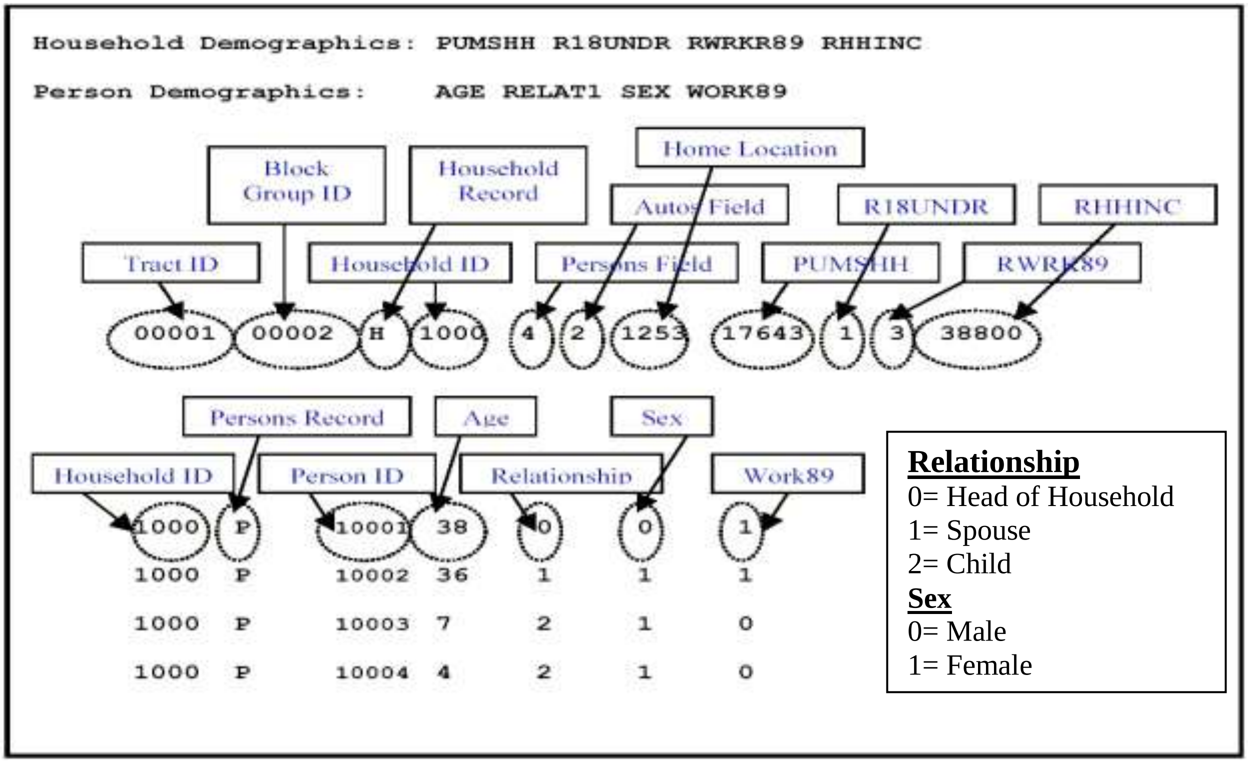

Figure 20: Synthetic Household Output File in TRANSIMS

The census survey data is called the public use microdata sample (PUMS), and it includes individual records for 5 percent of the people and housing units in each state. The information includes age, gender, income, employment, and vehicle type. The PUMS data is collected from geographic areas called public use microdata areas (PUMAs). PUMAs, which are similar in concept to the Four-Step model's zones, are defined by state data centers in cooperation with regional and affiliate data centers. The Population Synthesizer also uses the summary file (SF-3), another type of census data that includes a summary table of the study area's demographics.

The Population Synthesizer uses a two-step, iterative proportional fitting (IPF) procedure (Beckman, et al., 1996) to create a cross-classification of household characteristics that match the distribution of key household attributes for a specific location. It assigns the synthetic households to a specific activity location and then assigns vehicles to the household in the parking lot attached to the activity location. Tables 13 and 14 present a sample of TRANSIMS' person and household files, respectively.

HHOLD	PERSON	AGE	GENDER	WORKER
1	1	19	1	1
1	2	19	2	1
1	3	1	1	0
2	1	19	1	1
2	2	19	2	1

Table 13: Sample Person File

HHOLD	LOCATION	PERSONS	STATE	PUMA	VEHICLES	WORKERS	INCOME	HHAGE	NUM_LT5	NUM_5TO15
1	420	3	24	1201	2	2	3500	19	1	0
2	2393	3	24	1201	2	2	3500	19	1	0
3	2340	3	24	1201	2	2	3500	19	1	0
4	559	3	24	1201	1	1	1600	29	0	2
5	2381	3	24	1201	1	1	1600	29	0	2

Table 14: Sample Household File

The research team adopted several utility programs to generate the synthetic population. PUMSPrep utility program divided the PUMS household and person records into two separate files, household file and population file. PUMSPrep was also used to select and name the data fields for the TRANSIMS-required format. The developer selects the variables depending on the data needed for the cross-classification and the Activity Generator. The research team selected household ID, income, number of workers in the household, age of the head of household, number of children under 5 years old, number of children between 5 and 15 years old, and household type. The data selected for the population file were age, gender, relationship to the head of household, and employment status. The selected PUMA for the study area was PUMA number 201 and the state of Maryland code was 24.

Activity Generator

The Activity Generator, the second module in TRANSIMS, uses activity surveys to develop a list of activities for each member of a synthetic household over a 24-hour period. Travel-related activities (such as start and end time of the activity, mode of travel, and so on) are generated in this module. The Activity Generator uses a destination choice model to determine the non-home activity locations. Figure 21 is an example of the Activity Generator's location choice.

Each generated activity has the following features:

- activity type (such as home, work, school, etc.) and its priority
- start, end, and duration time preferences
- preferred travel mode

- list of possible locations for an activity
- list of other household participants (if the activity is shared)

The Four-Step model includes trip types (such as home-based work, home-based-other, and non-home-based), whereas the Activity-Based model includes different activities (such as home, work, school, social visit, serve passenger (giving ride), and so on). Travel modes can be specified into different modes of travel (e.g., walk, bike, car, bus, rail, and so on). Fourteen different travel modes were embedded in TRANSIMS.

