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A framework for guiding transportation improvements to support desired land use

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ABSTRACT

A FRAMEWORK FOR GUIDING TRANSPORTATION IMPROVEMENTS TO SUPPORT DESIRED LAND USE

by
Jiruttichut Leoviriyakit

There is a growing recognition that transportation and land use policies cannot succeed independently of one another. The interactions between them must be understood, analyzed, and accounted for in order for land use and transportation plans and policies to be effective and successful. A methodological framework is presented that can help urban planners determine what outcomes can be expected in terms of change in land use patterns within the targeted communities and within the county should a transportation project be undertaken.

The framework is based on an interaction between travel demand model TRANSIMS and land use model TELUM that enables complete regional transportation and land use analysis. The framework is applied on a real world case study in New Jersey. The study evaluates the value and impact of the transportation improvement project and ascertains if it brings a desired impact on land use and transportation infrastructure. This integrated model provides an understanding of the future network conditions which will consequently lead to a better assessment of transportation improvement alternatives and land use planning.

The framework provides answers to research questions in terms of what changes in land use patterns within the targeted communities and within the county can be expected if an improvement project of a transportation facility is undertaken. The framework also identifies changes in roadway network performance (travel time, speed, volume, delay) as well. The framework fully captures and incorporates induced travel demand into a regional transportation and land use analysis.

This dissertation describes in detail how MPOs, state DOTs, and other planning agencies can create an integrated transportation-land use model from the ground up or create it as an extension to their existing analytical tools to bridge the gap between the two models. The dissertation identifies shortcomings of current methodology used by MPO in analyzing the impacts of a reconstruction project. It provides guidelines which enable MPOs to achieve compliance with federal mandates. It also provides step-by-step guidance of how to develop a framework which integrates transportation system and land use.

The results show that the interactions between the transportation system and land use are complex and highlight the fact that the interrelationship between the two systems changes constantly and continues to evolve over time. The dissertation also explains how the integration between the two systems can be achieved through the use of multiple regression models which are built upon regional socioeconomic factors. The contributions of this dissertation to the field of transportation policy and planning are as follows:

- A framework allows planning agencies to utilize transportation improvement projects to guide future development patterns, densities and intensities of land use as well as encourage infill developments in an area of particular interest.

- A framework allows planning agencies to trace anomalies in land use patterns and identify crucial factors influencing such developments.

- It provides guidelines which enable planning agencies to achieve compliance with federal mandates. This dissertation discusses in detail how to create an integrated transportation-land use model from data that is readily available to planning agencies.

- It provides technical information in regards to TRANSIMS model development, the feedback process, and the convergence statistics.

- The developed model can assist urban planners to identify which transportation improvement projects should be undertaken, and at what location, in order to bring about desired outcomes.

The dissertation concludes with a methodology used to calculate the economic viability of a transportation improvement project. The methodology compares the costs of construction to the estimated benefits (or savings) in various user cost categories, including travel time, fuel consumption, and vehicle emissions.

A FRAMEWORK FOR GUIDING TRANSPORTATION IMPROVEMENTS TO SUPPORT DESIRED LAND USE

by
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APPROVAL PAGE

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To my beloved parents, courageous sister and dearest aunt

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CHAPTER 1

INTRODUCTION

The purpose of this dissertation is to present a methodological framework that will help urban planners to determine which transportation improvement projects should be undertaken, and at what location, in order to obtain a desired change in land use.

Transportation improvements, both minor (e.g., improvement of traffic signal timing) and major (e.g., roadway reconstruction) result in reduced travel time and increased mobility which inevitably shape development patterns and affect the economy. Their consequences range from short term (such as the rerouting of existing travelers to shorter routes) to long term (such as improved accessibility which attracts development to areas which were once deemed undesirable). Regardless of the extent of the impacts, they induce demand for travel, namely generate additional travel measured in Vehicle Miles Traveled (VMT).

Transportation planning and project prioritization processes at State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) are designed to identify and quantify the impacts of improvements on the local area within which the transportation project is undertaken to primarily alleviate or solve a specific problem at hand (e.g., road congestion). However, the new traffic patterns as a result of this improvement may have an unintended impact on an area quite some distance away by making it more attractive for working and living. The complexity of regional travel patterns overlaid over a complex transportation network can make the analysis of this impact difficult, if not intractable. Thus, the unintended consequence may be hard to ascertain immediately. It may manifest itself down the road where an unintended area experiences an unexpected surge of development and begins to generate travel that is overtaking the existing highway system which was not prepared for the additional demand.

To determine the impact of a transportation improvement project on both the local and regional area, the proposed framework integrates transportation and land use models. Figure 1.1 illustrates two distinctive approaches of how the framework can be utilized in the transportation planning process.

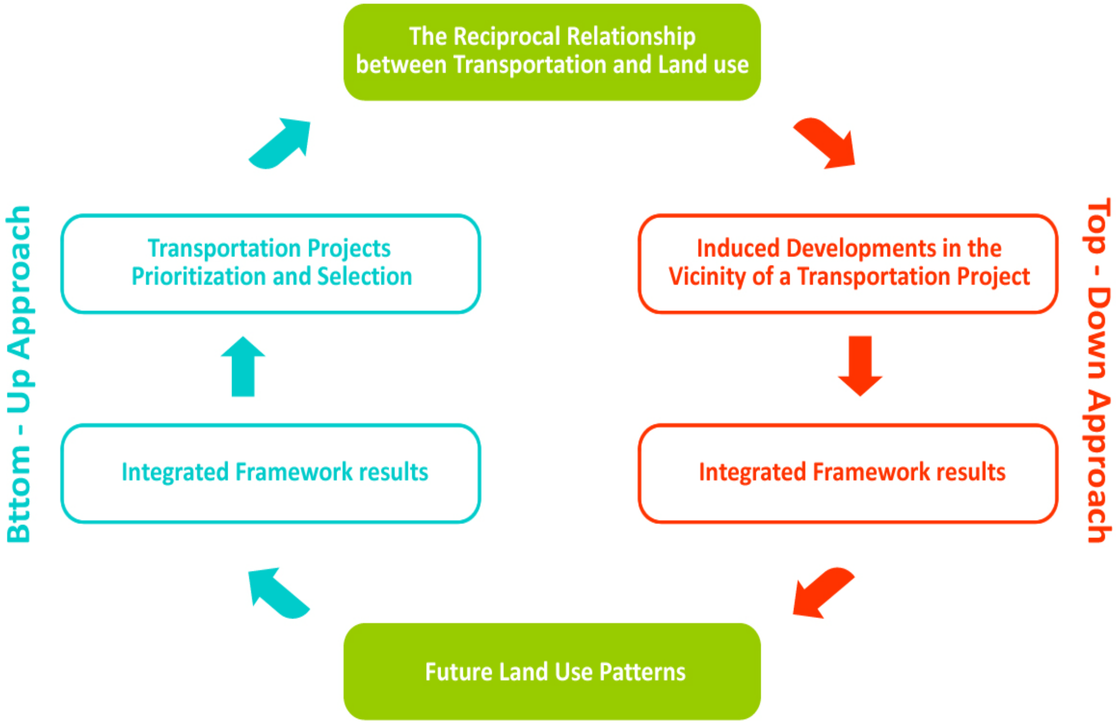

Figure 1.1 Integrated framework, top–down and bottom–up approaches.

In the top-down approach, an underlying assumption exists that there is a reciprocal relationship between transportation system and land use. The interactions between the two results in induced travel demand and the improved accessibilities affect activity location choices. In general, induced travel demand is the additional traffic as a result of changes in travel demand and land use patterns resulting from improvements of transportation facilities intended to mitigate congestion and/or improve accessibility.

Thus, urban planners can adopt this approach to gain a better understanding of how their transportation policies/decisions affect land use and vice versa. In this approach, planners can utilize the framework to assess the precision of the hypothesis that the selected improvement project will only encourage development within the vicinity of the project. The results obtained from the framework will reveal all consequences, including short term/long term and intended/unintended, that arises from the selected improvement project, thus allowing planners to capture its true value and effectively identify if it brings about the desired consequences.

In the bottom-up approach, given the framework’s ability to pinpoint exactly what the impacts of transportation improvement projects are, where the changes take place, and when they occur, the framework can also be utilized in a reverse sequence. In other words, rather than using the framework to identify the impacts of the selected improvement project, in this approach, the framework can be utilized to select an improvement project which brings about the most desirable outcomes in the targeted areas. The concept of the bottom-up approach is demonstrated on an example in Figure 1.2.

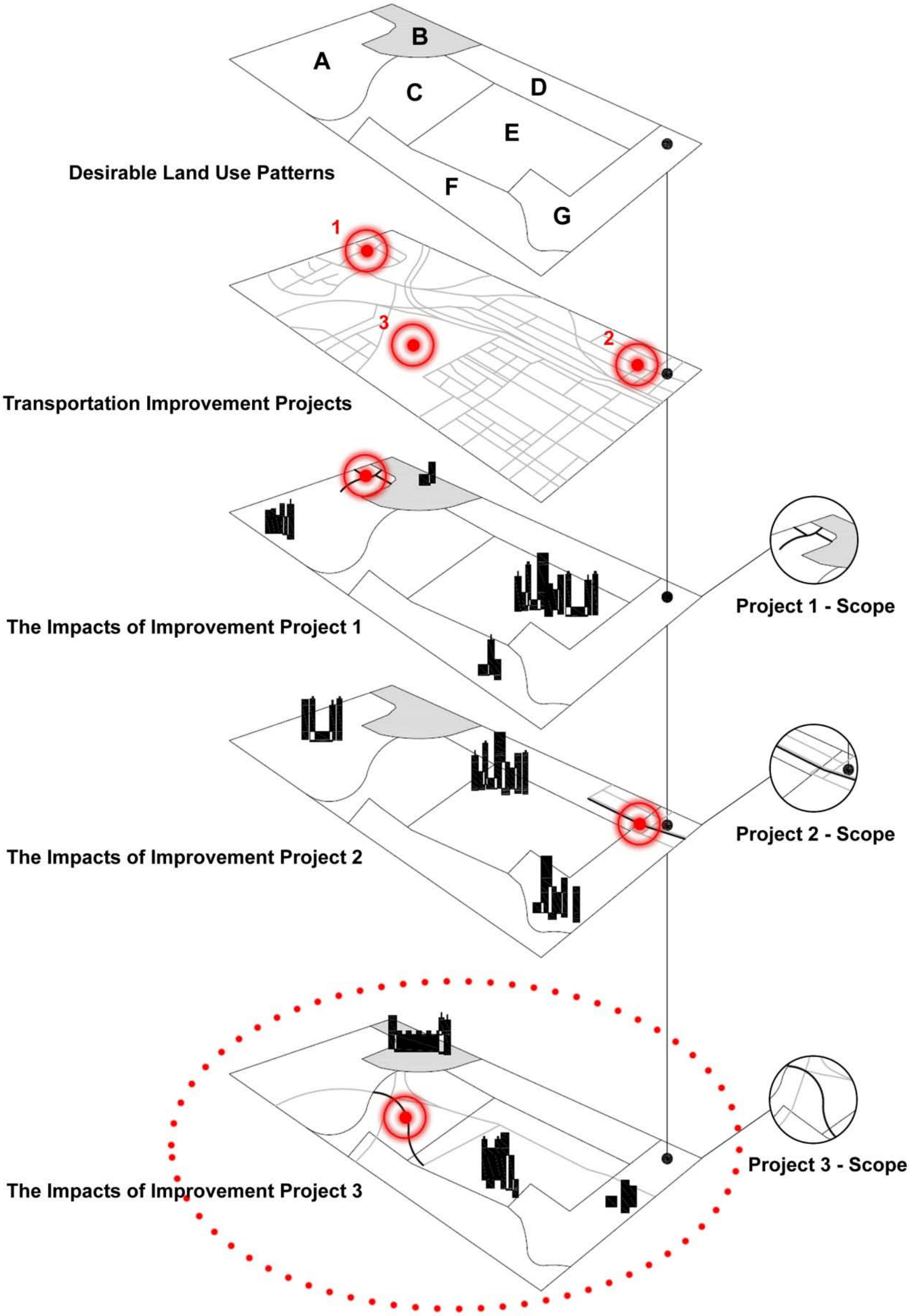

Figure 1.2 Interactions between transportation system and land use.

Figure 1.2 shows a total of seven zones (zone A to G). The implementation of a transportation project is desired such that land development increases in zone B (highlighted in gray). For this region, there are three transportation improvement projects competing for limited funds:

- Improvement Project 1: the reconstruction of the roadway between zones A and B
- Improvement Project 2: the reconstruction of the roadway between zones D and G
- Improvement Project 3: the reconstruction of the roadway between zones C and E

Since project 1 is in close proximity to zone B, implementing project 1, hypothetically, should help the community achieve its land use goal. However, anomalies may exist, and land use can react to transportation system changes in an unpredictable way. Figure 1.2 depicts erratic land use patterns which may occur by implementing improvement projects 1, 2 or 3.

Though project 1 is expected to bring about a large number of developments into zone B, only a few may be observed. Project 2, whose direct impacts are expected in zones D and G, may extend its influence to as far as zone A. And project 3, which is designed to create a direct connection between zones C and E, may unintentionally increase an attractiveness of zone B and induce developments in zone B. Based on the observed changes in land use patterns, project 3, located further away from zone B, should be selected since it encourages the desired land use patterns.

Since state DOTs and MPOs maintain a list of long term projects waiting for funding, by adopting and implementing this approach, the funding allocation can be prioritized based on the expected impacts from a transportation project.

In this dissertation, a transportation system is represented with a travel demand model that generates network performance measures (i.e., VMT, VHT[1], and VHD[2]) and travel impedances. Land use is represented with a land use model which forecasts changes in land use patterns as a result of transportation system changes. These changes are forecasted in terms of future spatial distributions of households and employment. These two models are integrated together through the use of trip production and attraction models which built upon regional socioeconomic factors that translate future land use patterns into future trip matrices. These future trip matrices are used as inputs in a travel demand model to generate traffic conditions for the same forecasting period.

To demonstrate the proposed framework, a case study for a Route 18 improvement project in Middlesex County, New Jersey is developed. Special attention is paid to the zones within a two-mile radius of the project area.

Two modeling scenarios, baseline and built scenarios, are developed. Also, a ten year transportation analysis (2000 – 2010) is performed for a Route 18 reconstruction area and the region covering Middlesex and Monmouth Counties as a whole.

1.1 Background

To effectively allocate limited resources, state and regional transportation planning organizations must follow a process established by Congress and set priorities for all proposed transportation improvement projects[3]. To ensure consistency and coordination in the project prioritization process, a federal mandate requires all Metropolitan Planning

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[1] Vehicle Hours Traveled

[2] Vehicle Hours Delay

[3] The fiscal constraint mandate of federal law (23 CFR Part 450.324) requires funding choices to be made among proposed projects.

Organizations (MPOs) across the country to develop two major planning documents: a Regional Transportation Plan (RTP) and a Transportation Improvement Program (TIP). RTP is a long-range transportation plan, usually developed every five years, which identifies all regionally significant transportation projects and programs that are planned in the metropolitan areas for at least 20 years into the future. TIP represents the transportation priorities of the region which are eligible to receive federal transportation funds. Depending on the agencies, TIP is usually updated annually and covers a period of four federal fiscal years[4,5]. All projects included in TIP must be drawn from the RTP and must help the region achieve its long-term goals. Any project that involves the construction of a large new facility or a new substantial expansion of an existing facility (i.e., adding new lanes to an existing highway or building a light-rail line) requires a Major Improvement Study (MIS) and Environmental Impact Statement (EIS) before inclusion into TIP. TIP must be financially constrained to the amount of funds that are expected to be available. Therefore, in order to add new projects to TIP, others must be deferred (DVRPC, 2008).

Recognizing that a fair project prioritization process can only be achieved when induced travel demand is incorporated into the analysis, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Clean Air Act Amendments of 1990 (CAAA) require Metropolitan Planning Organizations (MPOs) to integrate the impacts of transportation investment on land use in the Major Improvement Study (MIS) and Environmental Impact Statement (EIS) processes. Weiner (1997) summarizes the

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[4] On August 10, 2005, the *Safe, Accountable, Flexible, Efficient Transportation Act: A Legacy for Users* (SAFETEA-LU) was enacted into law and increases the period of constrained years in TIP from three to four years.

[5] A federal fiscal year begins on October 1st of a given year and ends on September 30th of the following year.

relevant aspects of ISTEA and other relevant legislation governing transportation planning. ISTEA requires MPOs to develop a 20-year metropolitan transportation plan which has to be coordinated with the transportation control measures required by CAAA. This long-range plan has to take into account 15 interrelated factors which integrate changes in transportation system and land use patterns together. The most recent and significant mandate is contained in Section 134(f) and Section 135(c) of the ISTEA. Section 134 states,

> "In developing transportation planning plans and programs pursuant to this section, each metropolitan planning organization shall, at a minimum consider the following..."
>
> 4. "The likely effect of transportation policy decisions on land use and development and the consistency of transportation plans and programs with the provision of all applicable short- and long-term land use and development plans."

Similarly, among the 20 factors required for consideration in State Transportation Planning, Section 135(c) requires States to undertake a transportation planning process which considers...

> 14. "The effect of transportation decisions on land use and land development, including the need for consistency between transportation

> decision making and the provision of all applicable short-range and long-range land use and development plans."

The Transportation Equity Act for the 21st Century (TEA-21), the 1998 successor to ISTEA, is built on ISTEA's initiatives. Although TEA-21 may have softened the requirement for integrated land use and transportation planning, it still recognizes the need for consistency in transportation and land-use plans. TEA-21 also requires transportation plans to conform to CAAA requirements, thereby integrating land use, transportation, and air quality. The Conference Report on TEA-21 (House of Representatives, 1998) does establish the link between transportation and land use with the following wording:

> "In considering the relationship between transportation and quality of life, metropolitan planning organizations are encouraged to consider the interaction between transportation decisions and local land use decisions appropriate to each area. The language (i.e., of the seven streamlined factors) clarifies that the failure to consider any specific factor . . . is not reviewable in court."

The above section discusses the federally mandated Regional Transportation Plan (RTP) and Transportation Improvement Program (TIP) which list projects and programs that will be funded in the next four years as well as federal laws and regulations that mandate the project prioritization process. The next section explores the project prioritization process currently employed by a New Jersey MPOs. The MPO's prioritization criteria are compared against federal requirements and analyzed accordingly.

1.2 Problem Statement

Since the passage of ISTEA and TEA-21, MPOs, state DOTs, and other planning agencies have come under intense pressure to respond to federal mandates to integrate transportation, land use, and environmental quality in their transportation planning and project prioritization process. However, neither ISTEA nor TEA-21 specifies how the transportation-land use integration is to be achieved. The absence of the guideline, the lack of resources and the fact that most MPOs are not equipped with planning models designed for this task, make it very difficult for them to comply with these requirements.

To demonstrate challenges facing MPOs, this section explores how one of the MPOs in New Jersey incorporates the impacts of proposed transportation projects on land use into their project prioritization criteria. The project priorities produced by such criteria will be analyzed to determine how well the current practice conforms to federal mandates.

Currently, the project prioritization process is built upon six policy goals set forth to improve transportation for people and goods within the region as follows (NJTPA, 2012):

- **Environmental Quality:** Protect and improve the quality of natural ecosystems and the human environment.
- **User Responsiveness:** Provide affordable, accessible and dynamic transportation systems responsive to current and future customers.
- **Economic Vitality:** Retain and increase economic activity and competitiveness.

- **System Coordination:** Enhance system coordination, efficiency and intermodal connectivity.
- **Repair Maintenance Safety:** Maintain a safe and reliable transportation system in a state of good repair.
- **Coordinate Land Use and Transportation:** Select transportation investments that support the coordination of land use with transportation systems.

These policies are translated into project prioritization criteria which served as a score-based ranking system. The system evaluates and scores proposed transportation projects based on technical measures of how well they fulfill the policies – the higher the score, the higher the ranking. The maximum possible total score is 1,000. Figure 1.3 summarizes how policies are translated into the prioritization criteria and their predetermined scores.

Based on the criteria displayed in Figure 1.3, a physical location of the project is the only land use-related variable incorporated into the project prioritization process. In order for a project to receive scores in Land Use/Transportation Planning criteria, a project must be designed to primarily serve a designated area or is located in the designated planning area predetermined by the MPO. Clearly, this criterion exists to serve two purposes: 1) promote development and spur economic growth while improving traffic conditions within these communities, and 2) fulfill the federal mandates which require MPOs to integrate the effects of transportation decisions on land use in their planning process. The questions therefore arise:

Can a complex relationship between the transportation system and land use be explained by a factor such as project location? Also, is it correct to assume that the improvement will only stimulate economic activities and induce developments in the vicinity of the transportation project?

In general, the interactions between transportation system and land use can be explained by simple microeconomics. As cost decreases, demand increases. In this case, when travel cost is reduced because of shorter travel times, travel demand will increase and land in the vicinity of the improved area will become more attractive. However, given that New Jersey is the most densely populated state in the nation (at 1,185 residents per square mile[6]) with vacant land only presents in the southern and northwestern parts of the state, an anomaly in future land use patterns as a result of transportation projects is bound to exist. In other words, the lack of vacant land in the vicinity of the project may drive the induced development elsewhere, and thus, render the agency's land use assumptions useless.