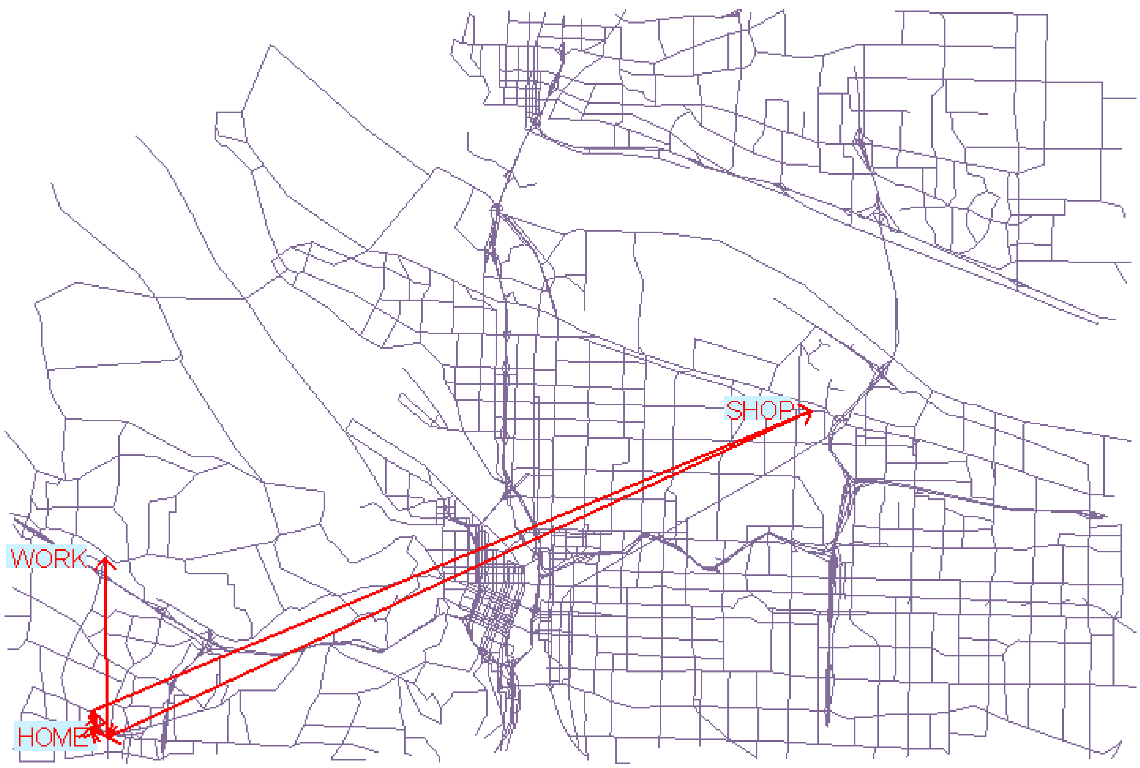

Figure 21: Example of the Activity Generator's Location Choice

The household activity survey data includes travel and activity information for each household member in the study region. This survey data is obtained from a detailed questionnaire that asks for socio-economic information, activities, and trips during a 24-hour period. Two files—household activity survey and household demographic data—are generated from the questionnaire. Table 15 presents a sample household activity survey, and Table 16 presents demographic and socio-economic data (e.g., income, age, etc.) for each person in the surveyed households.

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HHOLD	PERSON	ACTIVITY		PURPOSE	PRIORITY		START	END	DURATION		MODE	VEHICLE LOCATION
200007	1	1	0	0	0:00	10:33	10:33	1	0	1	0	0
200007	1	2	1	1	11:48	14:30	2:42	2	1	2	0	0
200007	1	3	1	2	14:45	19:00	4:15	2	1	3	0	0
200007	1	4	5	0	19:45	22:45	3:00	2	1	4	2	0
200007	1	5	0	0	23:30	1@3:00	3:30	2	1	1	0	0
200009	1	1	0	0	0:00	10:00	10:00	1	0	1	0	0
200009	1	2	12	2	10:10	12:10	2:00	3	0	2	0	0
200009	1	3	12	0	12:15	13:23	1:08	1	0	3	0	0
200009	1	4	0	0	13:45	1@3:00	13:15	1	0	1	0	0
200010	1	1	0	0	0:00	10:39	10:39	1	0	1	0	0
200010	1	2	13	0	11:10	11:25	0:15	2	2	2	1	0
200010	1	3	12	2	11:50	13:20	1:30	2	2	3	1	0
200010	1	4	15	0	13:40	14:30	0:50	2	2	4	1	0
200010	1	5	12	0	14:45	15:00	0:15	2	2	5	1	0
200010	1	6	0	0	15:21	15:51	0:30	2	2	1	1	0
200010	1	7	9	2	16:05	22:30	6:25	2	2	6	1	0
200010	1	8	0	0	22:45	1@3:00	4:15	8	0	1	1	0
200010	2	1	0	0	0:00	10:39	10:39	1	0	1	0	0
200010	2	2	13	0	11:10	11:25	0:15	2	1	2	1	0
200010	2	3	12	2	11:50	13:20	1:30	2	1	3	1	0
200010	2	4	15	0	13:40	14:30	0:50	2	1	4	1	0
200010	2	5	12	0	14:45	15:00	0:15	2	1	5	1	0
200010	2	6	0	0	15:21	15:51	0:30	2	1	1	1	0
200010	2	7	6	2	16:05	16:06	0:01	2	1	6	1	0
200010	2	8	0	0	16:20	1@3:00	10:40	2	1	1	1	0
200015	1	1	0	0	0:00	1@3:00	1@3:00	1	0	1	0	0
200020	1	1	0	0	0:00	14:20	14:20	1	0	1	0	0
200020	1	2	13	0	15:00	16:45	1:45	3	0	2	0	0
200020	1	3	13	2	17:00	19:00	2:00	1	0	3	0	0
200020	1	4	0	0	19:30	1@3:00	7:30	1	0	1	0	0
200029	1	1	0	0	0:00	9:15	9:15	1	0	1	0	0

Table 15: Household Activity Survey Sample

Survey_Population - Notepad

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HHOLD	PERSON	AGE	GENDER	WORK	RELATE
200007	1	29	2	1	1
200009	1	82	2	2	1
200010	1	25	1	1	1
200010	2	28	2	2	1
200015	1	82	1	2	1
200020	1	77	1	2	1
200029	1	66	2	1	1
200029	2	66	1	1	1
200029	3	45	1	1	4
200030	1	54	1	1	1
200037	1	40	1	1	1
200037	2	3	2	2	2
200037	3	7	2	2	2
200037	4	44	2	1	1
200045	1	25	2	1	1
200045	2	15	1	2	2
200045	3	39	1	1	1
200055	1	52	2	1	1
200055	2	51	1	1	1
200056	1	42	2	1	1
200056	2	17	1	1	2
200056	3	14	2	2	2
200056	4	12	2	2	2
200056	5	10	1	2	2
200057	1	43	1	1	1
200057	2	13	2	2	2
200057	3	13	1	2	2
200057	4	14	2	2	2
200057	5	15	2	2	2
200057	6	17	1	1	2
200057	7	42	2	1	1
200058	1	42	2	2	1
200058	2	46	1	1	1
200058	3	6	2	2	2
200058	4	3	2	2	2
200060	1	31	2	2	1
200060	2	63	1	2	1
200061	1	77	2	2	1
200061	2	75	1	2	1
200067	1	41	2	1	1
200067	2	42	1	1	1
200067	3	4	2	2	2
200067	4	2	1	2	2
200069	1	24	1	1	1
200069	2	23	2	1	1
200069	3	1	2	2	2
200070	1	70	2	2	1
200077	1	46	1	1	1
200077	2	36	2	1	1
200087	1	30	1	2	1
200087	2	30	2	2	1
200088	1	38	1	1	1
200088	2	42	2	1	1

Table 16: Survey Household Demographic Data Sample

Because the Activity Generator utilizes the Classification and Regression Tree (CART) algorithm to group survey households based on demographic variables, there is greater variation in the trip-making activity between the groups. In spite of the gravity model, the CART algorithm is behavioral. It produces a classification of household demographic characteristics (such as number of workers, household size, household income, and etc.) based on households travel behaviors (such as time spent at work, at home, at shopping centers, and etc.). The CART algorithm classifies each survey household into one of the tree's terminal nodes. The terminal nodes represent the end path of the selected household demographic characteristics. The tree is sensitive to the household behavior characteristics.

After building a classification tree, the Activity Generator matches the given synthetic household with a survey household, generates activity times and durations, and then creates activity locations. Table 17 presents part of the Activity Generator output for the MD 175 study area.