In the above example, the Land use/Transportation Planning criterion which is meant to integrate the interactions between transportation system and land use falls short and produces results opposite to intentions. Based on current practice, any project located within the MPOs designated planning areas will have an unfair advantage in competing for limited funds even though they do not fulfill the agency's land use goals. On the other hand, other projects which may improve traffic conditions and induce development to these intended communities are at disadvantage since their benefits are not fully captured and incorporated into the analysis.

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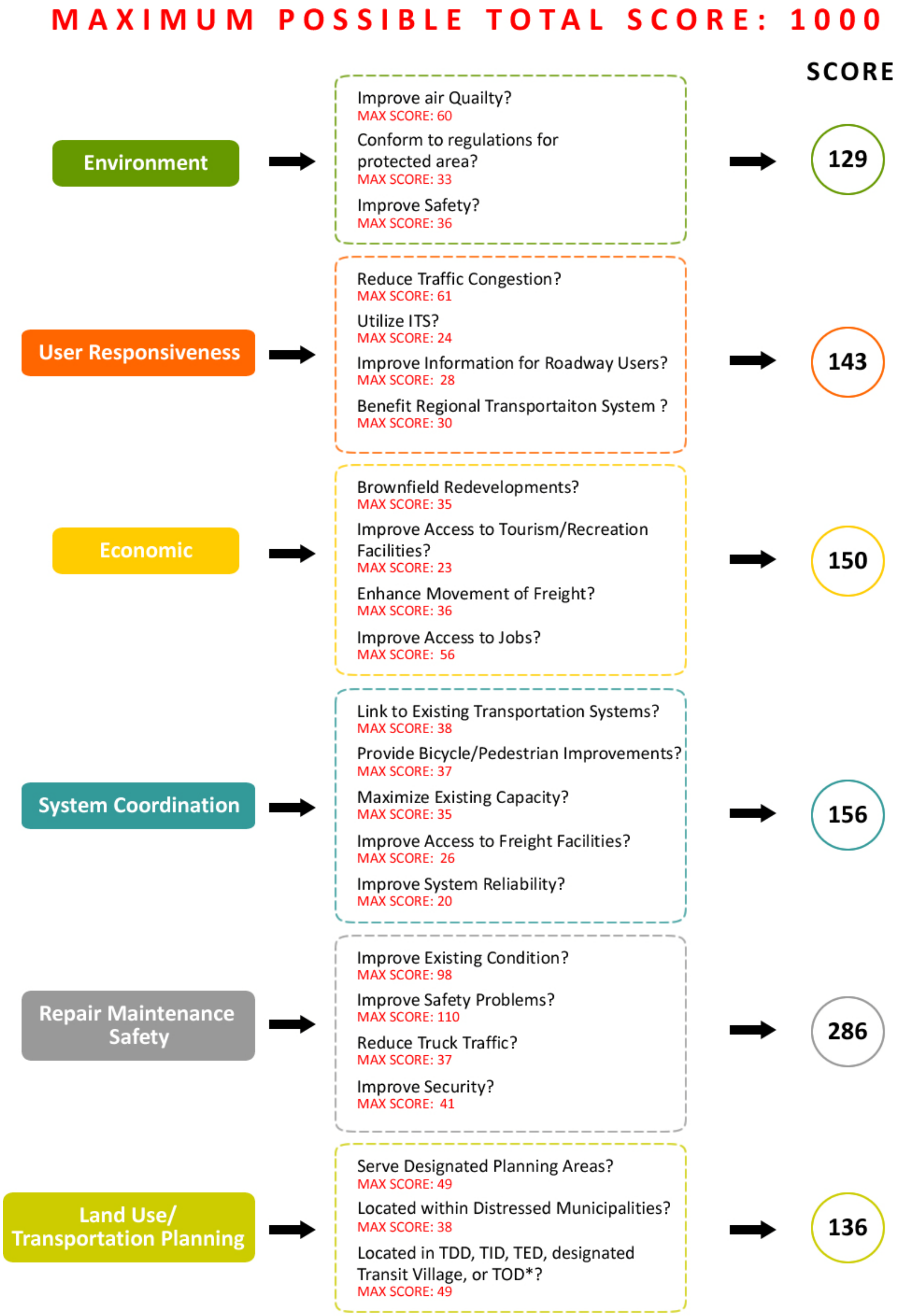
[6] U.S. Census Bureau.



*TDD - Transportation Development District, TID - Transportation Improvements District, TED - Transportation Enhancement District, TOD - Transit Oriented Development.

Figure 1.3 MPOs score-based project prioritization criteria.

1.3 Objectives

The objective of this dissertation is to present a methodological framework which will help the planning agency identify which transportation improvement projects should be undertaken, and at what location, in order to bring about desired outcomes and encourage certain land use patterns within the intended communities.

To examine the validity of a widely accepted land use assumption, the framework is utilized to determine the impacts of a transportation project not only in the vicinity of the improved area, but also on a system-wide level covering an entire region.

Through the use of this framework, a transportation agency can fulfill the federal mandates as well as pinpoint exactly where the intended benefits will occur. Thus, transportation improvement projects can be utilized as mechanisms to encourage desired land use patterns and stimulate economic development in the targeted communities.

Recognizing the time and budget constraints most states and MPOs are facing, the integrated model in this study is constructed based on data that is readily available to the planning agencies. The proposed framework is developed based on interactions between TRANSIMS[7] (an open-source travel demand model) and TELUM[8] (an open-source land use model). Through the use of TRANSIMS in conjunction with TELUM, a transportation planner can fully capture and incorporate induced travel demand into a regional transportation and land use analysis.

This dissertation describes in details how MPOs, state DOTs, and other planning agencies can create an integrated transportation-land use model from the ground up or create it as an extension to their existing analytical tools to bridge the gap between the

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[7] http://tmip.fhwa.dot.gov/community/user_groups/transims

[8] http://www.telus-national.org/products/telum.htm

two models. By utilizing this framework, not only the agency can achieve its goals, but the agency can also predict the future changes in both transportation and land use with more certainty, thus allowing the agency to effectively manage its limited funds and lead the community toward a more sustainable future.

1.4 Dissertation Organization

The dissertation is organized into nine chapters. Chapter 1 introduces the background and needs in developing the framework to integrate transportation system and land use. Chapter 2 summarizes the previous studies related to various aspects of the interactions between transportation system and land use. The quantification of such interactions is reviewed as well. Chapter 3 presents the methodology that determines the interactions between a transportation system and land use. Chapter 4 applies the discussion from Chapter 3 in order to develop the integrated framework for the case study. It presents the data requirements. Chapter 5 presents two modeling scenarios that will be analyzed and the existing land use patterns. Chapter 6 presents and discusses the results of the modeling scenarios. Chapter 7 presents and discusses the regional analysis results. Chapter 8 presents the cost benefit analysis. This analysis calculates the economic viability of a project in terms of travel time, fuel consumption, and vehicle emission. Finally, Chapter 9 summarizes the results obtained from the case study and presents the conclusions of the research. It also identifies the Dissertation’s contributions, and gives recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

Changes in transportation system affect land use patterns and changes in land use patterns inevitably have impacts on travel costs and trip generation. While most studies confirm the interrelationship between transportation and land use, not all can fully capture the complex linkage between them. The literature review in this chapter investigates the interrelationship between transportation and land use. Assuming such interrelationship exists, the question is how to measure the interactions between the two.

The literature review in this chapter consists of two sections:

- A review of literature on the impacts of transportation investment on land use patterns
- A review of algorithms and models used to quantify the interactions between transportation and land use

2.1 The Impacts of Transportation Investment on Land Use Patterns

A number of historical case studies have tied the growth and expansion of the United States closely to the improvements in the nation’s transportation system since decades before the Civil War. The accessibility created by roadway expansion was documented as one of the factors that revolutionized the nation. The transportation system changes people’s travel behavior and influences their choices of residential and employment locations. It also affects economic development by influencing the connections between demand and supply. Using housing construction statistics from 1889 to 1960, Adams (1970) developed a hypothetical model to examine the impacts of transportation system on the residential land use patterns in Midwestern cities. Four intra-metropolitan transport eras were identified and associated to the land use growth patterns:

- Walking-Horse-Car Era (1800 – 1890);
- Electric Streetcar Ear (1890 – 1920);
- Recreational Automobile Era (1920 – 1945);
- Freeway Era (1945 – present).

The land use statistics revealed that the land use patterns started to decentralize as soon as the transportation network began to expand from urban to suburban area. During 1890 to 1920, the electric streetcar was the driving force that shaped the spatial structure in urban areas and the mechanism that gave birth to suburban developments. From 1920 to 1945, due to the revolutionary in mass production of automobiles, the suburban developments continued to explode at an alarming rate that suburban residential developments exceeded those of the central cities. To cope with the shift in residential land use patterns, the majority of large cities began the construction of radial expressways in the Freeway Era. The purpose was to connect suburban population to the central business district (CBD). However, such connection had drawn more population and employment away from CBD and led to the increase in automobile-dependent suburban sprawl.

The impact of highway network expansion on residential land use pattern was also observed by Muller (1986). It was found that as the highway network further expanded, the metropolitan cities sprawled out into suburban area with new residential developments. From 1940, the population decentralization was accelerated in response to the highway network expansion, as can be seen from Table 2.1.

Table 2.1 Intra-metropolitan Population Growth Trends, 1910 – 1960

Decade	Central City Growth Rate	Suburban Growth Rate	Percent Total SMSA[9] Growth in Suburbs	Suburban Growth Per 100 Increase in Central City Population
1910 – 1920	27.7	20.0	28.4	39.6
1920 – 1930	24.3	32.3	40.7	68.5
1930 – 1940	5.6	14.6	59.0	144.0
1940 – 1950	14.7	35.9	59.3	145.9
1950 – 1960	10.7	48.5	76.2	320.3

Source: Muller (1986)

A path model was employed to trace the impacts of road improvements on travel demand and urban development (Ewing and Cervero 2001). The data for 24 California freeway projects encompassing 56 counties from 1980 to 1994 were utilized in the study. Four path models were developed as a system of log-linear equations including speed, development, demand, and supply. An analysis zone was defined as a four-mile wide buffer from the centerline of each roadway improvements. The model results revealed evidence of the interrelationship between transportation improvements and changes in land use. The induced development resulting from the increase in roadway capacity was substantially confirmed. The model outputs suggested that the influences of the roadway improvements on induced traffic were nearly four times as strong as those on induced developments. It was found that the higher operating speed was the most important factor

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[9] SMSA: Standard Metropolitan Statistical Area, comprised of the central city and the county-level political units of the surrounding suburban ring.

influencing the induced development in the analysis area. Residential development was also found to be the most sensitive to freeway improvements. The results suggested that, typically, it took around 2 to 3 years for development activity to respond to the additional roadway capacity, and another 3 years for VMT to respond to the shift in land use. The results also suggested that the co-dependencies between transportation investment and the shift in land use could be defined in term of a lagged structure which covered a period of 7 to 8 years.

A spatially explicit model based on von-Thünen theory was utilized in Belize to investigate the impact of new roadway construction on rural land use patterns (Chomitz and Gray, 1996). The study paid a particular attention on the induced deforestation which affects critical habitats and watersheds in the southern region of Belize. The model was constructed based on von-Thünen theory where a potential rent was attached to each use of each plot of land. Hence, each plot of land was devoted to the activity that yields the highest rent. The model was estimated using the land cover data covering eight towns in Belize from 1989 to 1992, representing 11,712 sample points. The data was based on SPOT satellite imagery with a base scale of 1:50,000. The land use/land cover data was segmented into about 10,000 subareas. The subareas were then categorized into 350 distinct classifications based on their chemical descriptors which determine the soil quality. To develop the model, different impedance weights were assigned to different types of terrain to reflect the relative cost of transport, the more rugged the terrain, the higher the impedance. To compute the distance to the roadway, the area was divided into 30-meter cells in which equal value of impedance was attached to it. The shortest path to the roadway was then calculated by using the standard iterative technique to determine the lowest cumulative impedance route. The model results suggested that the deforestation for commercial agriculture was highly sensitive to the proximity to the roadways and the soil quality. Where the soil quality favors agriculture and proximate to the roadway, there was a 34 percent chance that the land would be deforested and converted to commercial agriculture. The probability of commercial agriculture was also found to decline by 5.3 percent for every 1 distance index from the roadway.

Cosby and Buffington (1978) conducted a study to investigate the impact of the State Highway 30 improvement project on the land use patterns in an area of College Station, Texas. The improvement project, which began in July 1972 and completed in April 1974, upgraded the State Highway 30 from a two-lane to a four-lane facility. The facility's safety features were also enhanced by adding paved shoulders and stripping the existing medians. The land use data covered a ten-year period before, during, and after the construction was collected and used to analyze the impact of the improvement project on a study area which covered 581 acres of undeveloped land. The total acres in each type of land use and development rates before and after the improvement were estimated for both abutting and nonabutting properties. The study found that the properties abutting Highway 30 has a higher development rate than nonabutting properties during the 10 year period. This was largely due to the accessibility as a result of the improvement project which made the area more desirable for developments. Based on the land use data comparison, the improvement project induced a total of 61.34 and 7.25 acres of residential and commercial developments to the undeveloped abutting properties. Though the impact of the improvement project was less prominent in nonabutting area, it still led to a total of 17.90 and 3.31 acres of induced residential and commercial developments, respectively.

2.2 Measuring the Interactions between Transportation System and Land Use

Transportation and land use are related that changes in one thing affect the others is well established, both practically and legally. However, despite considerable research and study in the past decades, this relationship is not fully understood. And the ability to integrate transportation and land use models remains rather limited.

Although the passage of ISTEA and TEA-21 has put pressure on MPOs and other planning agencies to integrate transportation and land use in their analysis, most of the current practices still rarely acknowledge any feedback effects from transportation improvements on land use, and thereby ignoring these effects on project evaluation and plan process. This omission consequently leads to the exaggeration of social benefits resulting from the improvement projects and the understatement of their externalities.

This section review research efforts and studies that integrate changes in transportation and land use patterns in order to quantify the interactions between them.

Cervero (2003) used the path model to specify the chain of events between added freeway capacity, induced developments and traffic growth for 34 California counties. To capture the interactions between transportation and land use, data on VMT, lane miles, land use patterns, and socioeconomic factors for 24 freeway expansion projects over a twenty-year period were used to develop the model. It was found that roadway improvements, travel demand, and land use are jointly influenced each other. The roadway expansion projects did not directly affect the travel demand, rather, their influences were channeled through the improved travel speeds. The higher speeds consequently increase VMT. The path analysis showed that though the improved travel speeds were quickly eroded by the induced traffic, VMT and travel speeds would stabilize and reach equilibrium in the long run. The model estimated that about 20% of added capacity was preserved over an eight-year period following the freeway expansion. About 80% of additional roadway capacity would be filled with the additional peak-period travel demand (induced traffic). It was found that the changes in socioeconomic factors and the improved travel speeds had equal effects on the building activities along the improved corridors. This means that half of the induced developments was due to the added capacity, and the other half was the result of the changes in socioeconomic factors such as income and employment. Hence, only about 40% of the induced traffic can be considered as the direct result of the added capacity. The model also estimated the long-term elasticity of VMT with the respect to traffic speed to be 0.64, meaning that 100% increase in speed results in 64% increase in VMT.

A meta-analysis was conducted on the induced traffic resulted from regional highway expansion in Salt Lake city to identify the short and long-term elasticity of VMT with respect to lane miles and land use variables (Schiffer et al. 2005). The results concluded that the induced travel effects existed in various degrees depending on the time period and the size of the focus area. By measuring the increase in VMT with respect to an increase in lane-miles, it was found that the short-term induced travel effects were smaller than the long-term induced travel effects. The elasticity of the short-term effects was found to be in a range of near zero to about 4.0, while the elasticity of the long-term effects was between 0.50 and 1.00. The larger induced travel effects can be observed at the facility level comparing to those at the regional level. This was largely due to the different proportion of diverted traffic, that is, when measuring at the facility level, the percentage of induced traffic to the total traffic was greater than when measuring at the regional level. By investigating the induced travel effects and the land use variables, the study also identified the weakness of the traditional four-step models in capturing the relationship between roadway demand and supply. That is, the static nature of the traditional four-step models made it impossible to incorporate the changes in travel behaviors in response to changes in travel costs into the models. This means the models fail to account any induced travel demand into the future year scenarios. Hence, the results generated from such models will not predict accurate traffic patterns. The models will result in higher errors where the elasticity of commuting cost is high. And since the same parameters are carried out into future year scenarios, the models tend to overestimate the benefits of roadway improvements projects while underestimate the traffic congestion.

The cross-sectional time series data for VMT and lane miles of 50 US states between years 1984 and 1996 was utilized to develop growth, aggregate data, distributed lag, and simultaneous equation models to estimate the statistical significance and magnitude of the elasticity of VMT with respect to lane miles, land use and other socioeconomic factors (Noland, 2001). The model was estimated with different road types and further disaggregated by urban and rural classifications. According to the model results, the relationship between lane mile and VMT was found to be statistically significant and outweigh other factors such as building activities, per capita and population growth. The expansions of urban roadways were found to have greater impact on VMT growth than smaller rural road expansions which was largely due to the latent demand and greater congestion in the urban areas. Among all road types, collector road expansion was found to have the greatest influence on VMT which was most likely due the induced fringe developments that were built in conjunction with new collector road capacity. The elasticity of VMT with respect to lane miles was found to be 0.3 - 0.6 in short run (within five years after the expansion) and 0.7 - 1.0 in the long run. The elasticity values suggested that the short-run travel time benefits would eventually be diminished and the travel speeds would gradually reduce to the pre-construction level, if not lower. While 40% - 70% of the added capacity would remain unused during the first 5 years of the completion, the roadway would eventually reach the capacity due to the induced traffic and induced developments in the long run.

The log-linear models were developed to capture the relationship between the demand and supply of state highways in terms of lane-miles and VMT (Hansen and Huang 1997). The models were estimated based on two panels of area-level data covering the observations from year 1973 to 1990. The first panel consisted of 30 California urban counties that was part of a metropolitan statistical area (MSA). The second panel consisted of consolidated MSAs (CMSAs) which was the aggregations of counties that formed integral metropolitan regions. Together, the two panels account for 32 of 58 counties of the state of California. Several log-linear models, both unlagged and lagged, were developed and estimated into different versions such as regional fixed model, time period fixed model, and the combination of regional and time period fixed model. Among these, the models with the lowest value of the Akaike information criterion (AIC) were chosen. The model results confirmed that the increase in highway supply led to higher VMT and building activities. The elasticity of highway traffic with respect to California state highway capacity was measured to be 0.6-0.7 for county level and around 0.9 for the metropolitan areas. This means that, within five years of the improvement project completion, up to 90% of the added capacity would be filled with the induced traffic. The effect of induced traffic was expected to be even greater where vacant land was available for new developments. The models estimates suggested that every 1% increase in lane-mile would lead to an immediate increase in VMT of around 2% for the same time period. The results also suggested that it would take around two years after the change in road supply for the impact of vehicle-mile traveled to materialize at the county level and around four years for the metropolitan areas.

Ramsey (2005) examined the current practice of transportation planning models to verify any setbacks that might lead to inaccurate traffic forecasts. Based on the review, the greatest weakness of the current practice was found to be the missing linkage between changes in transportation systems and land use patterns. Due to the advance in technology, many transportation models are now able to simultaneously change travel schedules and destinations based on the traffic conditions, however, the majority of transportation models still lack the capability to integrate the changes in land use patterns in response to changes in transportation system into the models. The exclusion of induced traffic and induced development in the analysis would lead to substantial errors in the infrastructure project evaluations and the forecasts of future traffic conditions. In particular, when the models ignore the impact of transportation system on land use, the models tend to overestimate the societal benefits of the roadway improvement projects and underestimate the amount of traffic generated from the added capacity. In the case study, the comparison was made between two transportation planning models. The future land use projection was fixed on one model while changes could be made to the future land use patterns in the other. The societal benefits were calculated for both models. It was found that, by allowing changes in land use patterns, the societal benefits of the roadway project were dramatically decreased. This was mostly due to the induced traffic and induced development effects. The roadway improvements provided better accessibility which, in turn, encouraged automobile-dependent urban fringe development. When the auto dependency increased, the roadways became more congested. As a result, societal benefits had declined. It was found that if only 60,000 people (representing about 2% of the regional population) relocated to the fringe development area, the societal benefits of the project would be reduced by 50% comparing to the results obtained from the fixed land use model.