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HHOLD	PERSON	ACTIVITY		PURPOSE	PRIORITY		START	END	DURATION		MODE	VEHICLE	LOCATION	
1	1	1	0	0	0:00	7:13:18	7:13:18	1	0	382	0	0		
1	1	2	9	2	7:30	11:45	4:15	2	2	3819	0	1		
1	1	3	0	0	12:01:42		12:45	0:43:18	2	2	382	0	0	
1	1	4	9	2	13:00	16:00	3:00	2	2	3015	0	1		
1	1	5	6	0	16:15	16:20	0:05	2	2	3757	0	5		
1	1	6	0	0	16:30	1@3:00	10:30	2	2	382	1	2		
1	2	1	0	0	0:00	6:57:10	6:57:10	1	0	382	0	0		
1	2	2	6	0	7:15	7:20	0:05	2	1	3757	1	2		
1	2	3	9	2	8:00	12:00	4:00	2	1	3373	0	1		
1	2	4	5	0	12:05:40		12:45	0:39:20	8	0	3701	3	0	
1	2	5	9	1	13:00	17:00	4:00	8	0	3705	3	1		
1	2	6	0	0	17:35:45		1@3:00	9:24:15	8	1	382	0	0	
1	3	1	0	0	0:00	6:57:10	6:57:10	1	0	382	0	0		
1	3	2	7	2	7:15	16:20	9:05	10	1	3757	1	2		
1	3	3	0	0	16:30	1@3:00	10:30	10	2	382	1	2		
2	1	1	0	0	0:00	9:45:28	9:45:28	1	0	2274	0	0		
2	1	2	14	2	10:05	13:00	2:55	2	4	3235	0	0		
2	1	3	0	0	13:19:32		13:48:06		0:28:34	2	4	2274	0	0
2	1	4	2	0	14:05	14:25	0:20	2	4	2888	2	2		
2	1	5	3	2	14:45	15:35	0:50	2	4	3282	2	2		
2	1	6	0	0	16:00	16:55	0:55	2	4	2274	2	2		
2	1	7	16	2	17:10	17:11	0:01	2	4	3177	2	2		
2	1	8	0	0	17:30	20:00	2:30	2	4	2274	1	2		
2	1	9	9	2	20:30	1@2:00	5:30	2	4	3710	0	1		
2	1	10	0	0	1@2:17:25		1@3:00	0:42:35	2	4	2274	0	0	
2	2	1	0	0	0:00	13:48:06		13:48:06		1	0	2274	0	0
2	2	2	12	0	14:05	14:25	0:20	10	4	2888	2	2		
2	2	3	13	2	14:45	15:35	0:50	10	4	3282	2	2		
2	2	4	0	0	16:00	16:55	0:55	10	4	2274	2	2		
2	2	5	9	2	17:10	21:15	4:05	10	4	3177	2	2		
2	2	6	0	0	21:51:52		1@3:00	5:08:08	8	0	2274	1	0	
2	3	1	0	0	0:00	13:48:06		13:48:06		1	0	2274	0	0
2	3	2	12	0	14:05	14:25	0:20	10	4	2888	2	2		
2	3	3	13	2	14:45	15:35	0:50	10	4	3282	2	2		
2	3	4	0	0	16:00	16:55	0:55	10	4	2274	2	2		
2	3	5	6	2	17:10	17:11	0:01	10	4	3177	2	2		
2	3	6	0	0	17:30	1@3:00	9:30	10	4	2274	1	2		
3	1	1	0	0	0:00	12:10:59		12:10:59		1	0	2252	0	0
3	1	2	14	2	12:30	15:30	3:00	2	6	1351	2	2		
3	1	3	14	0	16:15	18:30	2:15	2	6	1677	2	2		
3	1	4	15	0	18:30	20:45	2:15	1	0	1677	0	0		
3	1	5	0	0	21:15	1@3:00	5:45	2	6	2252	2	2		
3	2	1	0	0	0:00	8:45:22	8:45:22	1	0	2252	0	0		
3	2	2	12	2	9:05	9:15	0:10	2	6	3155	0	0		
3	2	3	0	0	9:20	12:10:59		2:50:59	2	6	2252	0	0	
3	2	4	14	2	12:30	15:30	3:00	10	6	1351	2	2		
3	2	5	14	0	16:15	18:30	2:15	10	6	1677	2	2		

Table 17: Activity Generator Output Sample

Route Planner

The Route Planner uses the Activity Generator output to create routes and travel plans for each individual in the network.

TRANSIMS models the trip chains, and each trip has a set of travel legs between activity locations, parking lots, or transit stops. Each travel-leg has the following information:

- travelers' and passengers' identifications
- starting location and destination location
- starting time
- maximum travel time
- mode string

Route Planner uses a time-dependent, label-constrained shortest path (TDLSP) algorithm that is a modified version of Dijkstra's algorithm. Figure 22 presents a Route Planner example.

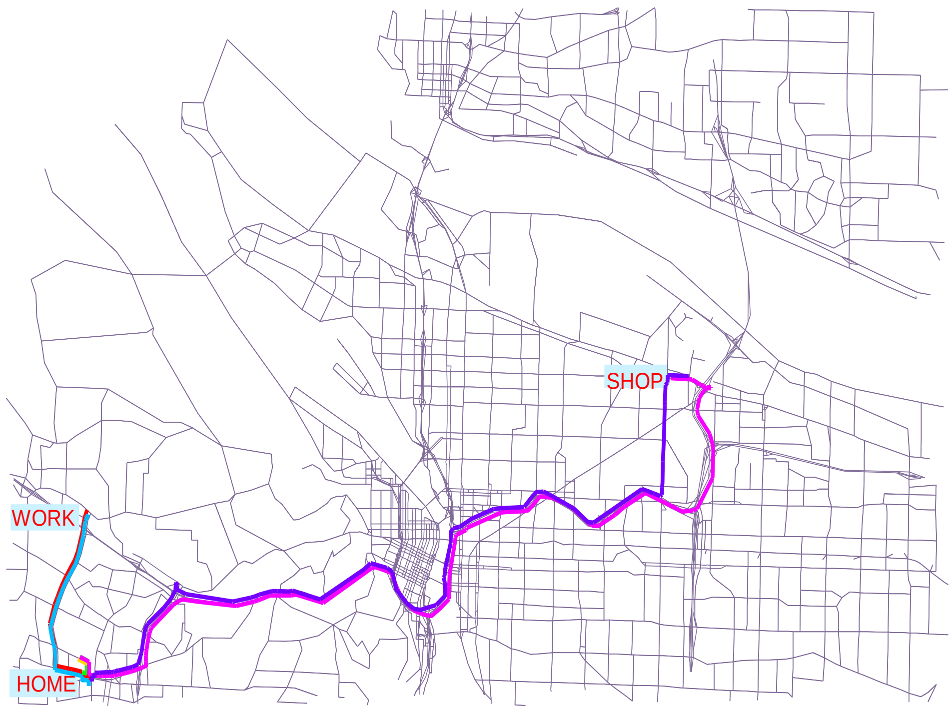

Figure 22: Example of the Route Planner's Shortest Path

In the Trip-Based and Hybrid models, the input data must be converted before Route Planner can be run. In the Trip-Based model, the OD matrices, which are zone-based trips allocated to activity locations within the zones and the trips' time of day, are selected based on the user-defined diurnal distribution. In the Hybrid model, the converted trips from the Trip-Based model need to be aggregated to the activities from the Activity-Based model.

The Route Planner views the network as a set of interconnected, unimodal layers. Each mode is on a separate layer. An imaginary link (called process link) connects the unimodal layers to each other. Based on individual traveler preferences and constraints specified in the Activity Generator output, the Route Planner arranges trips that consist of multiple modal legs such as walk-car-walk. The Route Planner makes an internal network that consists of links and nodes on all the layers. Each link in the internal network has an associated travel time.

Initially, the free-flow speed is utilized to calculate the travel times, assuming that there is no vehicle traffic in the network. The Route Planner then finds a shortest path for the trips in the internal network based on the time of departure and makes plans for all travelers in the network. The travelers' plans are simultaneously fed into the Traffic Microsimulator module. When the simulator simulates all the individual plans in the network and their interactions, the travel time of each link is calculated. This new travel time is used in the subsequent Route Planner runs in order to find the shortest path when the network includes all travelers. The travel time is calculated every 15 minutes.

The major output of the Route Planner is information about transportation activities for each traveler. This information includes routes (nodes, links, and travel modes), travel time for each link, and total travel time. The travel plan file, the output of the Route Planner, has the following information for each individual in the network:

- traveler ID
- trip ID
- leg ID
- starting time
- starting location ID
- starting accessory type
- ending location ID
- ending accessory type
- duration
- stop time
- monetary cost
- generalized cost function
- max time flag
- driver flag
- travel mode (car, transit, pedestrian, etc.)
- number of tokens
- vehicle ID
- number of passengers
- token ID

Figure 23 presents the travel-plan shape file for the MD 175 study area.