The least squares method was employed to quantify the amount of latent travel demand on the new transportation facilities in the state of Texas (Henk 1989). The purpose of the model was to lessen if not eliminate the errors in the design traffic volumes forecasted by traditional transportation models. Recognizing the time and budget constraints, the model was aimed to employ only the data that were readily available to the transportation planners. The model was developed based on the data of 34 study corridors obtained from 1950 to 1980. To estimate the model, the latent travel demand was determined by subtracting the pre-construction volumes from the post-construction volumes of the same corridor. Since the additional traffic utilizing a new facility within the first year represented latent travel demand in the form of either converted traffic (mode switch), diverted traffic (route switch), or induced traffic (new trips), this method allows the model to capture all components of the latent demand. The latent demand was then regressed on land use factors, V/C ratio, population density, facility type, and accessibility factors. The land use factors concentrated mainly on the developments that occurred after the roadway improvements. The population density was limited to the 3-mile radius of the improvements. The facility type was categorized to either freeway or non-freeway. And the accessibility factor was classified by whether or not the new improvements provided the crossing to and from a natural barrier (i.e., a bridge provided a crossing to the river and/or lake). Though the model only utilized the data that could be easily obtained, the predictive model was found to have a multiple correlation coefficient (R^2) of 0.69. This means that 69 percent of the variability in latent travel demand was explained by the independent variables. Also, the level of significance (*p*-value) of the model was found to be 0.0001, indicating that there was relationship between the predicted latent travel demand and the observed values.

To better handle the induced travel demand, an integrated framework between transportation and land use was implemented at the policy level in Hanover, Germany and Bristol, United Kingdom (Zaborowski, 2007). The objective of the framework was to attain sustainable accessibility for the society with minimum conflicts on economic, social and environmental issues. In both cases, the focus was put on the developments that enable people to meet their every-day needs locally through the use of public transit, cycling, and walking. With the emphasis on sustainable community, the system where transport network and land use policy could fully complement each other was created. In Germany, such system led to the “compact city” movement which attempted to reduce any external costs the urbanization process imposed on the environment as well as the society. The German transport policy gave priority to the extension of railway network and promoted the development of cycle lanes next to all types of roadways. This sustainable transport network was then collaborated with the land use policy which focused on increasing the densities, and encouraging the mixed-use developments along the railways and in the urban area. In England, besides the massive investment in rail network, the collaboration between the two policies also emphasized on the walkable community where trips by bicycle or on foot were viable alternatives to automobiles. The key policy of the British framework was promoting walking as a primary mode of travel. And the public transport interchange points were designed to reduce the walking distance between origins and destinations as well as give priority to people over the ease of traffic movement.

Yang et al. (2008) developed a Land-Use Transportation Problem based on Equity (LUTPE) model to examine the interactions between changes in transportation and land use patterns. The LUTPE model was intended to measure the relationship by estimating the potential trip generation of zonal development based on the equity consideration. The model was based on the game theory in which the network users comply with the deterministic user equilibrium (DUE) principle in route choice. To model the LUTPE, the upper level sub-problem was set to maximize the production of each residential zone subject to roadway capacity constraints and equity constraints, while the lower level sub-problem was set to characterize the network users' decisions with regard to routes, origins, and destinations, in response to the traffic conditions. Given that the proposed bi-level programming problem is intrinsically nonconvex, the Genetic Algorithms (GA) random search method was chosen to solve the model. Based on the case study results, by minimizing negative impacts on certain groups of users, the bi-level model was found to have the capability to predict the amount of induced travel demand that would be accommodated by the road network. Thus, it could be utilized as a powerful policy tool to address the impact of land use changes on traffic growth.

An integrated land use and transportation model, Sacramento MEPLAN model, was employed to evaluate the transportation improvement alternatives in Sacramento region, California (Rodier, et al. 2001). The purpose of the study was to incorporate the induced travel demand into the transportation analysis. The basis of the modeling framework was the interaction between two parallel markets – the land market and the transportation market. Based on the demand and supply logic, as both markets attempted to maximize their utilities, the travel mode, route choice and activity location with the lowest cost would be selected. The land market model in MEPLAN framework utilized the logit model to allocate volumes of activities to different geographic zones. The model focused mainly on the floor space utilized by activities in each zone. It was constructed based on eleven employment industries, three categories of household income, and eight types of land use classifications. The attractive of each zone was based on the total cost function which derived from the transportation cost and real-estate cost. The MEPLAN framework was quasi-dynamic which moved through time steps from one time period to the next. The feedback loop between the land use and transportation began with utilizing the land market model to generate origin-destination matrices of different types of trips. These matrices were then loaded on to a multi-modal network. The mode and route choices were determined by the nested logit traffic assignment model. The feedback loop was accomplished by feeding the network times and costs obtained from the transportation market model back to the land market model to simulate the changes in land use for the next time period. The Sacramento MEPLAN model was simulated to examine 10 transportation scenarios which were made in the year 2005. The model results were compared to the previous works which excluded the induced travel demand. It was found that the previous works overestimated the congestion reduction, emission reduction and employment location changes in a 20-year time horizon. Furthermore, the results strongly suggested that a fair evaluation of transportation projects could only be achieved through the use of the framework that allowed the integration between transportation system and land use.

Zhao and Chug (2003) developed a temporal GIS data model to identify the spatial and temporal interactions between transportation and land use. The model was constructed from the historical building permits data and transportation improvement project information from 1987 to 2001, covering Miami-Dade County, Florida. The land use variables in the models were categorized into either commercial or residential developments which were represented in terms of the sum of building square footage of applied building permits in a time unit. The transportation improvement variable in the model was the lane mile increase which was computed as the product of number of lanes and length of the improved section. The model was estimated by the least square method and GARCH method. Based on the model's results, it only took around two months for the land use to begin responding to the changes in transportation. And once the induced developments started, it took around 21 months for it to stabilize. The results of the time-series analysis also revealed that transportation improvements impacted land use at varying rates and intensities. The cumulative effect from a roadway improvement in the study corridor was found to be around 349,765.2 and 60,654.9 square feet for residential and commercial developments, respectively.

Payne-Maxie Consultants (1980) conducted a study, jointly commissioned by the U.S. Department of Transportation (USDOT) and the U.S. Department of Housing and Urban Development (USHUD), to examine the impacts of beltways on land use and urban development. The study involved a comparative statistical analysis of 54 metropolitan areas (27 with beltways and 27 without beltways), and eight case studies of beltways in Atlanta, Baltimore, Columbus, Louisville, Minneapolis-St. Paul, Omaha, Raleigh, and San Antonio. The analysis of variance (ANOVA) and multiple regression model were developed in this study to analyze the influence of beltway. The statistical models were built based on the data collected for the 1960-1977 time period which categorized into seven categories including: general economic and demographic information, employment and investment figures, retail trade statistics, commuting information, highway and beltway descriptions, socioeconomic indexes, and residential moving patterns. The data also included several indicators of beltway characteristics such as length in miles, number of interchanges, interchange density per mile, age, and location in terms of distance from CBD and political jurisdiction (central city or suburb) in which the beltway was located. Based on the results, the existence of beltway appeared to have impacts on urban development; however, the impacts were neither large nor consistent over time.

It was found that the construction of beltway led to the increase in urban fringe developments. The location of beltway was found to have great impacts on manufacturing, wholesale and employment growth in central cities. The results also suggested that beltway attributes such as length, interchange spacing, and distance from CBD had more influences on urban development patterns than the existence of beltway itself.

In response to USDOT emphasis on assessing the impacts of transportation improvements using a transportation-land use model system, Indiana Department of Transportation (INDOT) had developed the ISTDM-LUCI2 model which integrated the Indiana statewide travel demand model (ISTDM) with the Land Use Central Indiana 2 (LUCI2) urban simulation model (Jin and Fricker, 2008). ISTDM was a four-step travel demand model which included 11,200 road-miles of state highways and 7,800 road-miles of local roadways. The network covered the entire ninety two counties of the state of Indiana and encompassed parts of the neighboring states. LUCI2 was a statewide land use urban simulation model which utilized random utility theory and aggregated logit model to predict changes in employment and convert available nonurban land to residential and commercial developments.

To integrate ISTDM and LUCI2 models, the distance variable which was used to measure the accessibility in LUCI2 model was replaced by the updated travel time index from ISTDM model. This change allowed LUCI2 model to simulate changes in land use patterns based on changes in traffic condition and socioeconomic patterns. The lagged outputs from LUCI2 model then served as feedback to ISTDM model, forming a quasi-dynamic model for each five-year simulation period. The integrated ISTDM-LUCI2 model was run from year 2000 to year 2030. When compared to ISTDM model's results, it was found that the total VMT in the state of Indiana increase by 12.37%. This means that statewide network was predicted to be more congested when the interactions between land use and transportation system was included into the analysis.

To capture the effects of changes in transportation system on land use, and the consequent feedback effects on transportation system performance, the framework integrating UrbanSim and Wasatch Front Regional Council (WFRC) four-step travel model system was developed (Waddell et al. 2007). The models were tested and validated on network covering the Greater Wasatch Front Area, containing 80% of Utah's population and centered on Salt Lake City. UrbanSim and the WFRC models were interfaced periodically, with the intervals being no longer than 5 years. The specific interaction years used in this analysis were 1997 (Base Year), 2000, 2003, 2008, 2012, 2016, 2020, 2025, and 2030. Based on the results, the induced demand effects were quite significant in magnitude. By accounting the feedback between transportation and land use, the predicted Vehicle Miles Traveled (VMT) and Vehicle Hours Traveled (VHT) increased by 5% compared to the 2030 baseline model forecast which did not account for the land use feedback effects. The Total Congestion Delay (TDC) increased by almost 16% compared to the baseline model forecast. The models' results also confirmed induced congestion as a result of highway improvement projects. It was found that the elimination of highway projects in a rapidly growing section of Southwest Salt Lake County led to a 0.7% decline in both VMT and VHT and a 2.3 % decline in TDC comparing to the baseline scenario. The impact of land use policy on transportation system was also tested, by imposing a boundary limiting urban expansion, it was found that the VMT, VHT, and TDC decreased by 3.3%, 2.3% and 3.0%, respectively, comparing to the baseline model.

UrbanSim, an open-source model for microscopic simulation of land development, was used in conjunction with a transportation model to forecast the land use patterns in year 2030 for Austin region, Texas (KarthikKakaraparthi and Kockelman 2010). The Austin regional network was divided into a 150 m x 150 m grid cells (5.56 acres) where households and employments were spatially placed accordingly. Intensive sets of data were required to calibrate and run UrbanSim. These included grid-cell-level data sets of household, employment, built space, transportation, and energy. Though some restrictions on the data collection process were relaxed, it took approximately two person-years to obtain all the required data to run UrbanSim on the Austin region.

To create the feedback loop between a travel demand model and UrbanSim, regression models were used for trip generation, a multinomial logit model of household location choice was used for trip distribution, and deterministic network assignment routines were performed to obtain estimates of interzonal travel time and costs. To generate the results, UrbanSim was run every year from 2001 to 2030, and the travel demand model was run at a five-year interval from 2005 to 2030. Six modeling scenarios were developed in the study to investigate the impacts of transportation system on the future land use patterns including: 1)a No travel demand model (NoTDM) scenario in which the UrbanSim was ran continuously for 30 years without transportation model integration, 2) a Business as usual (BAU) scenario in which the Austin's transportation network was held constant over an entire forecast period, 3) and Urban Growth Boundary (UGB) scenario where the developments were allowed only within the designated urban area, 4) a double Travel-Cost Sensitivity (TCS) scenario, 5) an expanded network (EXPAN) scenario where the capacities of three major arterials in the Austin's network were doubled, and 6) an additional 49.2-mile stretch was added to the existing SH130 freeway (SH 130).

The model results suggested decentralizing patterns of households when comparing the BAU scenario to the NoTDM scenario. This means that when the transportation system fails to accommodate the growing society, the society compensate the rising transportation costs by migrating to the area where land prices were lower than CBD. The utility maximization patterns were also observed in the UGB scenario. The results showed that despite the employment growth that continue to centralize in CBD, the majority of household developments was found in the northern part of the designated urban area where abundant vacant lands existed at the lower prices. In the TCS scenario, where travel cost sensitivity was doubled, all jobs and households appeared to move closer to CBD in order to reduce their travel costs comparing to the BAU scenario. In the EXPAN and SH 130 scenarios, as expected, a pattern of induced developments emerged along the improved corridors to take advantage of new accessibility and lower travel costs.

The ILUMASS (Integrated Land Use Modeling and Transportation System Simulation) project was carried out between year 2002 to 2006 in Germany to develop a microscoping dynamic simulation model that captures the interrelationship between transportation system, land use, and environment in urban regions (Wager and Wegener, 2007). The project was the collaboration among seven research institutes which aimed to simulate urban traffic flows into a comprehensive model system that incorporated changes of land use, the resulting changes in activity and travel demand, and the impacts of transport on the environment.

The ILUMASS consisted of three main modules: 1) The land use module (IRPUD) which modeled the demographic development, household formation, firm lifecycles, construction activities, employment mobility in the regional labor market and household mobility in the regional housing market, 2) The transport module which modeled daily activity patterns based on socio-demographic data of each household member, travel modes based on the availability of vehicles in each household, departure time based on individual's schedule and traffic conditions, and the travel route which determined by the shortest-path algorithm, 3) The environment module which calculated the environmental impacts of transport and land use model, such as greenhouse gas emissions, air pollution, traffic noise, and barrier effects.

The study area of the ILUMASS project consisted of the metropolitan area of Dortmund in the Ruhr industrial district in Germany. The area comprised 26 municipalities with a population of 2.6 million and about 85,000 firms. The study area was divided into 352,000, 100m by 100m, grid cells. The synthetic population with identical statistical features corresponded to that of the real population was created for all 2.6 million population. The ILUMASS model started by running the transport module and followed by the environment module to generate travel demand, travel patterns, travel speed data, and environmental impacts. These results were then fed into the land use module to generate a new socio-economic and spatial structure for the following year. The ILUMASS model cycle was completed by feeding back the future land use patterns into the transport module to generate a forecast for the future traffic conditions. Due to the time-consuming nature of the simulation, only two scenarios were tested: 1) the baseline scenario where no policy intervention is allowed, and 2) the "compact city" scenario where new commercial and industrial developments are only allowed in the city of Dortmund.

The ILUMASS model was run from year 2000 to 2030. The results suggested that with the absence of land use policy, the suburbanization of workplaces continued to grow over the years. As the traffic congestion worsens, the larger cities in the study area including the city of Dortmund continued to lose commercial developments to the suburban areas. However, when the anti-sprawl policy was in place, not only the city of Dortmund enjoyed more development activities, a better traffic condition was also achieved as a result of better accessibilities.

2.3 Summary

The literature review provides the insight of how changes in transportation system affect land use patterns. When the travel cost falls, more users are encouraged to utilize the improved facility and more developments are induced to the vicinity areas. The literature also indicates the inaccuracy which may arise if the induced travel demand is excluded from the transportation analysis. Although many studies have successfully captured the interactions between transportation system and land use, these studies require comprehensive set of data, large amount of budgets, long analytical period, skilled personnel, and many other resources which may not be accessible to all planning agencies. Thus, the integrated framework which is constructed based on data that is readily available to the planning agencies should bring significant benefits in comparison to the costly alternatives. The relaxed data requirements and the less intensive data collection process not only allow planning agencies to develop the models in the timely manner, but also allow agencies of any size to incorporate induced travel effects into the analysis within the budget constraints.

CHAPTER 3

FRAMEWORK DEVELOPMENT

This chapter begins with an overview of the methodology used to develop a framework to integrate TRANSIMS and TELUM models. The framework discussion continues with a general summary of TRANSIMS and TELUM models and the interactive process of integrating the two models is discussed in detail.

3.1 Methodology Overview

To understand the transportation system, one needs to understand the relationship between transportation and land use. This connection can be viewed as a reciprocal relationship where supply and demand of the two systems are mutually interdependent.

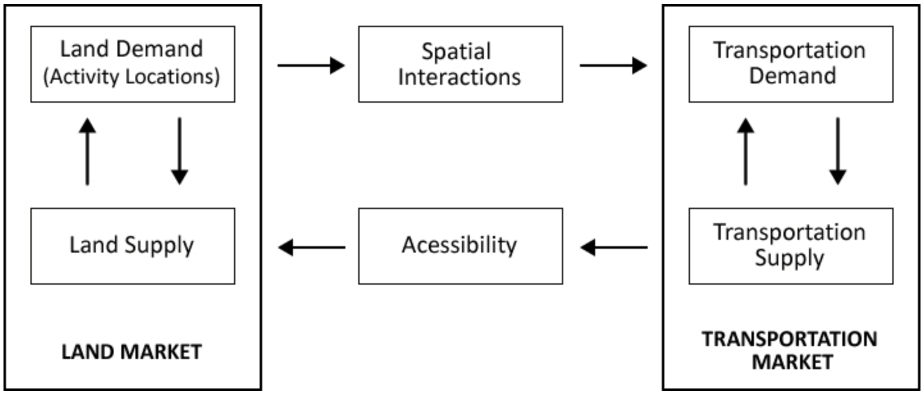

Figure 3.1 The reciprocal relationship between transportation system and land use.

As illustrated in Figure 3.1, the demand for available land interacts with the supply of land in the land market and the demand for transportation services interacts with transportation supply within the transportation market. The interaction between these two markets induce travel demand (i.e., students traveling to school, workers commuting to work, shoppers traveling to stores, etc.) caused by the spatial interactions between activities. At the same time, the accessibility provided by the transportation system induces activity location choices (i.e., residential and commercial developments are more likely to locate at points of higher, rather than lower, accessibility).

The proposed framework incorporates induced travel demand into the project evaluation process. A three-step iterative process between the two models is developed to estimate and quantify the induced demand. The steps are as follows:

- Estimate induced development
- Translate induced development into future O-D matrices
- Estimate future traffic patterns as a result of interactions between land use and transportation system, accounting for the induced travel demand.

For example, to perform a 10-year transportation analysis for any transportation improvement project, a land use model will determine the future locations of households and employment for the first 5-year period. The locations are determined based on the travel patterns produced by a travel demand model for the roadway network with highway improvements. These future land use patterns are translated into the future O-D matrices utilized by the travel demand model to generate forecasted future traffic flows on the regional transportation network for the first 5-year period.

At this point, the changes in both travel demand and land use are fully incorporated into a travel demand model's outputs. In other words, the outputs of a travel demand model contain induced demand from both land and transportation markets.

To generate the forecasts for the next 5-year period, a planner would again engage in a three-step iterative process. The inputs for a travel demand model and land use model are the forecasted future traffic flows from the first 5-year period. The result from a travel demand model is used as an input to a land use model to forecast future land use patterns. The land use patterns would then be translated into the future O-D matrices that are inputs to a travel demand model that will generate traffic flows for the second 5-year period.

3.2 TRANSIMS Overview

TRANSIMS (the Transportation Analysis and Simulation System) is part of the Travel Model Improvement Program (TMIP) sponsored by the U.S. Department of Transportation (USDOT) and the Environmental Protection Agency (EPA). TEA-21 has set aside $25 million in funding for TRANSIMS completion and deployment. TRANSIMS is a disaggregate travel demand forecasting model which simulates second-by-second movements of every individual and every vehicle in the transportation network. Simulation is performed based on the interactions between vehicles rather than deterministic equations. The household and personal demographics such as the age of an individual, the person’s income, gender, and employment status are the factors that are used to determine individuals’ locations and their activities. Thus, the movements in TRANSIMS represent realistic traffic dynamics produced from interactions of individual vehicles (LANL, 1999). The TRANSIMS model, applied in this dissertation, consists of three main modules including:

Route Planner module: Route Planner module computes routes by mode for each individual in order to accomplish their scheduled activities during the analyzed period (trip to work, shopping etc.) The route plans are based on a time-dependent shortest path algorithm for every individual.

Traffic Microsimulator module: Traffic Microsimulator module executes travel plans generated by Route Planner module and computes the overall intra- and inter-modal transportation system dynamics. It is updated every second and continuously computes the operating status, including speeds, acceleration, and deceleration of all vehicles throughout the simulation period. The output of the Traffic Microsimulator module is a detailed, second by second history of every traveler in the system during the simulated time period.

Feedback Controller module: Feedback Controller module is a primary mechanism used to achieve internal consistency among modules. Through the use of selector tools (i.e., PlanSelect, ProblemSelect, and PlanCompare programs), Feedback Controller module controls when the modules are run and how the data are routed between modules as an iterative process. For example, the selector script may be written so that TRANSIMS utilizes ProblemSelect program to select a subset of households containing travelers who are more than 20 minutes late for work, and then requests the Route Planner to be run for those selected travelers. The feedback process between modules not only nudges TRANSIMS model toward convergence, but also allows the model to abstractly reflect learned behaviors where travelers emulate the ability to avoid congestion.

3.3 TELUM Overview

The Transportation and Economic Land Use Model (TELUM) is an integrated, interactive model that examines the interrelationships between transportation infrastructure and land use patterns. TELUM draws upon current and historical household, employment, and land use data to make long term forecasts of the spatial distribution of new residential and nonresidential development based on the analysis of prior and existing patterns, the location of transportation improvement(s), and overall congestion in the system. TELUM uses both regional and zonal data. A region refers to the specific geographic area being modeled, typically a county or group of counties. A zone, on the other hand, is a relatively small subdivision. U.S. Census tracts are commonly used to represent zones. Zones with average populations between 3,000 and 10,000 persons are best suited to the TELUM modeling process. A region may have between 100 and 300 zones. TELUM has a maximum number of zones set to 800.