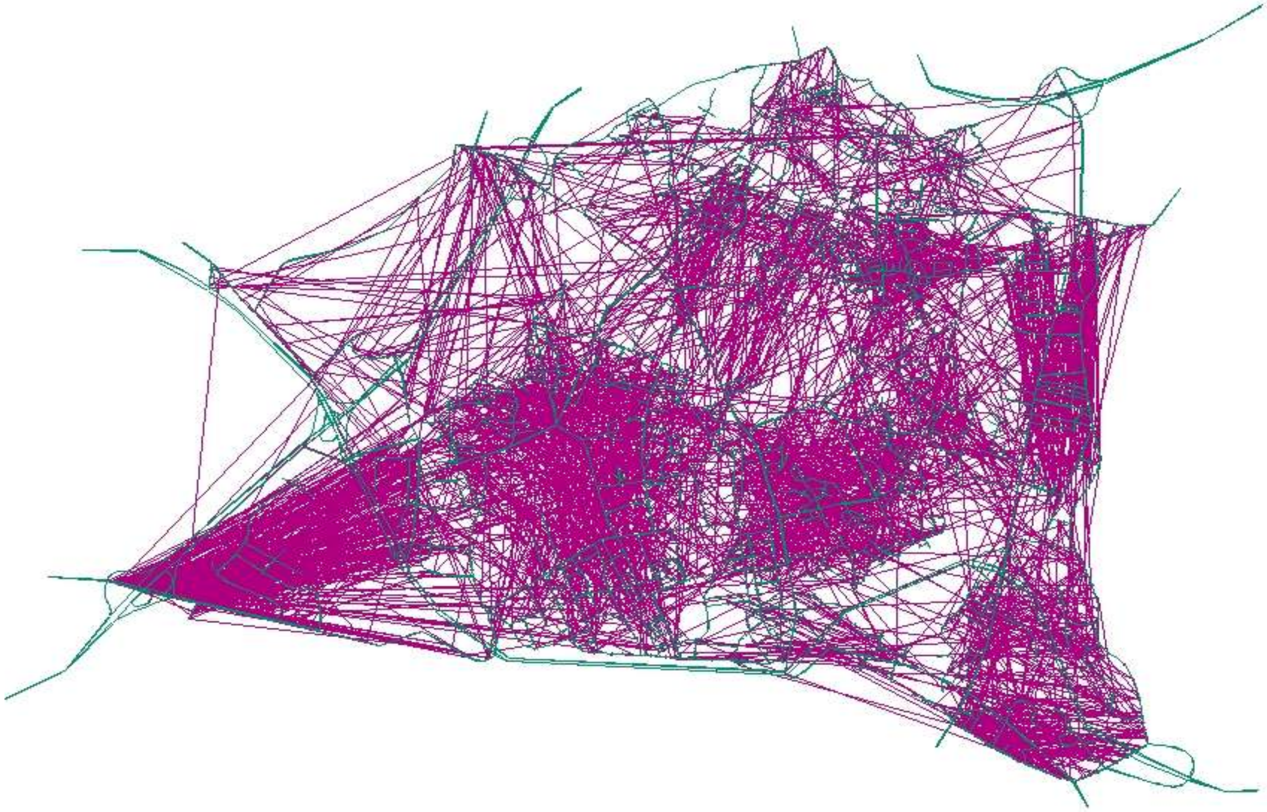

Figure 23: Travel Plan Shape File for MD 175

Traffic Microsimulator and Visualization

As stated earlier, the Microsimulator simulates travelers' movements and interactions throughout the study area network. It executes the individual travel plans provided by the Route Planner and computes the transportation system dynamics. The Microsimulator is a powerful tool that is capable of handling intermodal travel plans, multiple travelers per vehicle, multiple trips per traveler, and vehicles with different operating characteristics. The Microsimulator is capable of simulating detailed information on large networks using the Cellular Automata (CA) concept. The CA concept divides each link on the network into a finite number of cells that are 24.6 feet (7.5 meters) long. Therefore, the speeds are measured in 24.6 feet per second (7.5 meter per second) increments. Vehicles can accelerate, decelerate, turn, change lanes, pass, respond to traffic controls, and interact with other vehicles in the simulator. Figure 24 presents a section of a network in the Microsimulator.

The major Microsimulator outputs are traveler events, vehicle snapshot data, and summary data. The event data provides detailed information whenever an event occurs for a traveler, such as trip ID, leg ID, time, location, and so on. The vehicle snapshot data gives the positions of vehicles on links for every time step (e.g., one second). Summary data includes spatial data collected over roadway sections (such as flow, density, etc.) and temporal data (such as travel time over links). Summary data is sampled, accumulated, and reported periodically throughout the simulation. Figures 25-27 present some output files of the Microsimulator.

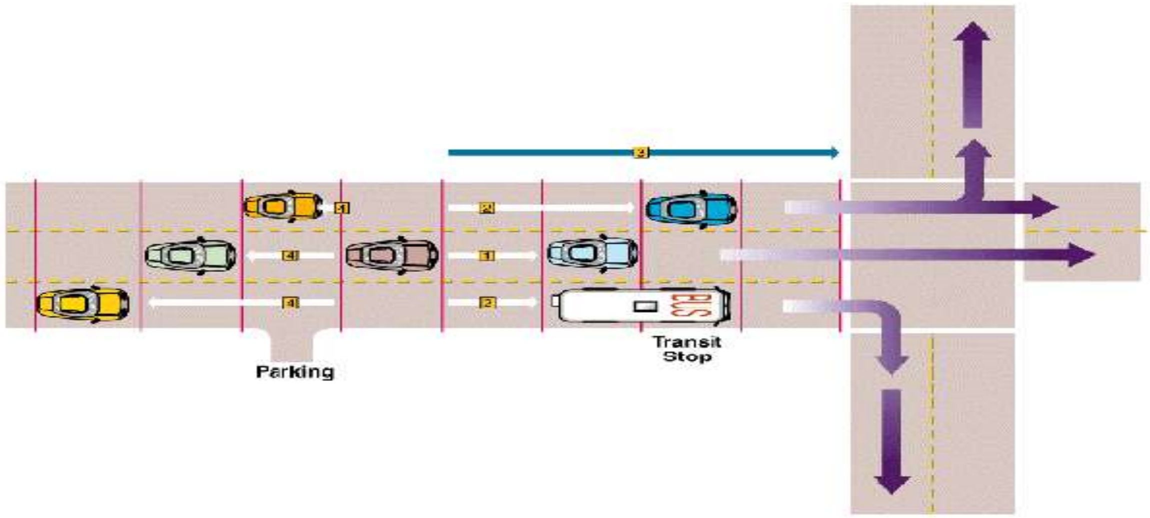

Figure 24: TRANSIMS' Microsimulator

```
10.MD175.2005.Trip - Notepad
File  Edit  Format  View  Help
LINK     DIR      START_TIME        END_TIME        AVG_VOLUME        IN_VOLUME        OUT_VOLUME        AVG_SPEED        AVG_TIME        AVG_DELAY        AVG_DENSITY
OUT_LINK          OUT_DIR  OUT_TURN          OUT_TIME
170      1        0:00     0:01     1        1        0        9.38     2.95     0.45     1.20     36.10    1.18     0.00     0        0        15.0     1.6      1
183      1        0        3.00
321      1        0:00     0:01     1        1        1        12.61    14.10    -1.80    0.94     11.25    0.89     0.00     0        0        118.5    9.4      1
584      1        1        12.70
473      1        0:00     0:01     1        1        0        13.89    11.21    -2.69    0.32     6.42     0.81     0.00     0        0        37.5     2.7      1
477      0        0        11.20
479      1        0:00     0:01     1        1        0        12.08    12.93    -0.97    0.53     12.80    0.93     0.00     0        0        60.4     5.0      1
645      1        0        10.40
544      1        0:00     0:01     1        1        1        13.83    4.10     -1.00    1.47     17.64    0.80     0.00     0        0        56.7     4.1      1
170      1        1        4.10
584      1        0:00     0:01     1        1        1        14.15    3.90     -1.00    1.51     18.12    0.80     0.00     0        0        55.2     3.9      1
473      1        1        3.90
707      1        0:00     0:01     1        1        1        12.04    15.91    -1.19    0.52     10.44    0.91     0.00     0        0        63.8     5.3      1
544      1        1        12.90
923      0        0:00     0:01     1        1        1        15.22    4.90     -1.80    1.34     13.40    0.73     0.00     0        0        74.6     4.9      1
924      0        1        4.90
924      0        0:00     0:01     1        1        0        14.32    18.24    -5.06    0.70     3.83     0.78     0.00     0        0        157.5    11.0     1
979      0        0        18.20
956      0        0:00     0:01     1        1        1        10.55    10.20    0.60     0.93     18.59    1.06     0.00     0        0        53.8     5.1      1
923      0        1        8.00
1215     1        0:00     0:01     1        1        1        10.33    21.60    1.70     0.45     8.96     1.09     0.00     0        0        55.8     5.4      1
1222     1        1        16.90
1222     1        0:00     0:01     1        1        0        14.58    9.18     -2.82    0.50     7.47     0.77     0.00     0        0        52.5     3.6      1
1456     1        0        9.20
1694     1        0:00     0:01     1        1        1        11.21    12.20    0.00     0.85     14.62    1.00     0.00     0        0        68.4     6.1      1
```

Figure 25: Trip Performance Result for the 10th Iteration of Microsimulation for MD 175

HOUSEHOLD	PERSON	TRIP	LEG	MODE	EVENT	SCHEDULE	ACTUAL	LINK	OFFSET
27781	1	1	2	0	1	0:06:09	0:04:49	-1325	59
120126	1	1	2	0	1	0:07:56	0:05:06	1442	84
44976	1	1	2	0	1	0:08:32	0:05:18	1705	72
91052	1	1	2	0	1	0:11:50	0:05:24	1587	140
71492	1	1	2	0	1	0:08:24	0:05:52	-971	37
38343	1	1	2	0	1	0:14:40	0:05:58	-1256	480
27781	1	1	3	2	0	0:06:09	0:04:49	1325	176
27781	1	1	3	2	1	0:06:39	0:05:19	1325	176
29608	1	1	2	0	1	0:12:58	0:06:12	-1022	73
126237	1	1	2	0	1	0:09:34	0:06:20	-1348	369
131378	1	1	2	0	1	0:08:16	0:06:41	1273	201
41716	1	1	2	0	1	0:08:43	0:06:54	1595	58
101184	1	1	2	0	1	0:11:24	0:07:15	80	47
119921	1	1	2	0	1	0:09:39	0:07:15	1091	35
72067	1	1	2	0	1	0:08:42	0:07:36	1480	93
39761	1	1	2	0	1	0:12:18	0:07:44	-1088	346
135552	1	1	2	0	1	0:09:08	0:07:47	884	112
120126	1	1	3	2	0	0:07:56	0:05:06	-1442	84
120126	1	1	3	2	1	0:08:26	0:05:36	-1442	84
87502	1	1	2	0	1	0:17:46	0:07:58	-742	314
28851	1	1	2	0	1	0:09:22	0:08:01	-1256	480
83834	1	1	2	0	1	0:10:27	0:08:01	153	54
113681	1	1	2	0	1	0:11:40	0:08:15	-1614	61

Figure 26: Microsimulation Event Result for the 10th Iteration for MD 175

VEHICLE	TIME	LINK	DIR	LANE	OFFSET	SPEED	ACCEL	VEH_TYPE	DRIVER	PASSENGERS
49814	7:00	204	0	2	600.0	30.0	0.0	1	4981401	0
4701	7:00	1029	1	2	217.5	30.0	0.0	1	470101	0
29262	7:00	1029	1	2	405.0	30.0	0.0	1	2926201	0
55759	7:00	336	0	1	457.5	15.0	0.0	1	5575901	0
56195	7:00	204	0	2	652.5	22.5	-7.5	1	5619501	0
136618	7:00	402	1	2	472.5	15.0	0.0	1	13661801	0
141510	7:00	772	1	1	382.5	15.0	0.0	1	14151001	0
106680	7:00	1569	0	1	90.0	0.0	-15.0	1	10668001	0
18429	7:00	1271	1	1	187.5	15.0	0.0	1	1842901	0
23507	7:00	1765	1	1	600.0	15.0	0.0	1	2350701	0
49214	7:00	562	1	3	120.0	37.5	0.0	1	4921401	0
56123	7:00	1759	0	2	30.0	30.0	0.0	1	5612301	0
85823	7:00	126	1	1	240.0	15.0	0.0	1	8582301	0
118912	7:00	436	1	2	345.0	0.0	0.0	1	11891201	0
85155	7:00	1755	0	1	210.0	15.0	0.0	1	8515501	0
78651	7:00	1406	0	1	345.0	22.5	0.0	1	7865101	0
118605	7:00	436	1	2	360.0	0.0	0.0	1	11860501	0
5752	7:00	1494	0	1	307.5	7.5	-7.5	1	575201	0
119126	7:00	402	1	2	67.5	22.5	0.0	1	11912601	0
8531	7:00	1458	1	1	15.0	15.0	0.0	1	853101	0
8786	7:00	1668	1	1	37.5	22.5	7.5	1	878601	0
40241	7:00	1492	1	2	322.5	22.5	0.0	1	4024101	0
77561	7:00	1700	0	1	360.0	15.0	0.0	1	7756101	0
57666	7:00	335	0	1	300.0	22.5	0.0	1	5766601	0

Figure 27: Trip Snapshot Result for the 10th Iteration of Microsimulation for MD 175

The vehicle snapshot data can be presented using visualization software such as NEXTA (Zhu, 2010). NEXTA reports minute-by-minute, link-specific vehicle spatial information, volumes, speed, travel time, and bottlenecks. Figure 28 presents a snapshot of the NEXTA output for the MD 175 study area's PM peak. The red lines in this figure indicate that the average speed in the corresponding streets is less than half of the speed limit.

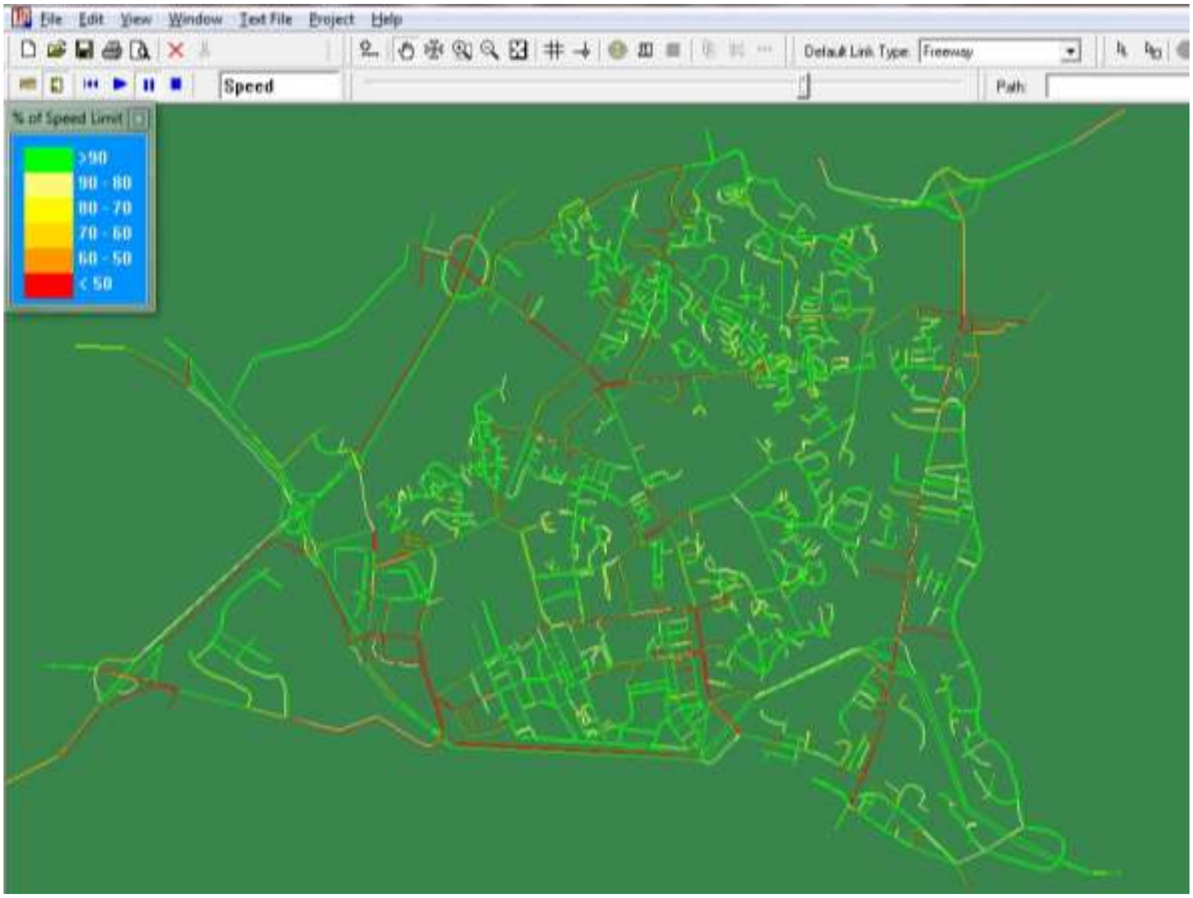

Figure 28: Snapshot of Speed in NEXTA at 5:00 p.m.