Two main spatial allocation models, the Disaggregated Residential Allocation Model (DRAM)[10] and the Employment Allocation Model (EMPAL)[11], are integrated into the TELUM framework. In TELUM, they are known as TELUM-RES and TELUM-EMP. TELUM-RES is used to quantify the interactions between regional population location patterns and the underlying transportation network. TELUM-EMP is used to quantify the interactions between employment location patterns and the underlying transportation network.

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[10] Forecasts residential locations by allocating their place of work to residential zones. The forecast is done on the basis of the attractiveness of residential zones and the travel time and/or cost between place of work and place of residence.

[11] Forecasts employment locations by allocating households to work zones. The forecast is based on the attractiveness of work zones and travel time and/or cost between homes and work places.

TELUM forecasting is done in time increments of five years. Such intervals allow for the adjustment of employment, residence, land use, and transportation forecasts in response to changes of each other within the interval. Each forecasting iteration begins with the execution of TELUM-EMP which produces a forecast of the spatial distribution of employment by employment type. The output of TELUM-EMP is then used as an input of TELUM-RES to produce the spatial distribution of households by income group given the forecasted locations of employment. Finally, the land consumption sub-model (LANCON) calculates land consumption by making a simple reconciliation of the demand for location by employers and households with the supply of land in each zone.

These residence and employment location forecasts produced by TELUM are used as inputs to a travel demand forecasting model (e.g., trip generation, trip distribution) to produce a trip table with the travel pattern forecast for the same time period. These trip tables are input in the TRANSIMS model which consequently calculates traffic flows on the network, speeds and the highway volume/capacity (V/C) ratios.

3.4 Interactive Process between TRANSIMS and TELUM Models

The interactive process between TELUM and a generic travel demand model is shown in Figure 3.2. The interaction between the two models is twofold. The travel demand model generates zone-to-zone travel time which is one of the inputs for TELUM. TELUM model generates the forecast of future residential and employment land use patterns. These newly acquired land use data enable the travel demand model to develop new trip patterns.

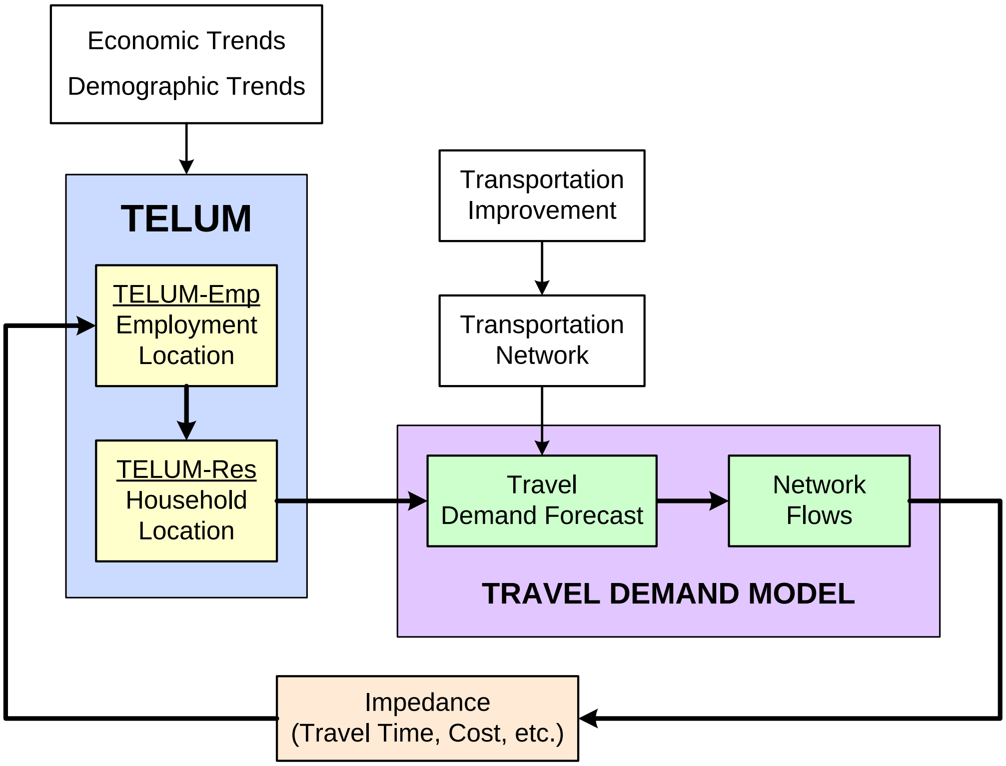

Figure 3.2 Schematic description of the feedback loop between TELUM and travel demand forecasting model (The feedback loop is represented by the bold arrow-lines).

The interactive process between TRANSIMS and TELUM consist of the following sub-processes:

1. TRANSIMS Model -- Optimal Assignment and Travel Impedance. The TRANSIMS model performs a series of iterations that result in an optimal assignment of vehicles across the network (dynamic user equilibrium). After the dynamic user equilibrium is achieved the travel impedance (or skim) file is generated.

2. TELUM Model -- Running the TELUM with Travel Impedance. The travel impedance file, population and household data are inputs into the TELUM model. The results produced by TELUM model are the future spatial locations of residential and commercial developments.

3. Future Trip Distribution -- TELUM's outputs are translated into trips and used to modify the existing origin and destination (O-D) trip matrices.

4. Simulating Future Trips across the Network -- Finally, the modified or adjusted O-D trip matrices are fed into TRANSIMS model to produce forecasts of future traffic flows.

Figure 3.3 illustrates the feedback loop that integrates TRANSIMS and TELUM models which is applied in this dissertation to evaluate the impact of traffic improvements on changes in the land use patterns.

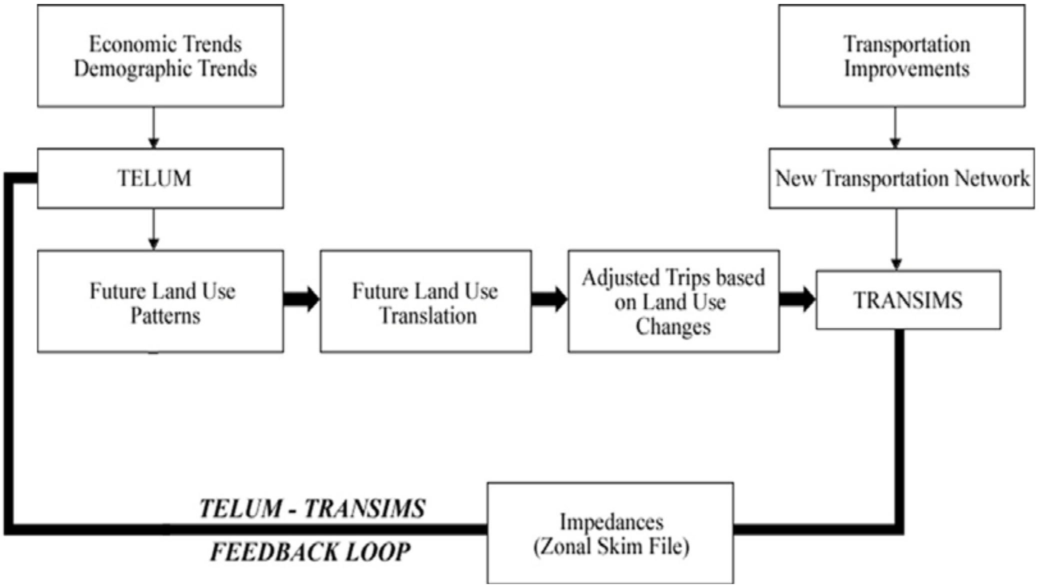

Figure 3.3 Schematic of the Interaction between TRANSIMS and TELUM.

CHAPTER 4

CASE STUDY: TRANSIMS AND TELUM MODEL DEVELOPMENT

Chapter 3 provided an overview of the framework integrating TRANSIMS and TELUM models. This chapter applies the discussion from Chapter 3 in developing the integrated framework for the case study. This chapter will also present the data requirement in developing these two models.

The case study is based on the New Jersey Department of Transportation improvement project of Route 18 in New Brunswick, Middlesex County, which underwent a long-awaited major reconstruction designed to enhance the safety and operations for motorists, pedestrians and bicyclists.

The following steps are taken in the process:

- **TRANSIMS model development.** The development of the transportation network that will capture changes in speed and travel time as a result of network improvements.
- **TELUM model development.** The development of the zonal structure for the study area with all socioeconomic data.
- **Development of the feedback loop between the two models.** Multiple regression models are developed and utilized to translate future residential and commercial developments into trip productions and trip attractions, respectively.

4.1 Geographical Location of Route 18 Reconstruction Area

The geographic location of the Route 18 reconstruction area is in the vicinity of the city of New Brunswick in Middlesex County, New Jersey (Figure 4.1). New Jersey Route 18 is a 4-lane signalized arterial that provides access to New Brunswick, Rutgers University, Johnson & Johnson's Corporate Headquarters, Saint Peter's University Hospital and

Robert Wood Johnson University Hospital, local businesses, performing arts centers and residential neighborhoods.

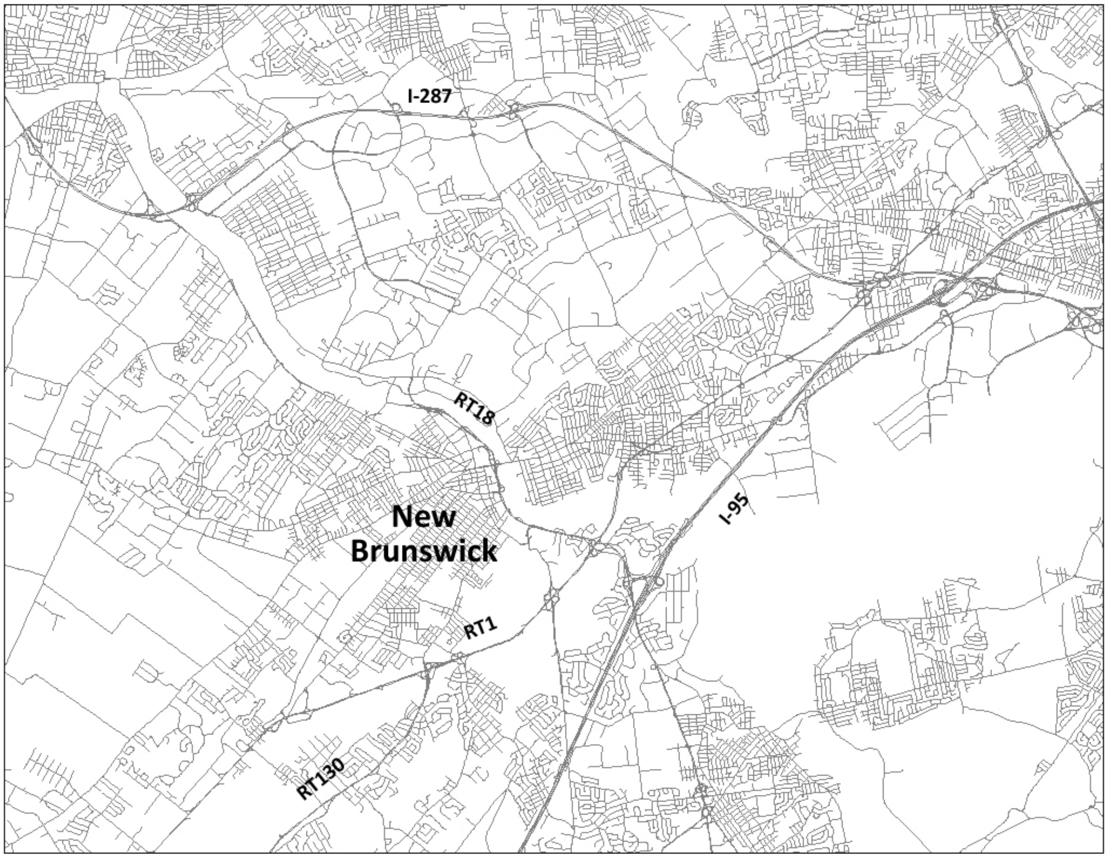

Figure 4.1 Analysis area.

In 2009, Route 18 carried an Average Annual Daily Traffic (AADT) of over 85,000 vehicles per day and is considered one of the most heavily congested corridors in the state. The primary study area is identified as a 4-mile section of Route 18 (Figure 4.2), between milepost 40.61 (interchange of Route 18 and US 1) and milepost 42.54 (interchange of NJ 18 and Amtrak railroad line). The purpose of this reconstruction project is to improve safety and enhance traffic operations by eliminating substandard geometric features. The project's intent is to improve access to and from New Brunswick and enhance access for pedestrians and transit users. It is expected to cost $ 200 million and be constructed in four years, with planned completion date in summer of 2010.

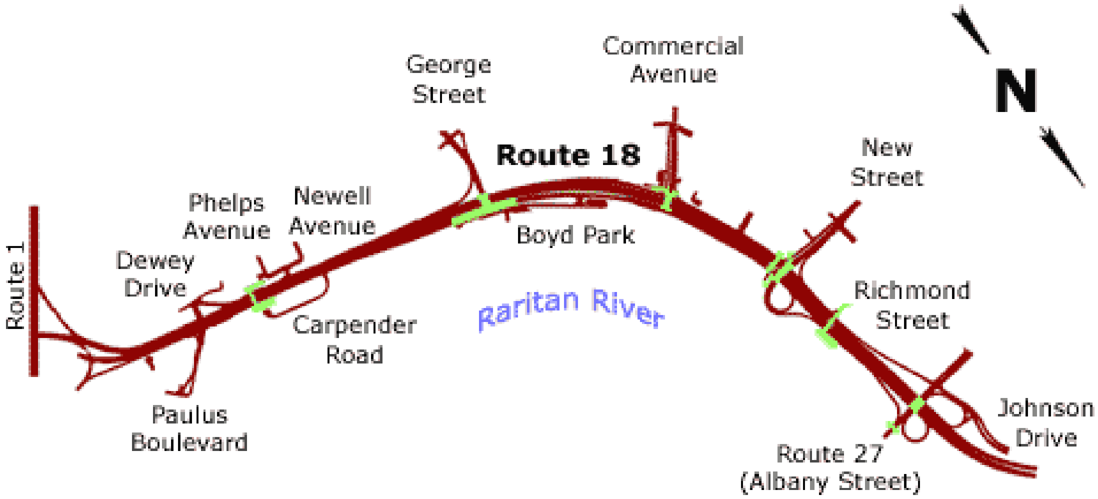

Figure 4.2 Proposed sections of Route 18 for reconstruction, highway structures highlighted in green.

Source: http://www.state.nj.us/transportation/commuter/roads/route18/map.shtm.

4.2 TRANSIMS Model Development

The TRANSIMS model for this dissertation is based on the existing North Jersey Regional Trip-based TRANSIMS model[12] which is centered on Middlesex and Monmouth Counties. It includes a total of approximately 700,000 auto trips in the peak period in Middlesex and Monmouth Counties. It consists of 5,381 lane miles and 14,154 activity locations. The model's network is shown in Figure 4.3.

Due to the purpose of the dissertation, particular attention will be paid on the highway network in Middlesex County. The network zonal structure of the Middlesex County portion is aggregated into 576 block groups based on the data from the 2000 US

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[12] The model is developed under a separate FHWA project with CUPR at Rutgers University

Census. The same data are used to match the structure of the land use TELUM model. Figure 4.4 shows the zonal structure of Middlesex County, New Jersey.

For the complete data utilized in developing TRANSIM model, refer to Section 4.5 of this chapter.

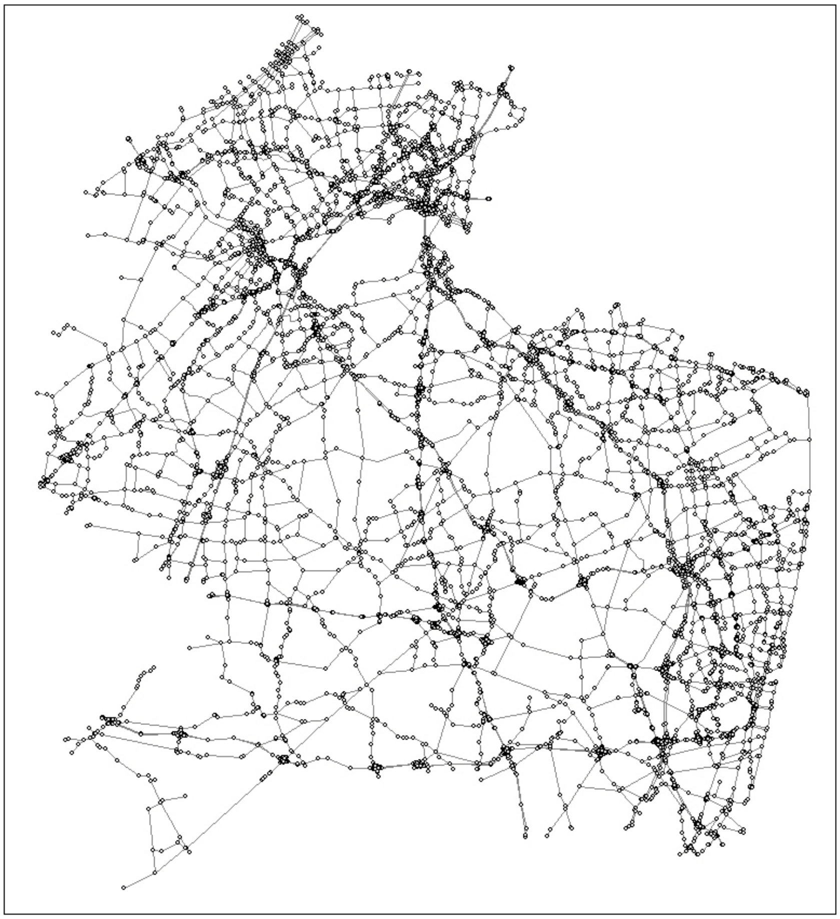

Figure 4.3 North Jersey regional trip-based TRANSIMS's model highway network.

To validate TRANSIMS model, a total of 220 feedback iterations are run with year 2000 demand (refer to Appendix F). Travelers are randomly selected at certain iterations to observe the impact of router stabilization process on their route choices. The improvement in their paths and the corresponding decrease in their travel time as the model moves toward convergence are displayed and discussed in Appendix F.2.

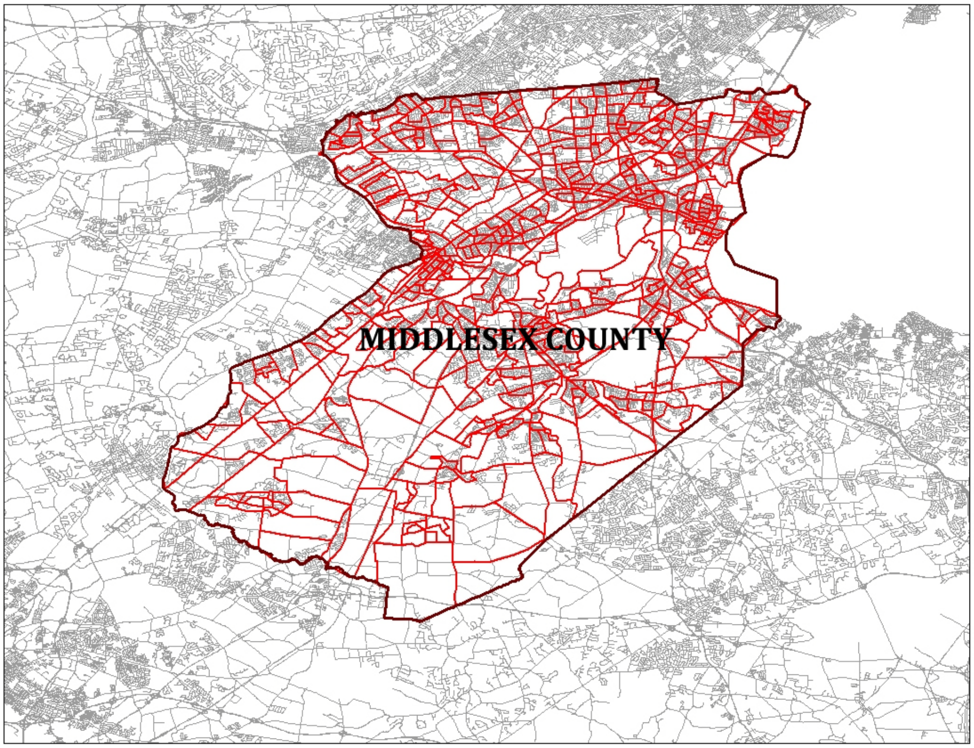

Figure 4.4 Zonal structure of Middlesex County, New Jersey with 576 zones.

The TRANSIMS model is validated against the existing traffic counts obtained from the New Jersey Department of Transportation for the roadways within Middlesex County, New Jersey. These traffic counts are collected between the years 2006 and 2008. A total of 305 Automated Traffic Recorder (ATR) records are available for the study area and are used for model validation. The model is validated in terms of link traffic volume levels and highway facility types (refer to Appendix F.3 for the complete validation statistics and discussion).