Feedback Module and Calibration

The Feedback process is the calibration tool in TRANSIMS. Feedback can be run between two or more modules. It is used to calibrate the model; to stabilize travel times in the network; to yield the desired Mode Choice; and to correct network, locations, modes, and activity times. Figure 29 presents different feedback loops.

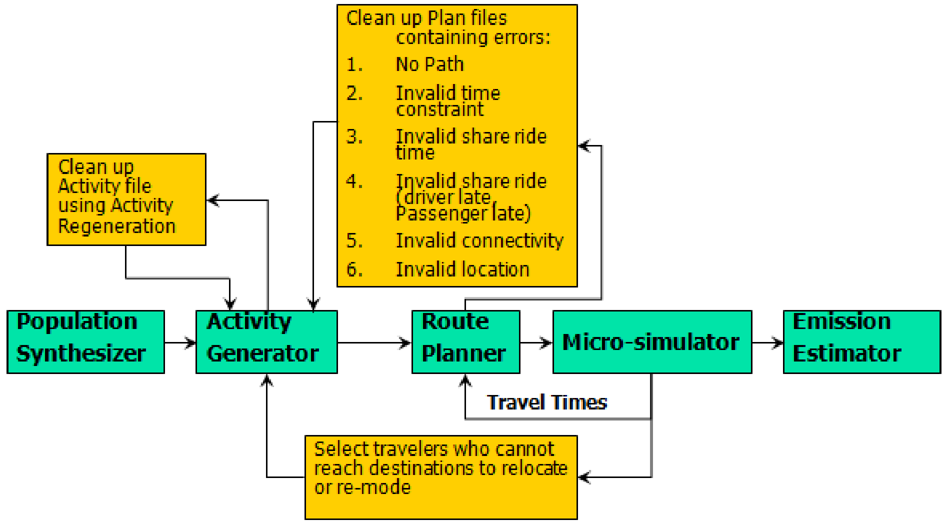

Figure 29: TRANSIMS Feedback Process

The research team performed the feedback between the Route Planner and the Microsimulator 11 times in order to stabilize travel times. As stated earlier, at the first iteration, the Route Planner used free-flow travel times to find the shortest path. However, after all vehicles were loaded onto the network, the link travel times were higher than the free-flow travel time, especially in the congested areas. As a result, some routes were no longer the shortest path. The Feedback randomly re-routed 15 percent of travelers until the link travel times stabilized.

Several feedbacks were performed to correct the network. Connection problems between the links and process links were addressed. Because TransCAD is not sensitive to network geometry, some links in the imported network, especially ramps, did not have the proper curvature. As a result, the Microsimulator could not load cars on the links. The research team modified the network to address the issue. Several feedbacks were performed to clean up the activity and plan files.

However, the TRANSIMS Activity-Based models could not be fully calibrated and validated for the study area because, as mentioned earlier, the external trips could not be generated. Since the MD 175 study area is small and external trips make up a significant portion of its traffic, the lack of proper estimation of external trips by the TRANSIMS Activity-Based Model causes some links to have lower traffic volumes than the real world. The research team expects that a Hybrid model can address this problem.

Emission Estimator

The Emissions Estimator is the last module in TRANSIMS. It translates vehicular traffic interactions into emission and energy consumption. This module estimates tailpipe emissions for heavy-duty vehicles and tailpipe and evaporative emissions for light-duty vehicles. In spite of other emission models, it considers the effect of transient power change. The research team did not implement this module since it was out of scope of this study.

RESEARCH FINDINGS

The developed, calibrated, and validated models for the base year were utilized to develop the models for years 2010, 2020, and 2030. Since some traffic counts were available for 2010, this year served as the comparison year. Since the detailed model yielded many zero volumes and the b-node model was modified by the Sub-TAZ to give better-distributed volumes, only the base and Sub-TAZ models were compared.

The developed models for 2010 were validated with the traffic counts. As presented in Table 18, Sub-TAZ model's forecasts were closer to the actual traffic counts for the year 2010 than the based model's were. The original 2005 model for the Sub-TAZ was a little bit better calibrated than the base model (i.e., its calibration/validation values were closer to the FHWA guideline and to the traffic counts presented in Table 19). However, the Sub-TAZ model yielded significantly better values than the 2010 base model.

The research team successfully developed the Activity-Based model in TRANSIMS. The traffic volumes for the internal links, especially around MD 175, were consistent with the TransCAD output (Figures 30 and 31). Figure 30 compares the three estimated volumes to the 2005 ground counts. While the Base model produced the highest R^2, TRANSIMS yielded a coefficient closest to one. The forecasted volumes and 2010 traffic counts are presented in Figure 31, and they verify that TRANSIMS and Sub-TAZ models outperform the Base model in short-term forecasting. Figure 32 presents a snapshot of the bottleneck during the study area's PM peak period.

	Base Model	Sub-TAZ Model
Correlation coefficient	0.86	0.94
Percent error regionwide	8.0%	16.4%
Sum of differences by functional class		
Freeway	6.2%	12.1%
Principal arterial	-16.5%	-8.6%
Minor arterial	44.3%	39.9%
Collector	-	-

Table 18: Validation of the 2010 ADT Base vs. Sub-TAZ Model, MD 175

	FHWA Guideline	Base Model	Sub-TAZ Model	TRANSIMS
Correlation coefficient	0.88	0.94	0.92	0.93
Percent error regionwide	5%	-5.7%	5.8%	10.9%
Sum of differences by functional class				
Freeway	7%	-5.6%	-1.7%	11.5%
Principal arterial	10%	-11.5%	0.2%	14.9%
Minor arterial	15%	1.0%	24.4%	4.7%
Collector	25%	-41.2%	-5.4%	-1.4%

Table 19: Calibration Results of the 2005 Base vs. Sub-TAZ Model

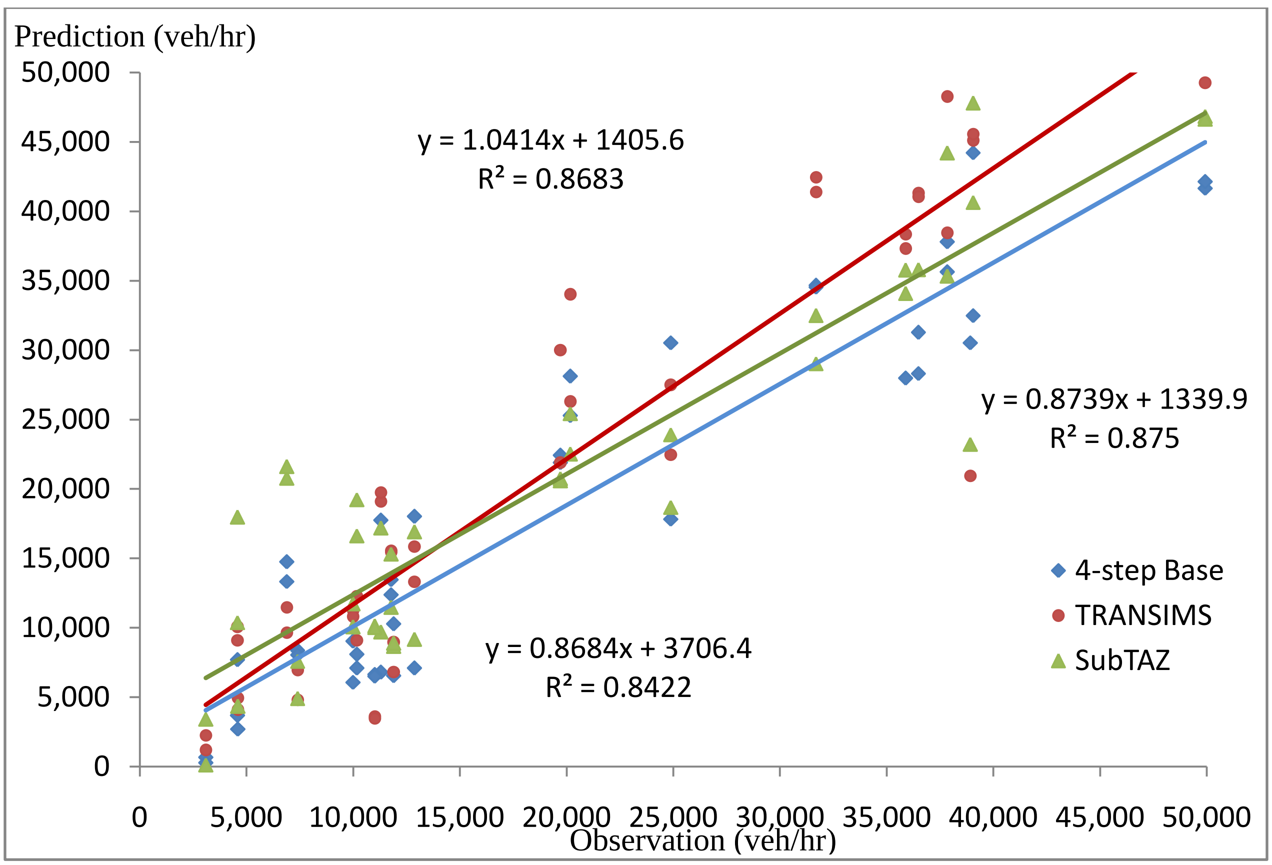

FIGURE 30: Estimation-Observation Regression Lines for the AADT 2005 Base, Sub-TAZ, and TRANSIMS Models

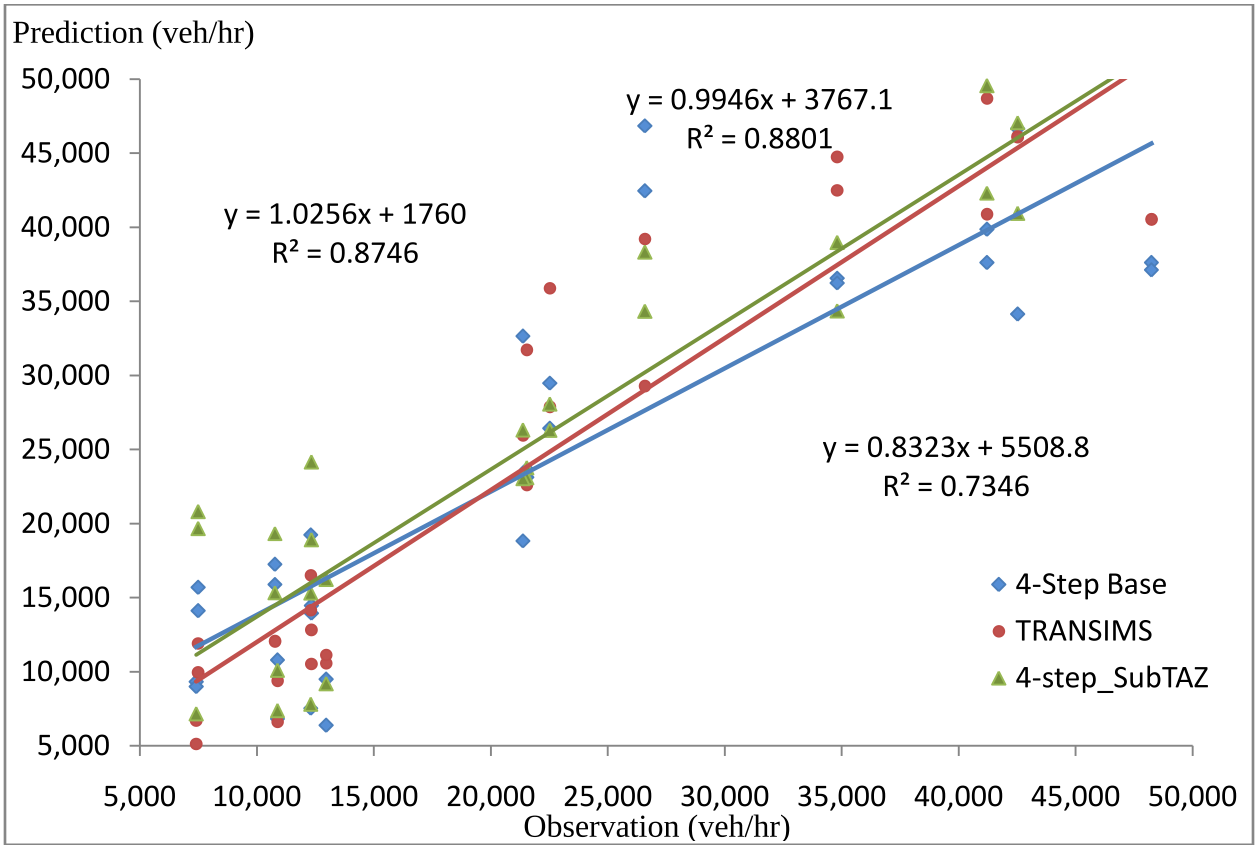

FIGURE 31: Forecast-Observation Regression Lines for the AADT 2010 Base, Sub-TAZ, and TRANSIMS Models