A total of 785 TRANSIMS feedback iterations are run to generate results for all analysis scenarios: 220 iterations for baseline scenario-year 2000, 100 iterations for baseline scenario-year 2005, 135 iterations for baseline scenario-year 2010, 90 iterations for built scenario-year 2000, 90 iterations for built scenario-year 2005, and 150 iterations for built scenario-year 2010 (refer to Appendix G for TRANSIMS model simulation results and the convergence statistics summary).

4.3 TELUM Model Development

The land use data for TELUM is based on the land use/land maps (cover data) obtained from New Jersey's Department of Environmental Protection (NJDEP, 2000). The regional and zonal household and employment data used in this model are based on US Census 2000, Public Use Microdata Sample (PUMS 2000). The employment data is obtained from U.S. Census Bureau and U.S. Department of Labor.

The TELUM model has 576 zones, each of which corresponds to a census block of Middlesex County (shown in Figure 4.4). The model is built upon current and historical household, employment, and land use data of Middlesex County.

In 2000, there were a total of 266,402 households in Middlesex County having a median income of $61,446. The household data is categorized into seven groups based on household income. The resulting classification is shown in Table 4.1.

Table 4.1 Year 2000 Classification of Household by Income Group

Income Type	Household Income	Number of Households
1	Up to $19,999	33,226
2	$20,000 to $34,999	34,986
3	$35,000 to $49,999	37,169
4	$50,000 to $59,999	23,926
5	$60,000 to$74,999	33,526
6	$75,000 to $99,999	42,671
7	$100,000 or more	60,898
Total		**266,402**

Source: U.S. Census Bureau

In 2000, there were a total of 369,221 jobs in Middlesex County. The employment data in the model is categorized into seven groups based on the Standard Industrial Classification (SIC) Code. The classification is shown in Table 4.2.

Table 4.2 Year 2000 Area Employment by SIC Code

Employment Type	Employment Sector by SIC Code	Employment
1	Educational, health and social services	67,718
2	Manufacturing	57,657
3	Professional, scientific, management, administrative, waste management, armed forces, and other services	70,442
4	Retail trade	42,495
5	Finance, insurance, real estate, rental, leasing, information, arts, entertainment, recreation, accommodation, and food services	69,301
6	Construction, agriculture, forestry, fishing, hunting, and mining	16,541
7	Wholesale trade, transportation, warehousing, and utilities	45,067
Total		**369,221**

Source: U.S. Census Bureau

One of the objectives of this dissertation is to demonstrate the ability of this framework to predict future changes in both transportation and land use. Thus, the socioeconomic projections for year 2005[13] and 2010[14] are implemented in the TELUM model. It is projected that the population and employment in 2005 will be 783,700 and 378,110, respectively, and 803,500 and 387,214 in 2010.

For the complete data utilized in developing TELUM model, refer to Section 4.5 of this chapter.

4.4 The Interactive Process between TRANSIMS and TELUM

This section discusses the development of multiple regression models for estimating trip productions and attractions. It also discusses the models selected for implementation in detail, explaining how they will be used to estimate the future origin-destination trip matrices. These O-D matrices will be used in the analysis of different travel demand scenarios.

For details regarding the commonly deployed trip generation and trip distribution models, refer to Appendix H and I, respectively.

4.4.1 Translation Process Overview

After the traffic flow equilibrium is approximated and the zone-to-zone skim file is generated from TRANSIMS model, the zone-to-zone skim file is fed into TELUM model to generate the future land use patterns. To complete the feedback loop between TRANSIMS and TELUM models, these future land use patterns must be fed back to TRANSIMS model. The question therefore arises: how can changes in land use patterns

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[13] obtained from the US Census Bureau
[14] obtained from the US Census Bureau

forecasted by TELUM be translated into corresponding future trips and used as inputs to TRANSIMS model?

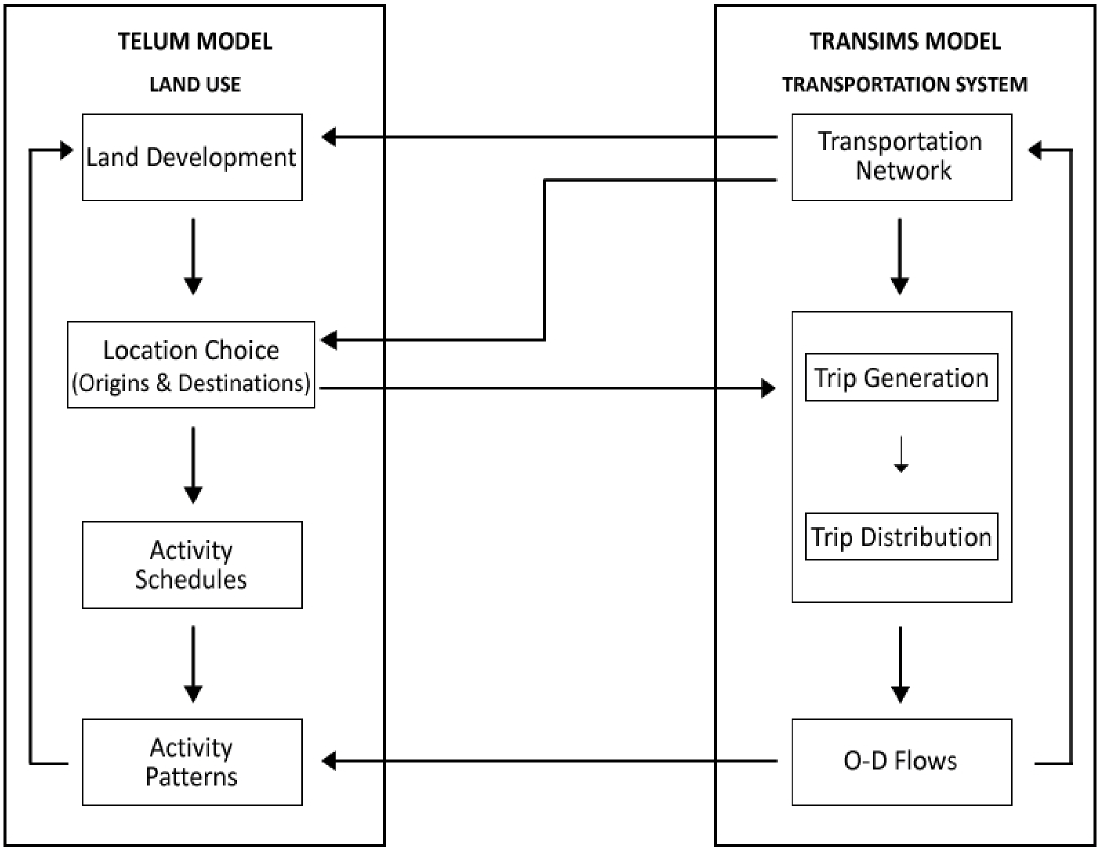

Figure 4.5 Land use and transportation system interactions.

According to Figure 4.5, future land use patterns forecasted by TELUM have a direct impact on trip generation and trip distribution utilized in TRANSIMS model. Thus, in order to convert future land use patterns into future trips, all future residential developments must be translated into future trip productions and, likewise, all future commercial developments must be translated into future trip attractions. These newly translated trips must then be distributed among all zones in TRANSIMS network.

It should be noted that although the translation process discussed in this chapter is developed for a trip-based TRANSIMS model, it is applicable for both trip-based and activity-based TRANSIMS models. For activity-based TRANSIMS model, the translation process will be used to convert the future land use patterns forecasted by TELUM into future activities rather than future trips. These future activities will then be assigned to synthetic individuals in order to generate activity-based traffic patterns for the same time period.

4.4.2 Estimating Origin-Destination Matrix for the Subsequent Analysis Year

TELUM generates the allocation of households and employment to all zones in the network. These allocations will produce and attract trips. The trips need to be tied together into trip interchanges and turned into the internal origin-destination trip tables.

In order to generate the trip table, a two-step process is developed. In the first step, a Multiple Regression Model for Trip Generation is developed. This method will translate the TELUM's households and employment outputs into future trips produced by and attracted to each zone. Trip production will be expressed as a multiple linear or non-linear regression model which will be a function of household types. Trip attraction will be expressed as a multiple linear or non-linear regression model which will be a function of employment types. In the second step, after zonal trip productions and attractions are estimated, the Furness Method will be utilized to generate the zone-to-zone trip tables.

The following actions are required to produce a set of future origin-destination trip matrices.

- Trip Production Estimation
- Trip Attraction Estimation

- Matching Productions and Attractions
- Trip Distribution

4.4.2.1 Trip Production Estimation. Starting from the household data categorized in terms of household income, the following multiple regression equation is stated:

$$O_{vi} = \beta_0 + \beta_1 H_{11} + \beta_2 H_{12} + \ldots + \beta_p H_{ip} \tag{4.1}$$

where

i = Zone index (i = 1, …, N),

p = Household income category index (p = 1, …, n)

v = Vehicle Class (v = SOVS - Single Occupancy Vehicles, HOV2 - 2 Person Occupied Vehicles (HOV2), HOV3 and HOV4 - 3 and 4 Person Occupied Vehicles, and TRKS – trucks)

O_{vi} = Trip production of vehicle class v in zone i,

H_{ip} = Number of households in income category p in zone i, and

β_k, (k = 0, 1, …, p) = Model parameters.

Two types of multiple regression models, linear and exponential are constructed. Each model is regressed on two sets of household income variables, census tract and block group. Separate models are developed for each vehicle class based on the corresponding OD matrices, namely Single Occupancy Vehicles (SOVS), 2 Person Occupied Vehicles (HOV2), 3 and 4 Person Occupied Vehicles (HOV3&4), and trucks (TRKS). HOV3 and HOV4 are grouped together due to the very low numbers of HOV4 traffic in the OD tables.

The trip production models developed in this dissertation are separately evaluated in order to determine the best model that explains the relationship between household characteristics and trip productions. The comparison is made between linear and exponential regression as well as census-tract and block-group variables. The coefficient of determination, R^2, is a statistic that will give some information about the goodness of fit of a model and how well the regression line approximates the observed data. The value of R^2 approaching 1.0 indicates that the regression line fits the data very well.

Despite the different characteristics inherited in each vehicle class, based on the highest value of R^2, the linear multiple regression model based on the census-tract demographics is proven to be the best model (See Appendix D for the complete trip production models for each vehicle class). Table 4.3 summarizes the best selected linear trip production models for each vehicle class.

Besides the apparent multicollinearity[15], the selected production models in Table 4.3 appear to be good descriptors of the relationship between household income and trip productions. The R^2 values are 0.8177 and greater, except for the 0.4702 value for TRKs. Upon the review of selected SOVs production model, the positive coefficients of household incomes type 4 to 7 (household income of \$50,000 - \$100,000 or more) suggest that SOV is the preferred mode of transportation for the upper-middle and high income households. For example, the coefficient +3.1736 of household income type 4 indicates that an increase of one unit in household type 4 leads to an increase in the mean

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[15] A statistical phenomenon occurs when 2 or more independent variables in a multiple regression model are highly correlated. Though multicollinearity does not reduce the predictive power of the model as a whole, it affects the coefficient estimates of individual predictors and therefore the coefficient may have an incorrect sign. Also, with the large sample size utilized in this study, even extreme multicollinearity will not be able to reduce the reliability of the model and it will not be observable in the final results (Bae et al. 2003 and Blanchard 1987).

of the probability distribution of SOV trip production of 3.1736 trips. The positive coefficients of household type 1 and 2 (household income of less than \$10,000 - \$34,999) in HOV2 and HOV3&4 models, also reveal that non-SOV are the preferred mode of transportation for the lower income households in the study area.

Table 4.3 Selected Trip Production Models

	Vehicle Class	**R^2**	**Equation**
Trip Production Model	HOV2	0.8717	$O_{vi} = 0.1416H_{i1} + 0.1167H_{i2} - 0.0096H_{i3} + 0.5922H_{i4} - 0.1784H_{i5} + 0.0113H_{i6} + 0.1312H_{i7} + 20.9395$
	HOV3&4	0.8897	$O_{vi} = 0.0541H_{i1} + 0.0416H_{i2} + 0.009H_{i3} + 0.2663H_{i4} - 0.0717H_{i5} - 0.0055H_{i6} + 0.0619H_{i7} + 6.8987$
	SOVs	0.8177	$O_{vi} = 0.311H_{i1} - 0.264H_{i2} - 1.5011H_{i3} + 3.1736H_{i4} + 2.1135H_{i5} + 0.4689H_{i6} + 0.6573H_{i7} - 24.2362$
	TRKs	0.4702	$O_{vi} = 0.1873H_{i1} - 0.1363H_{i2} - 0.215H_{i3} + 0.1946H_{i4} + 0.1257H_{i5} + 0.1566H_{i6} - 0.041H_{i7} + 6.3581$

4.4.2.2 Trip Attraction Estimation. Given the employment data in Table 4.2, the following multiple regression model for estimating trip attractions is stated:

$$D_{vj} = \alpha_0 + \alpha_1 E_{11} + \alpha_2 E_{12} + \ldots + \alpha_q E_{jq} \tag{4.2}$$

where

j = Zone index (*j* = 1, …, *N*),

q = Employment category index (*q* = 1, …, *n*)

v = Vehicle Class (v = *HOV2, HOV3&4, SOVS, TRKS*)

D_{vj} = Trip attractions of vehicle class v in zone in zone j,

E_{jq} = Number of employment in category q in zone j, and

α_k, (k = 0, 1, …, q) = Model parameters.

Two types of multiple regression models, a linear and an exponential type, are constructed to estimate the trip attractions for each vehicle class (D_{vi}). Each model is regressed on two sets of employment type variables, census tract and block group. Separate models, shown in Appendix E, are developed for each vehicle class.

The trip attraction models developed in this study are separately evaluated in order to determine the best model that explains the relationship between employment characteristics and trip attractions. A comparison is made between linear and exponential regression as well as census-tract and block-group variables using the coefficient of determination R^2. The linear multiple regression model based on the census-tract demographics is proven to be the best model due to the highest value of R^2. Table 4.4 summarizes the selected linear attraction models in detail.

According to the R^2 values in Table 4.4, the selected attraction models appear to be acceptable descriptors of the relationship between employment types and trip attractions, having R^2 values of 0.6389 and higher. Upon a review of independent variable coefficients, it appears that most of the trips are attracted to the study area by employment type 4 (retail trade). Its coefficient is the highest in all selected models.

Table 4.4 Selected Trip Attraction Models

	Vehicle Class	R^2	Equation
Trip Attraction Model	HOV2	0.6492	$D_{vj} = -0.0082E_{j1} + 0.0213E_{j2} + 0.0279E_{j3} + 0.4205E_{j4} - 0.0022E_{j5} - 0.2398E_{j6} - 0.064E_{j7} + 153.4793$
	HOV3&4	0.6459	$D_{vj} = -0.0053E_{j1} + 0.0077E_{j2} + 0.0249E_{j3} + 0.1873E_{j4} - 0.0082E_{j5} - 0.1054E_{j6} - 0.0381E_{j7} + 67.7581$
	SOVS	0.6389	$D_{vj} = -0.1411E_{j1} + 0.121E_{j2} + 0.3656E_{j3} + 0.8788E_{j4} + 0.4396E_{j5} - 0.7848E_{j6} + 0.4708E_{j7} + 579.865$
	TRKS	0.7209	$D_{vj} = 0.0092E_{j1} + 0.0101E_{j2} + 0.0349E_{j3} + 0.0838E_{j4} - 0.0177E_{j5} - 0.0851E_{j6} + 0.0068E_{j7} + 24.7171$

4.4.2.3 Matching Productions and Attraction. Since future trip productions and attractions are calculated separately, it is necessary to ensure that the total number of trips originating in all zones will be equal to the total number of trips attracted to them. In other words, the following expression must hold:

$$\sum_{i=1}^{N} O_i = \sum_{j=1}^{N} D_j \tag{4.3}$$

For equation (4.3) to hold, each zone’s trip attraction is multiplied by the ratio of total productions to total attractions. This approach is based on the expectation that the trip production model is a better predictor of trip rates than its trip attraction counterpart. Equation (4.4) represents the correction factor:

$$f = \frac{\sum_{i=1}^{N} O_i}{\sum_{j=1}^{N} D_j} \tag{4.4}$$

4.4.2.4 Trip Distribution. Due to the availability of future trip productions and attractions, the Furness method is utilized to estimate the flow of future trips in Middlesex County. Since the focus of this study is in Middlesex County, all external trips are assumed to be constant for all forecasting periods. Separate distribution models are developed for each vehicle class based on the corresponding O-D matrix. Thus, the trip pattern is assumed to remain the same in the future as it is in the base year. The condition required for the convergence of this method is that the growth rates produce target values $\boldsymbol{T_i}$ and $\boldsymbol{T_j}$ such that

$$\sum_i \theta_i \sum_j t_{ij} = \sum_j \gamma_j \sum_i t_{ij} = T_i = T_j = T \tag{4.5}$$

where

θ_i = Origin-specific growth factor of zone *i*,

γ_j = Destination-specific growth factor of zone *j*,

t_{ij}= Trip flows between zone *i* and zone *j*,

T_i = Total future trip productions (target production values), and

T_j = Total future trip attractions (target attraction values).

The following iteration process is required to achieve the condition in equation (4.5):

a) Total the base-year zonal trip productions for each zone.

b) Determine the zonal origin-specific growth factors of future productions as compared to base-year productions.

c) Multiply the zonal trip productions by the corresponding zonal origin-specific growth factors.

d) Total the new zonal trip productions and attractions for each zone.

e) Determine the zonal destination-specific growth factors of future attractions as compared to adjusted base-year attractions.

f) Multiply the zonal trip attractions by the corresponding destination-specific growth factors.

g) Repeat the iteration process in steps a)-f) until the estimated matrix is within 1% of meeting the target trip ends.

At this point, the changes in land use patterns resulting from either demographic/economic growth or induced developments are fully integrated into the future trip table. This trip table will then be processed and fed into the TRANSIMS model to forecast future traffic flows and network performance.

4.5 Summary of Data Requirement of TRANSIMS and TELUM Models

All data utilized in developing TRANSIMS and TELUM models are summarized as shown in Figure 4.6.

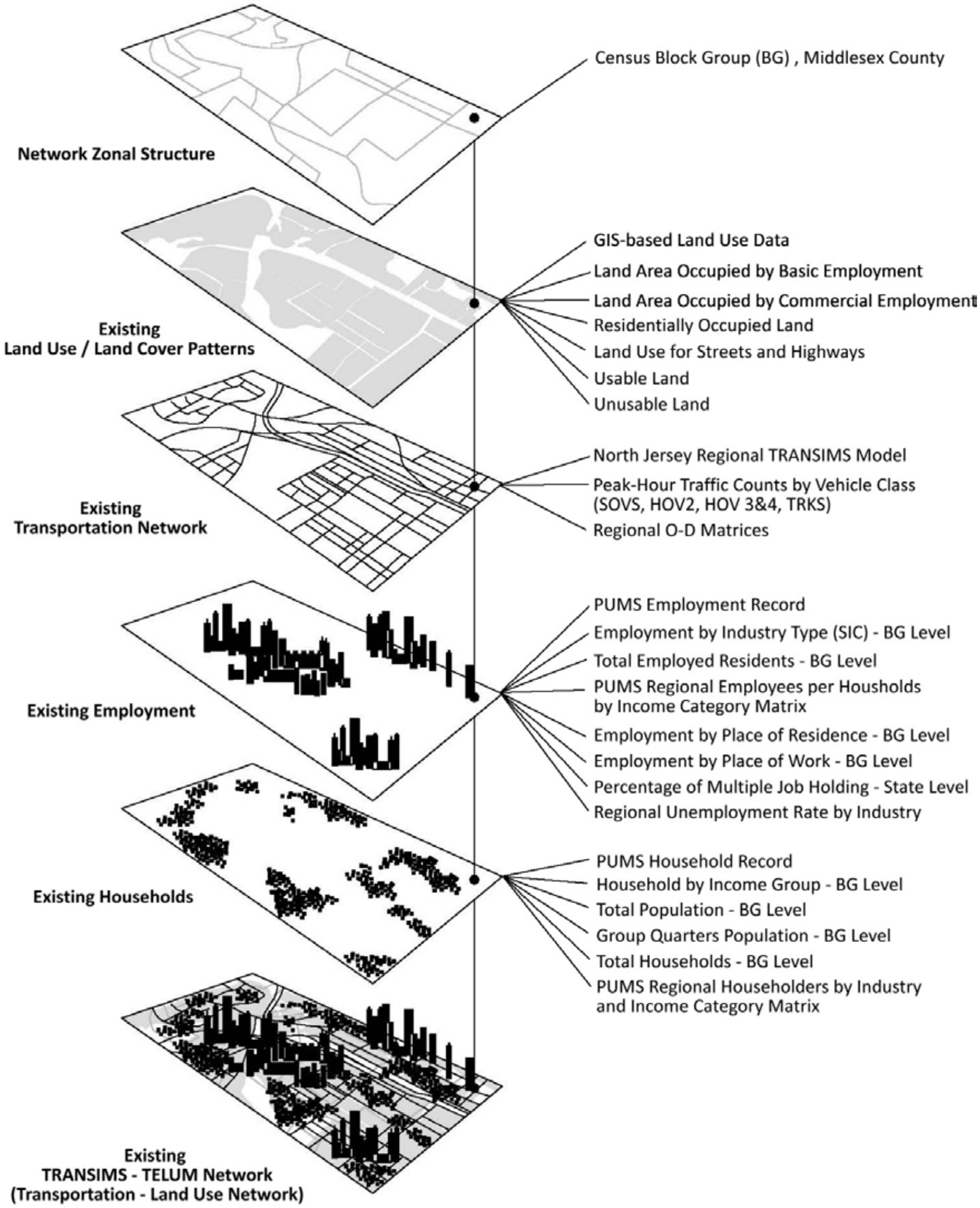


Figure 4.6 TRANSIMS and TELUM models data requirement.

The data utilized in developing TRANSIMS and TELUM models are categorized into the followings:

- **Network Zonal Structure:** the zonal structure data defines the zonal boundaries of all zones within TRANSIMS and TELUM models. Due to the interactive nature of the framework developed in this dissertation, the zonal structure of the two models must be consistent with one another. Zones in TRANSIMS and TELUM models contain geographic locations of trip origins and destinations, thereby, represent traffic movements within, into, and out of the modeling network.

- **Land Use/Land Cover Patterns:** the zonal acreage of the following land use data must be obtained and used as inputs in TELUM model:

    - Total Land Area: land only (i.e., no water).

    - Unusable Land: environmentally constrained land where development should be severely restricted (i.e., floodplains, wetlands, and steep slopes).

    - Usable Land: vacant developable land and developed land.

    - Streets and Highways Land: land designated as transportation infrastructure and right of way.

    - Basic Employment Land: land designated for industrial and institutional employment.

    - Commercial Employment Land: land designated for retail and office employment.

    - Residential Land: land designated for all housing types (i.e., single family, group quarter)

- **Transportation Network:** the North Jersey Regional Trip-based TRANSIMS model is utilized in this dissertation to generate traffic conditions for various analysis scenarios. The peak-hour traffic counts and regional O-D matrices are based on the network covering Middlesex County and Monmouth County, New Jersey.

- **Employment Data:** employment data is required for two different time periods – base year and lag year (five years prior to the base year). It is important to note that the zonal employment data utilized in TELUM model is the employment data by place-of-work rather than by place-of-residence.

- **Household Data:** household data is also required for two different time periods-base and lag years. The time periods of household data must be consistent with those of employment data.

For technical details regarding TRANSIMS model including dynamic user equilibrium, skim file generation process, model validation, and convergences statistics, refer to Appendices A, B, F, and G, respectively. For information regarding the sources of data utilized in developing TRANSIMS and TELUM models, refer to Appendix C.

CHAPTER 5

ANALYSIS SCENARIOS

Chapter 4 presented the development of TRANSIMS and TELUM models and provided the study area location. As stated in Chapter 3, the purpose of the Route 18 reconstruction project is to enhance the safety and operations for drivers, pedestrians and cyclist. This chapter presents two modeling scenarios that will be analyzed to evaluate the impacts of the Route 18 reconstruction project:

- **Baseline Scenario:** The models represent roadway infrastructure and land use patterns without any geometry changes on Route 18.
- **Built Scenario:** The reconstruction plan and associated roadway geometric changes are implemented in the TRANSIMS network.

The following sections present details of the Route 18 improvement project and changes in the TRANSIMS network that are made to reflect the Route 18 improvement project. The land use patterns in terms of households, employment, and vacant land in Middlesex County before the reconstruction of Route 18 are presented as well.

5.1 TRANSIMS Network - Built Scenario

The proposed road improvements are shown in Figure 5.1. To enhance the traffic operations of this section of Route 18, the outer roadways are built (both northbound and southbound) to separate the local traffic from the express traffic. These outer roadways will enhance the accessibility to and from the city of New Brunswick by connecting to the new bridges over the express lanes at Albany Street., New Street., Commercial

Avenue, and George Street. Traffic signals are also installed at various locations to ensure safe and efficient movements of vehicles and pedestrians. The differences between the TRANSIMS roadway networks before and after the reconstruction are shown in Figures 5.1 to 5.4.

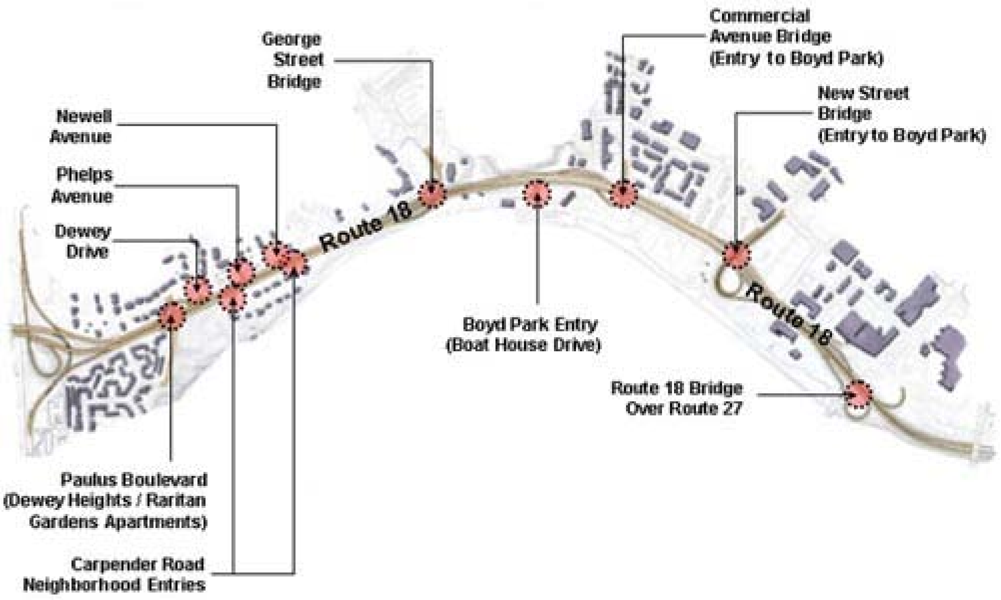
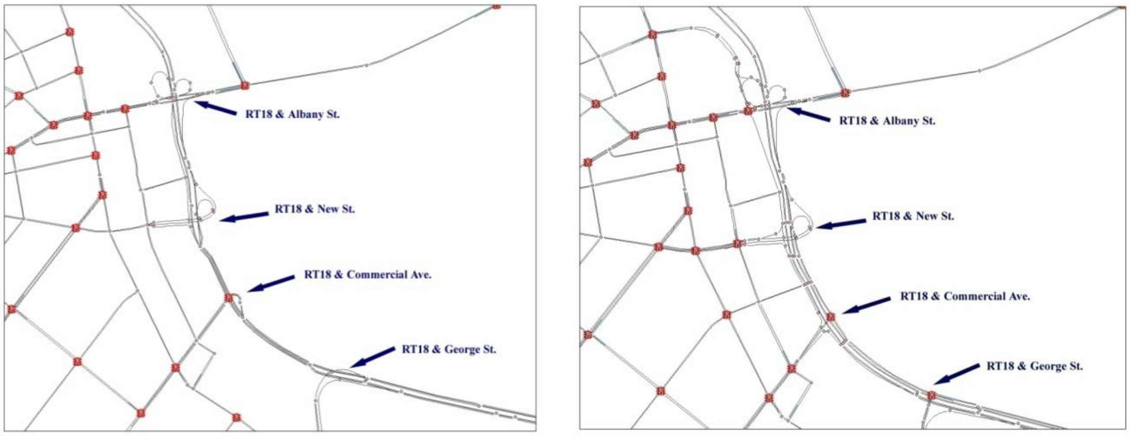


Figure 5.1 Improvements of access and adjacent streets on Route 18.

Source: http://www.state.nj.us/transportation/commuter/roads/route18/map.shtm.



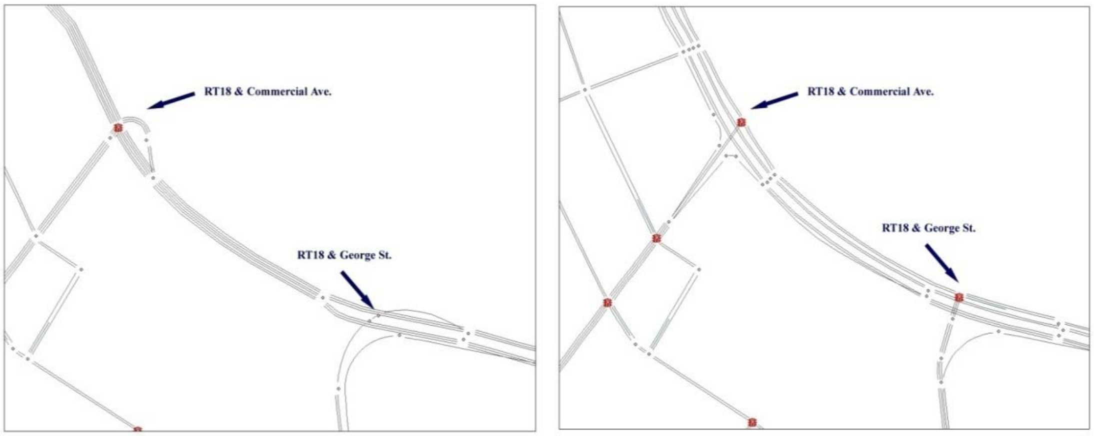
Network Before Reconstruction

Network After Reconstruction

Figure 5.2 Sections of Route 18 before and after the construction.

Network Before Reconstruction Network After Reconstruction

Figure 5.3 Route 18 at Albany Street and New Street before and after the construction.



Network Before Reconstruction Network After Reconstruction

Figure 5.4 Route 18 at Commercial Avenue and George Street before and after the Construction.

To account for these proposed improvements, the following changes are made to the TRANSIMS highway network:

1. Johnson Dr. is added to connect the traffic from George Street to Route 18. The capacity of Johnson Dr. is 500 vehicles per hour in each direction.

2. A traffic signal is added at Route 18 and Albany Street. The old southbound outer roadway is replaced by the new one. The capacity at this location remains the same.

3. A northbound outer roadway is added at Route 18 and New Street which increases the total northbound capacity from 2,012 to 3,018 vehicles per hour. A ramp is also added in this location to provide direct access from RT18 southbound to New St.. The capacity of the ramp is 500 vehicles per hour.

4. The old 6-lane Route 18 (3 lanes in each direction) from New St. to George St. (the end of Route 18 reconstruction project) is replaced by the new roadways that separates express and local traffic. The new Route 18 consists of 4 express lanes (2 in each direction), 1-lane southbound outer roadway, and 2-lane northbound outer roadway. The capacity of Route 18 increases from 5,030 to 7,042 vehicles per hour.

5. Oliver Street is added to the network to connect the local traffic to Route 18 with a capacity of 500 vehicles per hour in each direction.

6. The one-way ramp connecting Route 18 northbound traffic to Commercial Ave. is replaced by the signalized intersection between the northbound outer roadway and Commercial Ave. This allows the traffic to travel to and from Route 18 northbound.

7. The off-ramp from Route 18 northbound at George St. is replaced by a signalized intersection connecting traffic between George St. and Route 18 northbound outer roadway.

8. Traffic signals are also added to the following intersections:

    a. New St. and Neilson St.

    b. New St. and George St.

    c. Commercial Ave. and Neilson St.

    d. George St. and Oliver St.

5.2 Existing Land Use Patterns – Year 2000

Based on the socioeconomic data obtained from the US Census Bureau, there were a total of 266,402 households and 369,221 jobs in Middlesex County in year 2000. Figures 5.5

and 5.6 show the zonal spatial distributions of households and employment in Middlesex County. The darker color shade represents greater number of households and employment within the zone.

It can be observed from Figures 5.5 and 5.6 that a high number of households are located in the eastern and western parts of Middlesex County, and high employment is located in the south. Also, there is a dense concentration of households and employment in the zones north of and in the Route 18 reconstruction area. This suggests intensive mixed-use development in these zones.

The vacant land in Middlesex County for the year 2000 is shown in Figure 5.7. The green color represents the available vacant land, and white indicates the fully-developed zone with no vacant land available. The darker the shade of green, the larger the vacant land in the zone.

Figure 5.7 shows that the majority of vacant land is located in the southern part of Middlesex County (highlighted in dark green). The zonal vacant land in the northern and western parts is relatively small in size, with the largest parcel being 40 acres. The white zones in the Route 18 reconstruction area indicate that the area is fully developed and that there is no vacant land available.

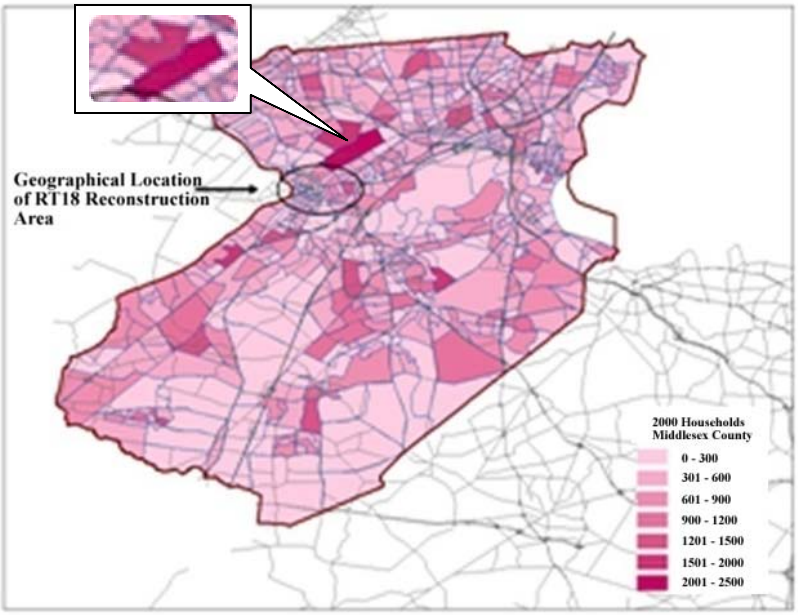


Figure 5.5 Zonal spatial distributions of current households in Middlesex County, year 2000.

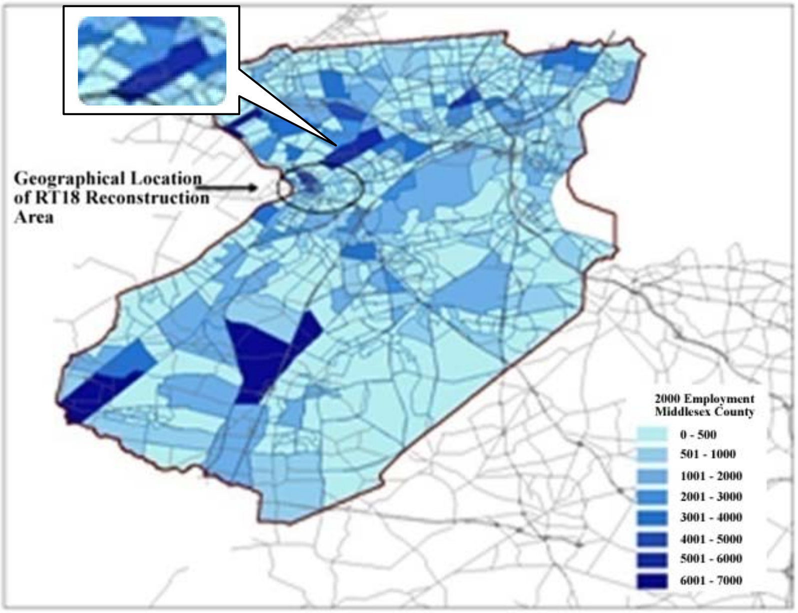


Figure 5.6 Zonal spatial distributions of current employment in Middlesex County, year 2000.

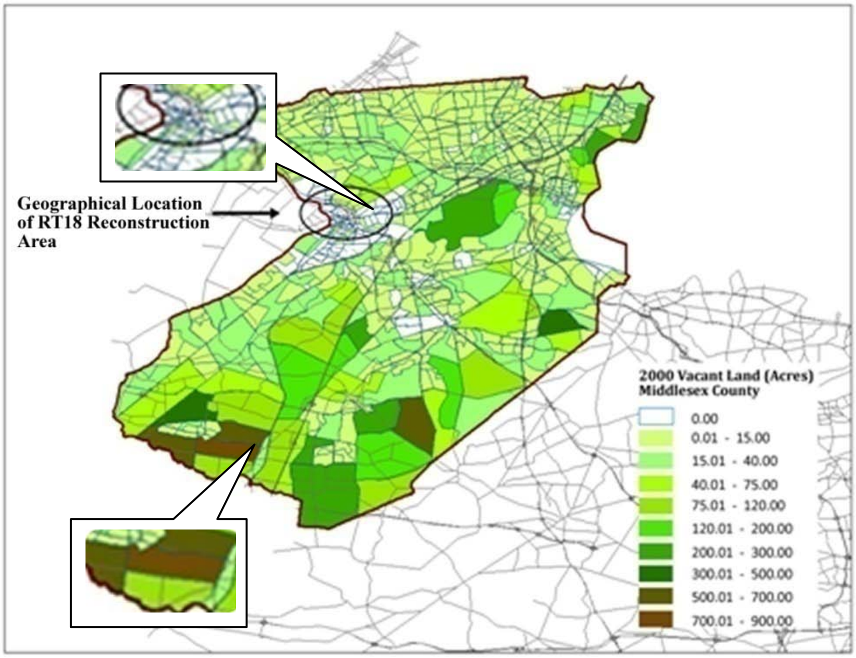


Figure 5.7 Zonal vacant land in Middlesex County, year 2000.

5.3 Built Scenario Development and Analysis Process

The following steps are taken to incorporate the Route 18 improvement project in the built TRANSIMS and TELUM models:

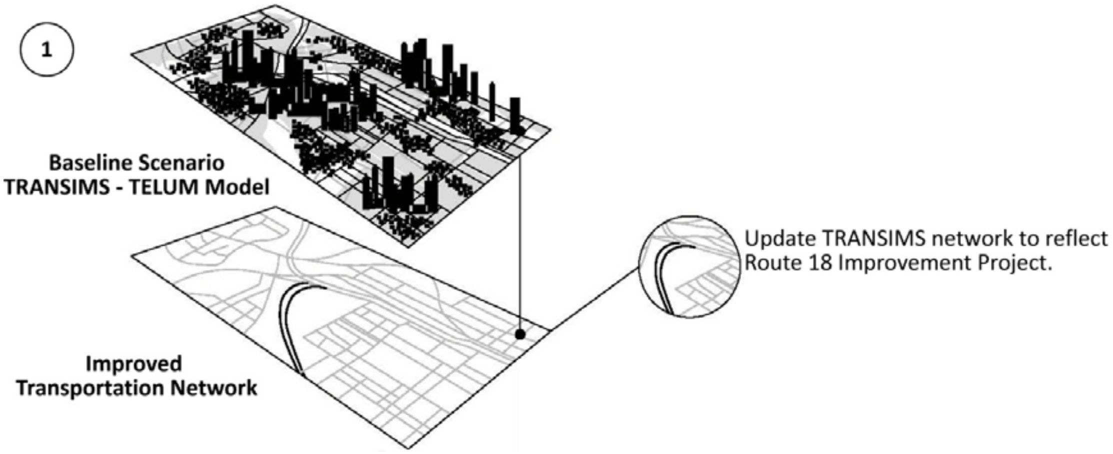


Figure 5.8 TRANSIMS network adjustment.

Development: The baseline TRANSIMS network is updated to reflect the changes in roadway geometry as a result of the Route 18 improvement project (section 5.1). After all changes are made (Figure 5.8), the built TRANSIMS model is run to generate the traffic conditions and zone-to-zone skim file.

Analysis: The first component of induced traffic (rerouting traffic) is identified by comparing the built-scenario results with the baseline-scenario results of the same time period.

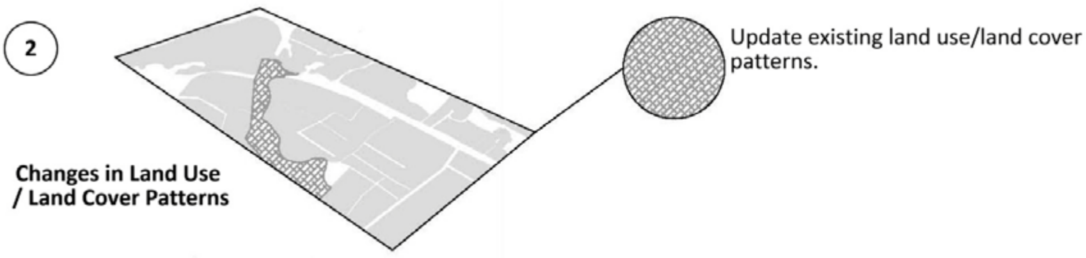


Figure 5.9 Land use/land Cover adjustment.

Development: The next step is to update the existing land use data in baseline TELUM model (Figure 5.9). Since the Route 18 improvement project involves expanding the existing facility, this update results in a decrease in usable land for future developments.