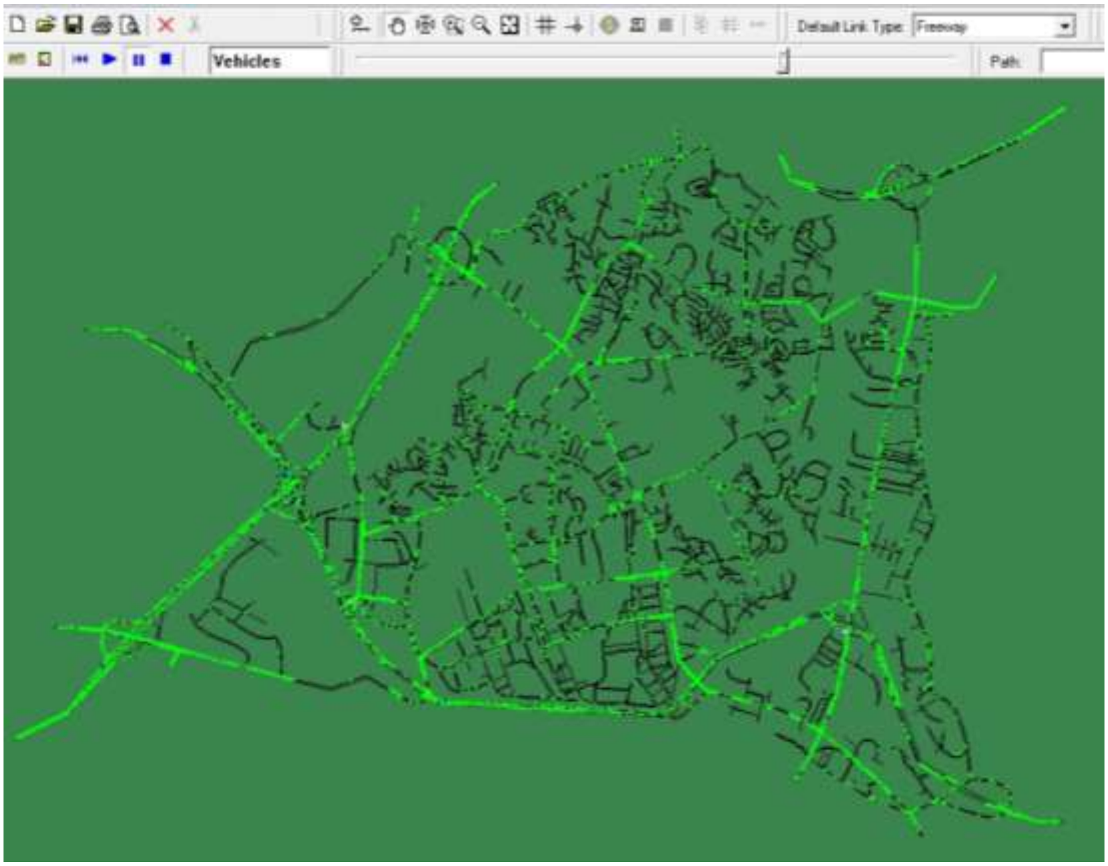

Figure 32: TRANSIMS Vehicle Snapshot of the MD 175 Study Area's PM Peak Period

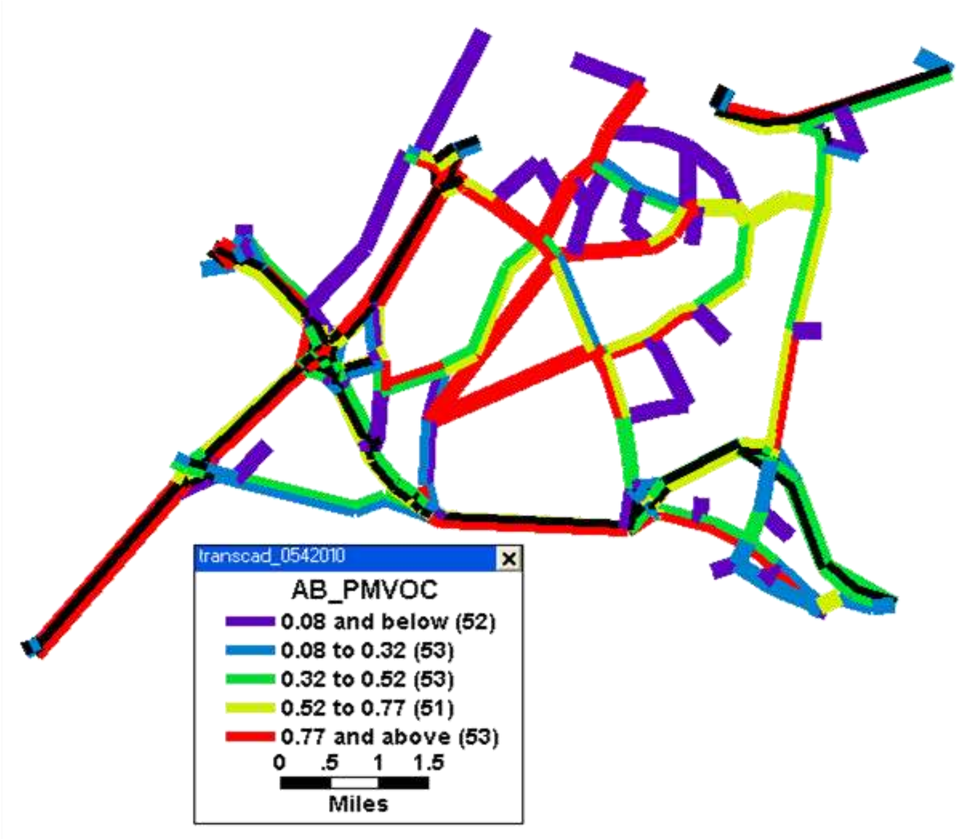

Figure 33: The Volume-Capacity Ratio for the PM Peak Period of the MD 175 Area in TransCAD

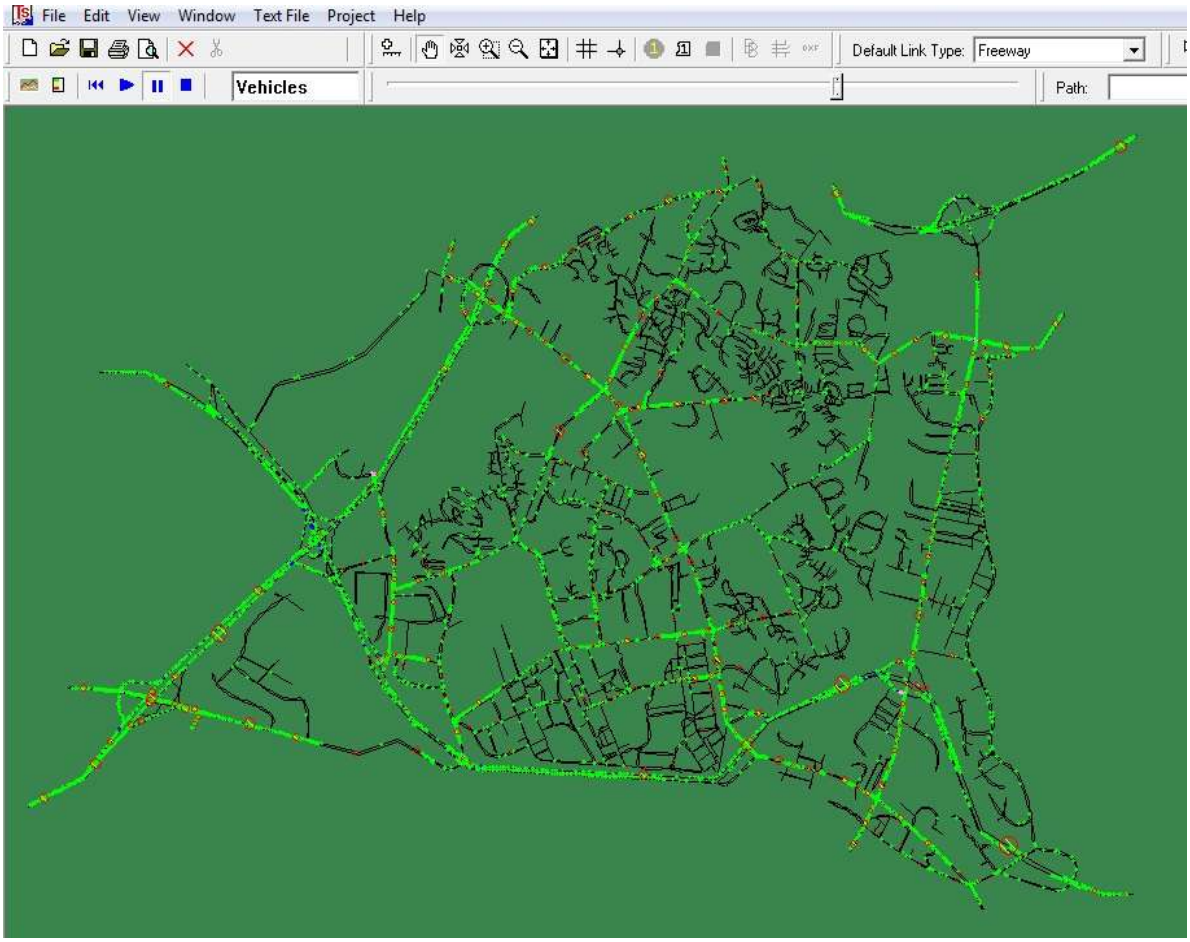

Figure 34: Bottleneck in the MD 175 Study Area

CONCLUSIONS

Conventional TIS methods are insufficient for CTIS. The conventional TIS simply uses ITE trip generation rates to estimate the trips that a development will generate. After developing, calibrating, and validating the four different Four-Step models, the research team concluded that the Sub-TAZ model was most suitable for CTIS. The regional model can be used as a base and be zoomed in to a smaller study area to have a more detailed network for the area. This can be done by developing a Sub-TAZ model for the study area in order to forecast the trips generated by all approved, submitted, and potential developments in the study area.

The research team used TRANSIMS to develop an Activity-Based model for the MD 175 study area. The results indicated that Activity-Based modeling could be applied to specific regions in Maryland or the entire state. The regional or statewide model can be improved with the Sub-TAZ, TRANSIMS Track 1, or TRANSIMS Hybrid model. Although the Hybrid model is the most challenging, it is also the most rewarding because it is activity based and includes external trips.

This research could be extended to make a guideline and framework for the CTIS using the Sub-TAZ model. In addition, the TRANSIMS Hybrid model can be developed, calibrated, and validated for the study area. Using the experience of developing TRANSIMS Activity-Based model for the MD 175 study area, the current statewide model can be developed in TRANSIMS in near future.

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