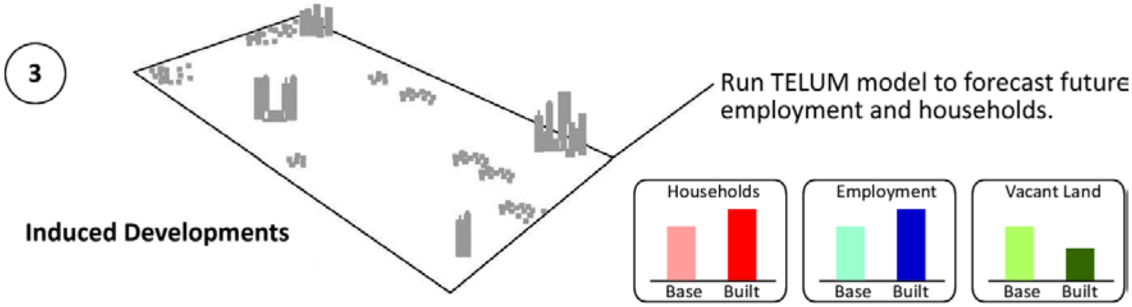


Figure 5.10 Induced development generation.

After the land use data is updated, TELUM is run with the skim file generated in step 1 to generate the forecast for future land use patterns for the built scenario.

Analysis: The induced development (both residential and commercial) is identified by comparing the results from the built scenario with the baseline scenario. The changes in vacant land as a result of induced development will also be identified and analyzed (Figure 5.10).

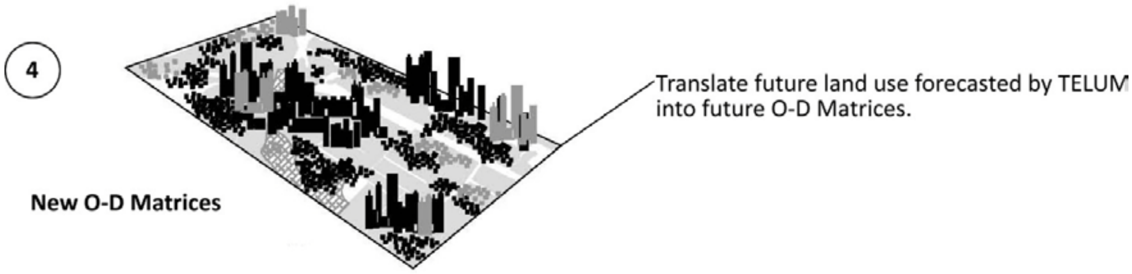
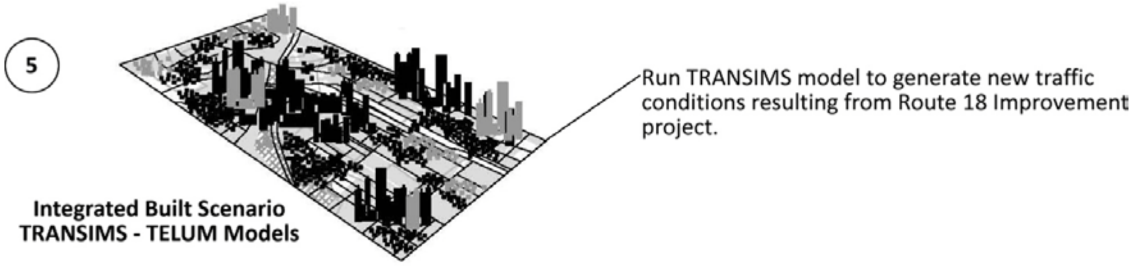


Figure 5.11 Future O-D matrices generation.

Development: The future land use obtained in step 3 is then fed into the trip production and attraction models to generate the future trips for the built scenario. These future productions and attractions are then matched and distributed to generate the O-D matrices for the built scenario (Figure 5.11).



Run TRANSIMS model to generate new traffic conditions resulting from Route 18 Improvement project.

Figure 5.12 Future traffic condition generation.

The O-D matrices obtained in step 4 are fed back to the built scenario TRANSIMS model. The model is then run to generate traffic conditions as a result of induced travel demand (Figure 5.12).

Figure 5.13 below summarized the steps for incorporating the Route 18 improvement project into the baseline models as discussed above.

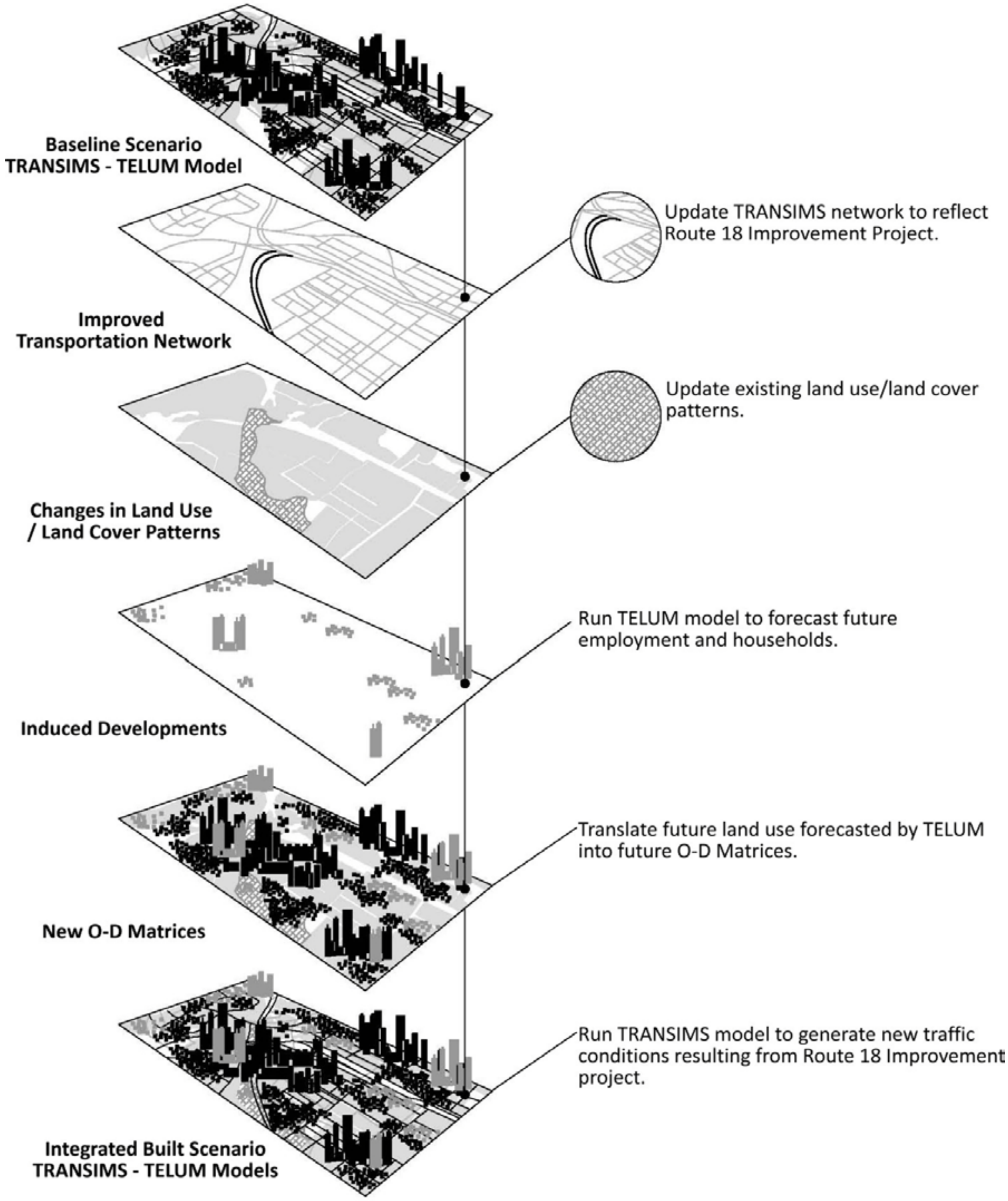


Figure 5.13 Built scenario development.

5.4 Transportation Analysis for a 10-Year Period

To demonstrate the ability of this framework to predict future changes in both transportation and land use a 10-year transportation analysis will be performed by comparing TRANSIMS and TELUM models' results between the baseline and built scenarios for years 2000, 2005 and 2010. Figure 5.14 summarizes the integrated modeling framework between TRANSIMS and TELUM from year 2000 to 2010.

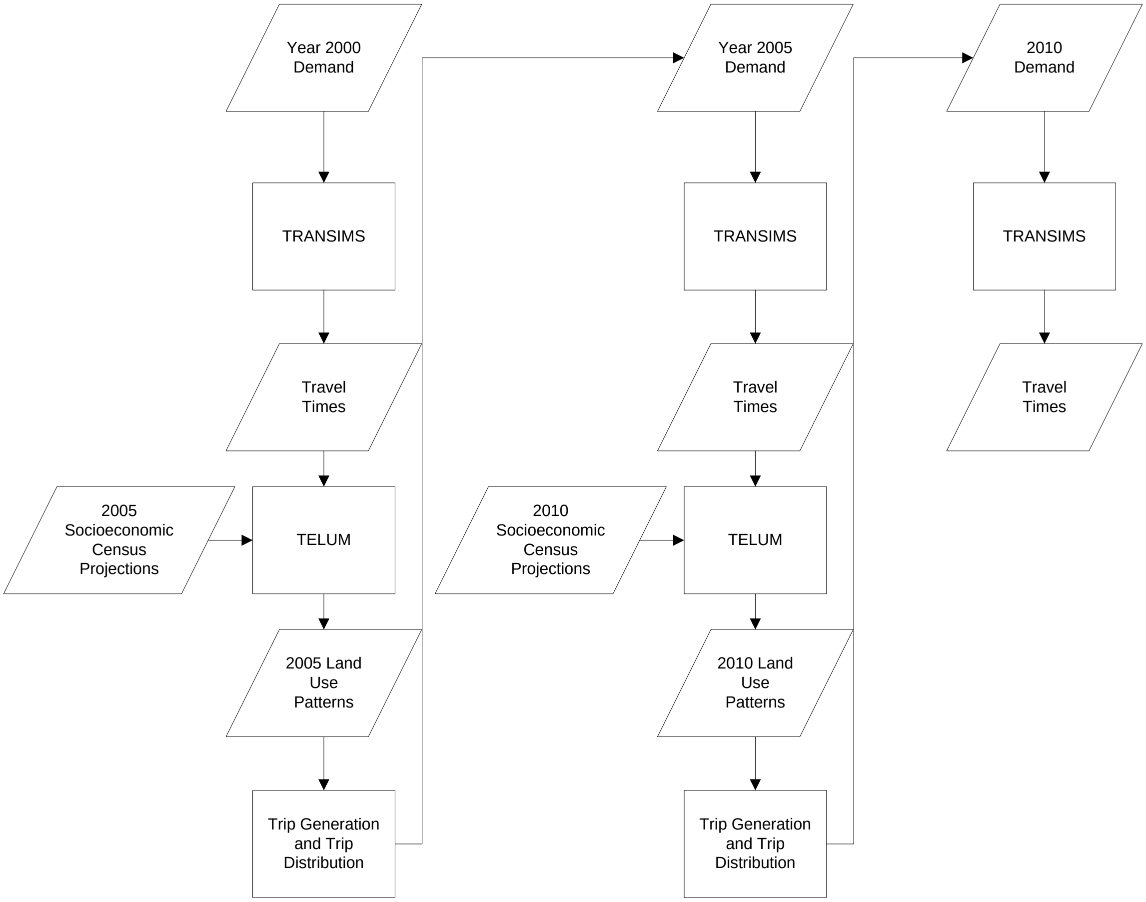


Figure 5.14 TRANSIMS and TELUM integrated modeling framework, year 2000 – 2010.

CHAPTER 6

ROUTE 18 RECONSTRUCTION AREA ANALYSIS RESULTS

It is an established fact that scheduled infrastructure projects tend to induce traffic and development in the adjoining areas. The improvement in accessibility and connectivity almost instantly draws both residents and businesses alike to the areas which were once deemed less desirable.

This chapter presents the analysis results for the Route 18 reconstruction area. It first summarizes the analysis results obtained from the baseline scenario, and then the results obtained from the built scenario. The chapter concludes with the comparison between the two modeling scenarios' results. The impacts of highway improvements on the Route 18 reconstruction area are identified in terms of changes in land use patterns and traffic conditions.

Also, the purpose of this chapter is to examine the validity and reliability of the above stated fact which greatly influences land use practices adopted by various planning agencies.

6.1 Introduction

To investigate the accuracy of the land use assumption currently adopted by the MPO, the zones located within a two-mile radius of the Route 18 reconstruction project are selected for detailed analysis. This area, called the Route 18 reconstruction area is comprised of 53 zones (Figure 6.1).

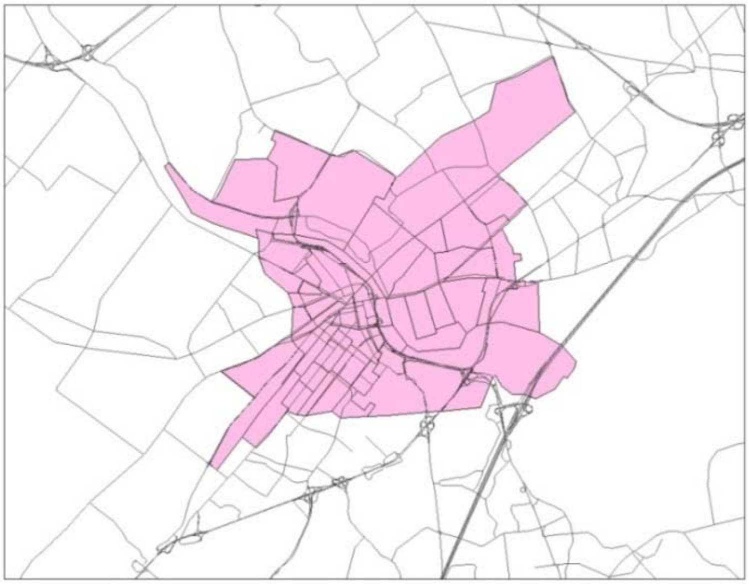


Figure 6.1 Route 18 reconstruction area.

Due to its proximity to the improvements, the majority of induced developments are anticipated to take place in this area. However, due to the current high-density developments and the lack of vacant land in the area, the results achieved from the models may be surprising. In other words, the availability of vacant land in zones outside the Route 18 reconstruction area, especially the southern part of Middlesex County, may play a significant role in attracting households and employment, therefore, shaping the future land use patterns in Middlesex County differently from what MPO has anticipated.

6.2 Baseline Scenario Analysis Results

This section summarizes the Route 18 reconstruction area analysis results for the baseline scenario for years 2000, 2005 and 2010, respectively. The results obtained from TELLUM model are summarized in terms of changes in land use patterns, and the results obtained from TRANSIMS model are summarized in terms of changes in traffic conditions.

6.2.1 Changes in Land Use

Tables 6.1 and 6.2 display the changes in land use patterns and the corresponding trip ends in the Route 18 reconstruction area obtained from the baseline scenario for years 2000, 2005, and 2010.

Table 6.1 Route 18 Reconstruction Area - Baseline Scenario Changes in Land Use Patterns

	Baseline Scenario		
	Year 2000	**Year 2005**	**Year 2010**
Households	24,656	25,696	23,849
Employment	51,237	52,448	53,686

Table 6.2 Route 18 Reconstruction Area - Baseline Scenario Changes in Trip Productions and Attractions

	Baseline Scenario		
	Year 2000	**Year 2005**	**Year 2010**
Trip Productions	17,781	20,089	19,632
Trip Attractions	20,107	21,729	28,754

According to Tables 6.1 and 6.2, without the Route 18 reconstruction project, in 2005, the area experiences a 4.22%[16] and 2.36%[17] increase in households and employment. This leads to a 12.98%[18] and 8.07%[19] increase in trip productions and trip attractions, respectively.

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[16] (25,696-24,656)/ 24,656

[17] (52,448-51,237)/ 51,237

[18] (20,089-17,781)/ 17,781

[19] (21,729-20,107)/ 20,107

In 2010, the Route 18 reconstruction area experiences a 7.19%[20] decrease in households and a 2.36%[21] increase in employment. These changes lead to a 2.27%[22] decrease in trip productions and 32.33%[23] increase in trip attractions.

6.2.2 Changes in Traffic Conditions

Table 6.3 displays the changes in traffic condition in Route 18 reconstruction area obtained from the baseline scenario for years 2000, 2005, and 2010.

Table 6.3 Route 18 Reconstruction Area - Baseline Scenario Changes in Traffic Conditions

	Baseline Scenario		
	Year 2000	**Year 2005**	**Year 2010**
Route18 Traffic Volume	5,877	6,173	6,563

According to the results shown in Table 6.3, in 2005 and 2010, the Route 18 reconstruction area experiences a 5.04%[24] and 6.32%[25] increase in traffic volume, respectively.

6.3 Built Scenario Analysis Results

This section summarizes Route 18 reconstruction area analysis results for the built scenario for years 2000, 2005 and 2010. It first summarizes the changes in land use patterns, and then the changes in traffic conditions.

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[20] (23,849-25,696)/ 25,696
[21] (53,686-52,448)/ 52,448
[22] (19,632-20,089)/ 20,089
[23] (28,754-21,729)/ 21,729
[24] (6,173-5,877)/ 5,877
[25] (6,563-6,173)/ 6,173

6.3.1 Changes in Land Use

Tables 6.4 and 6.5 display the changes in land use patterns and the corresponding trip ends in Route 18 reconstruction area obtained from the built scenario for years 2000, 2005, and 2010.

Table 6.4 Route 18 Reconstruction Area - Built Scenario Changes in Land Use Patterns

	Built Scenario		
	Year 2000	**Year 2005**	**Year 2010**
Households	24,656	25,719	23,880
Employment	51,237	52,447	53,674

Table 6.5 Route 18 Reconstruction Area - Built Scenario Changes in Trip Productions and Attractions

	Built Scenario		
	Year 2000	**Year 2005**	**Year 2010**
Trip Productions	17,781	20,250	19,796
Trip Attractions	20,107	21,743	28,732

According to Tables 6.4 and 6.5, as a result of the Route 18 reconstruction project, in 2005 the area experiences a 4.31%[26] and 2.36%[27] increase in households and employment, respectively. This leads to a 13.89%[28] and 8.14%[29] increase in trip productions and trip attractions, respectively.

In 2010, the Route 18 reconstruction area experiences a 7.15%[30] decrease in households and a 2.34%[31] increase in employment. This changes lead to a 2.24%[32] decrease in trip productions and 32.14%[33] increase in trip attractions.

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[26] (25,719-24,656)/ 24,656
[27] (52,447-51,237)/ 51,237
[28] (20,250-17,781)/ 17,781
[29] (21,743-20,107)/ 20,107
[30] (23,880-25,719)/ 25,719

6.3.2 Changed in Traffic Conditions

Table 6.6 displays the changes in traffic conditions in the Route 18 reconstruction area obtained from the built scenario for years 2000, 2005, and 2010.

Table 6.6 Route 18 Reconstruction Area - Built Scenario Changes in Traffic Conditions

	Built Scenario								
	Year 2000			**Year 2005**			**Year 2010**		
	Local	**Express**	**All**	**Local**	**Express**	**All**	**Local**	**Express**	**All**
Route18 Traffic Volume	2,021	4,416	6,437	2,099	4,448	6,547	2,182	4,691	6,873

Based on Table 6.6, in 2005 the area experiences a 3.86%[34] and 0.72%[35] increase in local and express traffic volume, respectively. This results in a 1.71%[36] increase in the overall traffic volume on Route 18.

In 2010, the Route 18 reconstruction area experiences a 3.95%[37] and 5.46%[38] increase in local and express traffic volume, respectively. This results in a 4.98%[39] increase in the overall traffic volume on Route 18.

6.4 Route 18 Reconstruction Area Analysis Results

This section concludes the analysis results for the Route 18 reconstruction area. The impacts of highway improvements on land use patterns and traffic conditions are

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[31] (53,674-52,447)/ 52,447
[32] (19,796-20,250)/ 20,250
[33] (28,732-21,743)/ 21,743
[34] (2,099-2,021)/ 2,021
[35] (4,448-4,416)/ 4,416
[36] (6,547-6,437)/ 6,437
[37] (2,182-2,099)/ 2,099
[38] (4,691-4,448)/ 4,448
[39] (6,873-6,547)/ 6,547

identified by comparing the results obtained from the baseline and built scenarios. The comparison is done for years 2005 and 2010.

6.4.1 Year 2005 Conclusion

6.4.1.1 Impacts on Land Use Patterns, Year 2005. The comparison of the spatial distribution of households and employment between the baseline and built scenarios in 2005 for the Route 18 reconstruction area is shown in Figures 6.2 and 6.3. The light shade represents the baseline scenario results, and the dark shade represents the built scenario results.

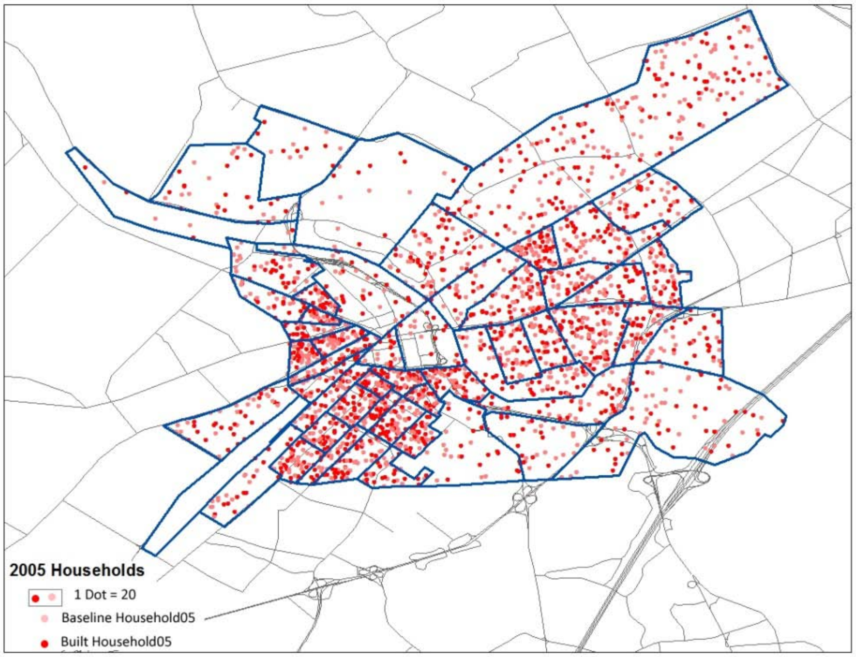

Figure 6.2 Baseline and built scenarios household spatial distribution comparison, year 2005.

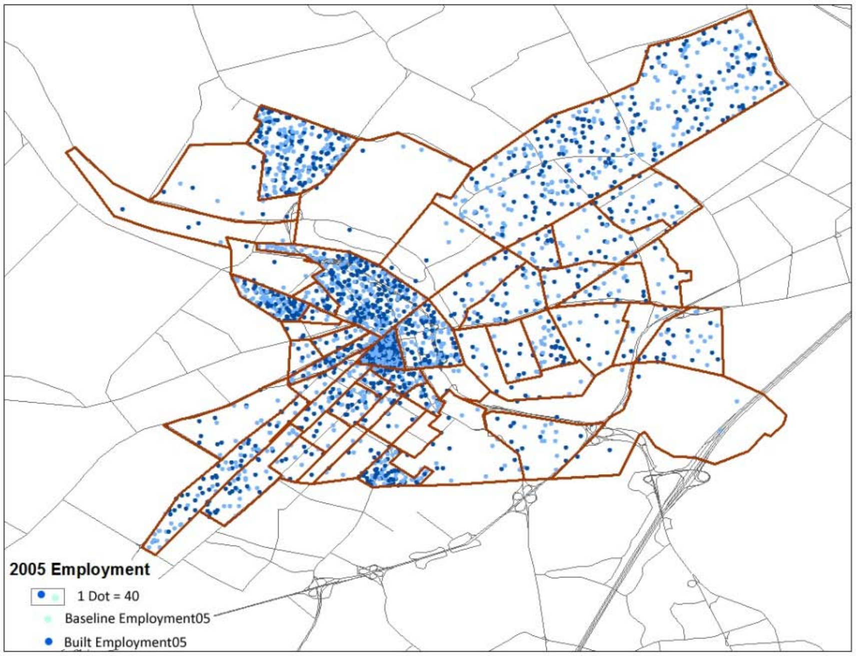

Figure 6.3 Baseline and built scenarios employment spatial distribution comparison, year 2005.

Based on Tables 6.1, 6.2, 6.4, and 6.5, the capital improvements on Route 18 lead to a total of 23 induced households (25,696 and 25,719 for the baseline and built models, respectively) in the area. The improvements also lead to a loss of one job (52,448 and 52,447 jobs for the baseline and built models, respectively). Figure 6.4 is generated to display the changes in zonal employment. The results suggest that Route 18 improvements only induced a total of 22 developments into the Route 18 reconstruction area (see Figure 6.5).

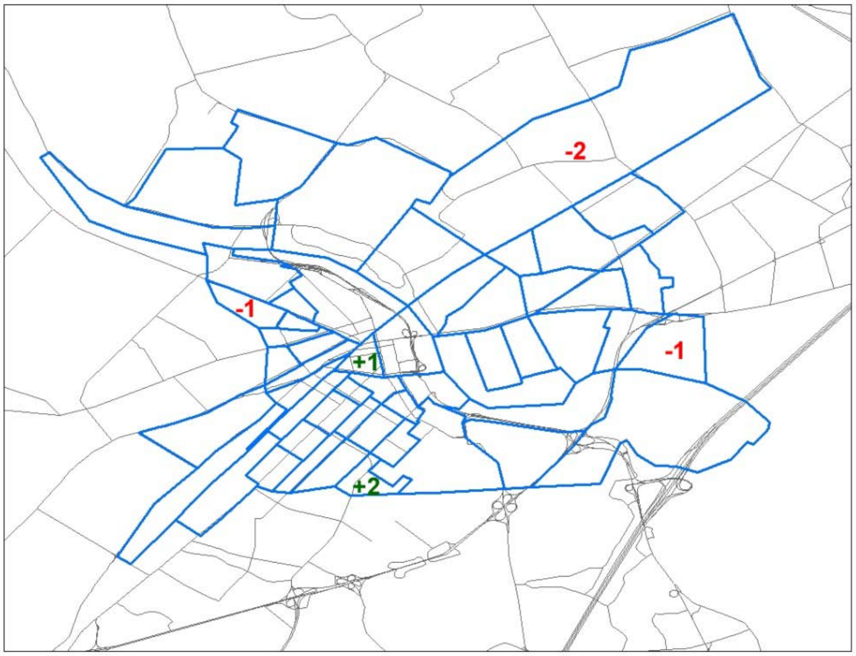

Figure 6.4 Zonal changes in employment, year 2005.

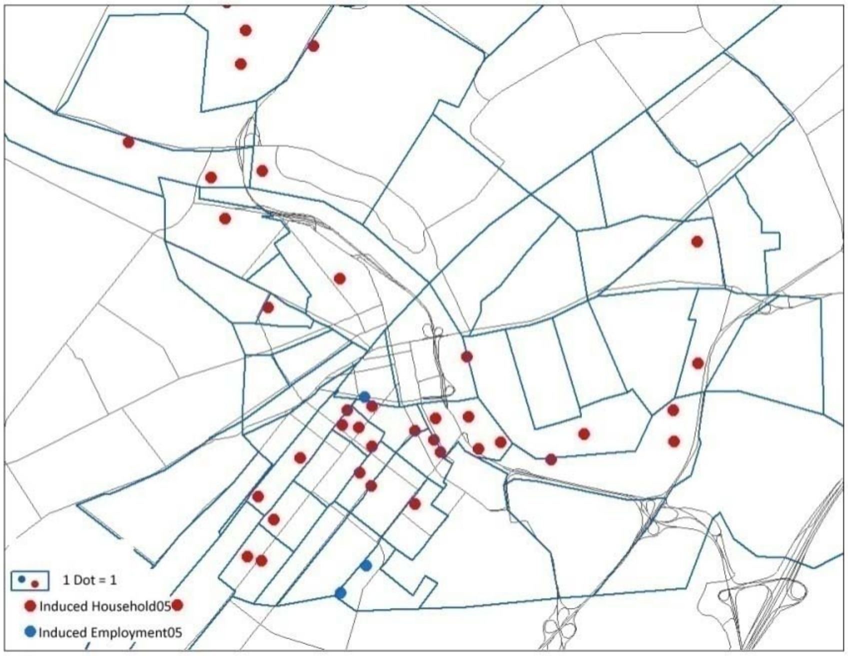

Figure 6.5 Induced households and employment, year 2005.

The induced development and the changes in land use patterns due to the Route 18 improvements lead to a total of 175 induced trips ends: 161 productions and 14 attractions, displayed in Figure 6.6.

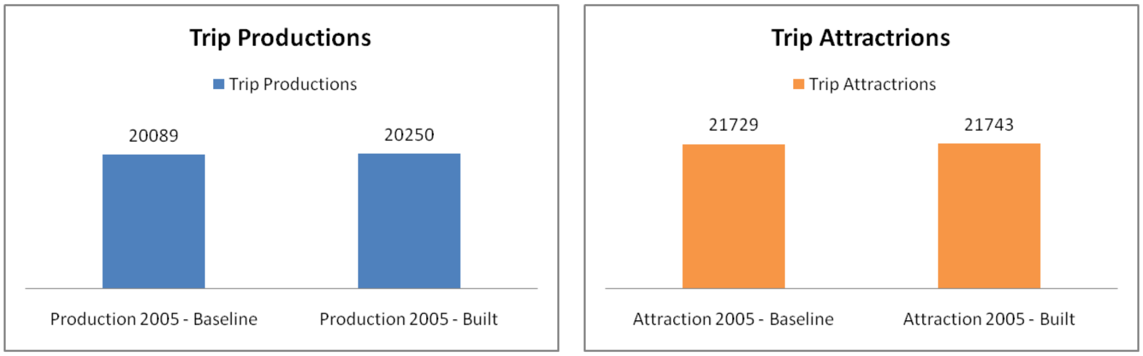

Figure 6.6 Changes in trip productions and attractions between the baseline and built scenarios in Route 18 reconstruction area, year 2005.

6.4.1.2 Impacts on Traffic Conditions, Year 2005. Based on Tables 6.3 and 6.6, the improvements on Route 18 result in a total of 374 induced trips (or a 6.06%[40] increase in traffic volume) in the area. This additional traffic represents both components of induced demand: rerouted trips and trips resulting from induced development.

Table 6.6 also shows that 32.06%[41] of the traffic uses the local lanes (or outer roadways), while 67.94%[42] is utilizing the express lanes. The express lane traffic on the improved Route 18 equals 72.05%[43] of the baseline scenario traffic in 2005. This implies that a portion of the traffic in the baseline scenario is rerouted to the new outer roadways. Thus, the newly-built outer roadway not only enhances the accessibility to the city of New Brunswick, but also improves the traffic circulation on Route 18.

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[40] 6,547 - 6173/6,173
[41] 2,099/6,547
[42] 4,448/6,547
[43] 4,448/6,173

Figures 6.7 and 6.8 are generated to display the comparison of simulated average speed and V/C ratios on Route 18 express lanes during the AM peak period between the baseline and built scenarios with year 2005 demand. The blue line represents the baseline scenario results, and the red line represents the built scenario results.

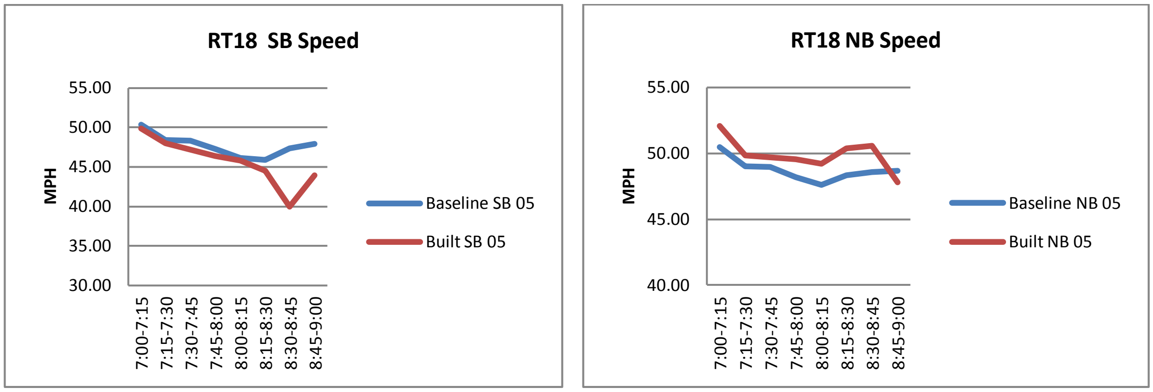

Figure 6.7 Route 18 southbound and northbound speed comparison, year 2005.

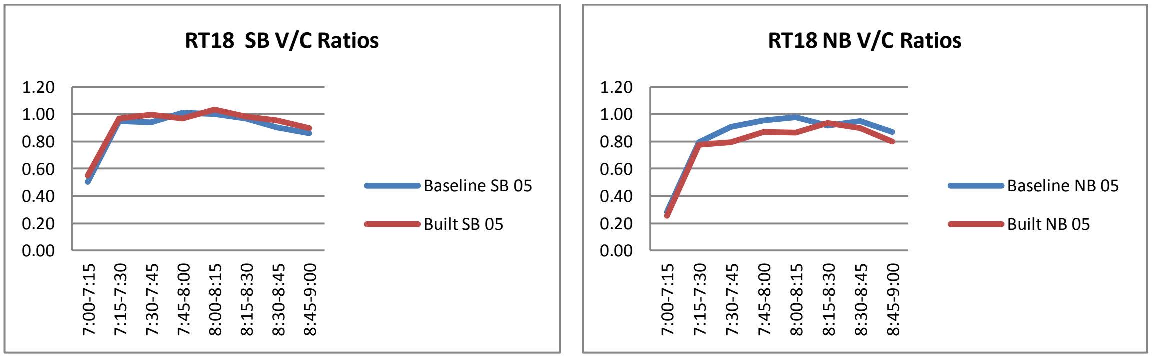

Figure 6.8 Route 18 southbound and northbound V/C ratios comparison, year 2005.

In Figure 6.8, it can be noticed that the southbound approach is operating close to or at capacity. The average speed, for the southbound direction, in the built scenario is slightly lower than the speed in the baseline model until 8:30 AM when the speed starts to dramatically decline. Upon close investigation, the primary cause of the sharp decline in the speed appears to be the heavy merge from Route 1. To demonstrate the congestion, Transims ArcDelay program is utilized to generate the average queue (in vehicles) between 8:00 and 9:00 AM. Figure 6.9 displays the congested on-ramp from the Route 1 northbound approach to Route 18 southbound. For the Route 18 northbound direction, the traffic in the built scenario appears to move more efficiently compared to the baseline scenario. In the northbound direction, the speed is higher in the built scenario except during the 8:45 to 9:00 AM period.

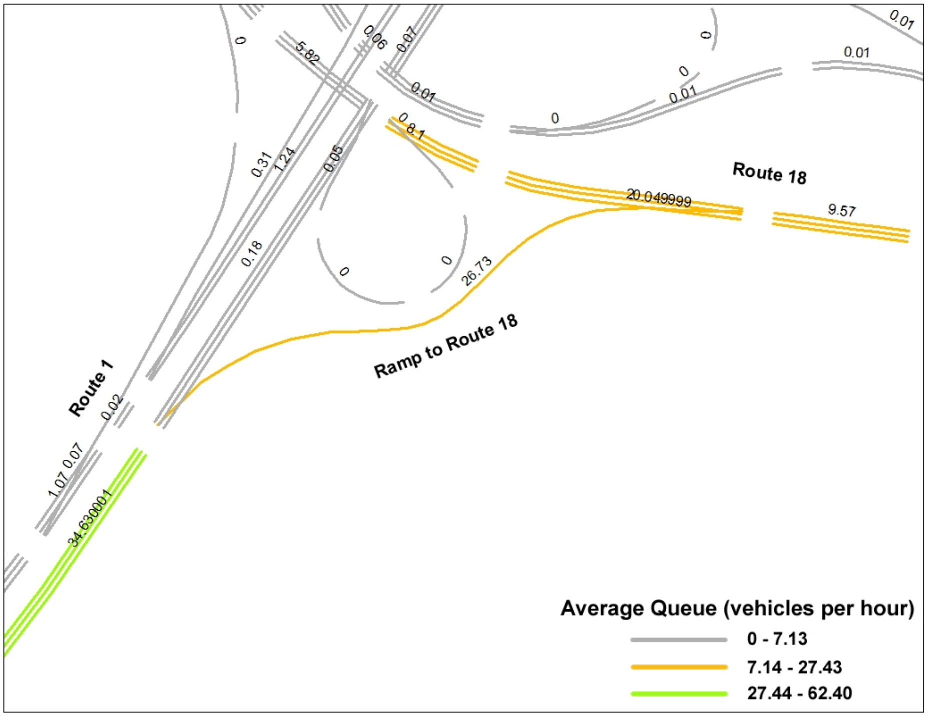

Figure 6.9 Average queue on Route 18 and Route 1, built scenario, year 2005.

6.4.2 Year 2010 Conclusion

6.4.2.1 Impacts on Land Use Patterns, Year 2010. The comparison of the spatial distribution of households and employment between the baseline and built scenarios in 2010 for the Route 18 reconstruction area is shown in Figures 6.10 and 6.11. The light shade represents the baseline scenario results, and the dark shade represents the built scenario results.

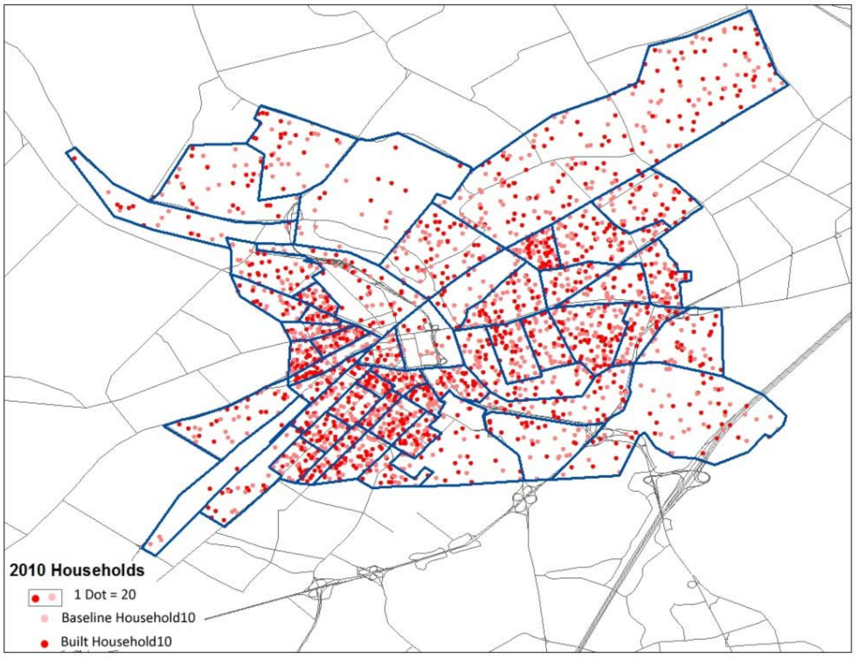

Figure 6.10 Baseline and built scenarios household spatial distribution comparison, year 2010.

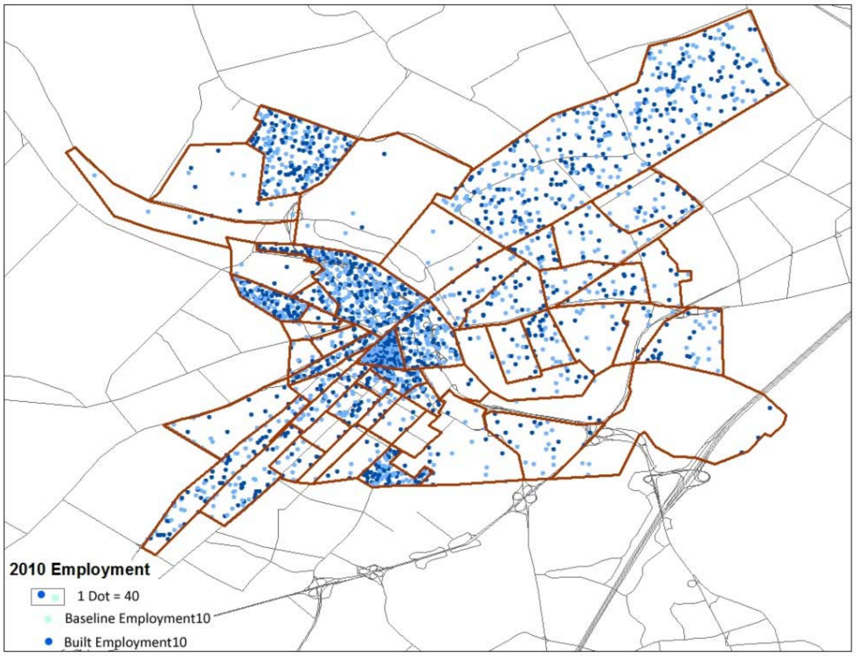

Figure 6.11 Baseline and built scenarios employment spatial distribution, year 2010.

Based on Tables 6.1, 6.2, 6.4, and 6.5, the capital improvements on Route 18 lead to a total of 31 induced households (23,849 and 23,880 for the baseline and built scenarios, respectively) in the area. The improvements also lead to a loss of 12 jobs (53,686 and 53,674 jobs for the baseline and built scenarios, respectively). Figure 6.12 is generated to display the changes in zonal employment. The results suggest that Route 18 improvements only induce a total of 19 developments into the Route 18 reconstruction area (see Figure 6.13).

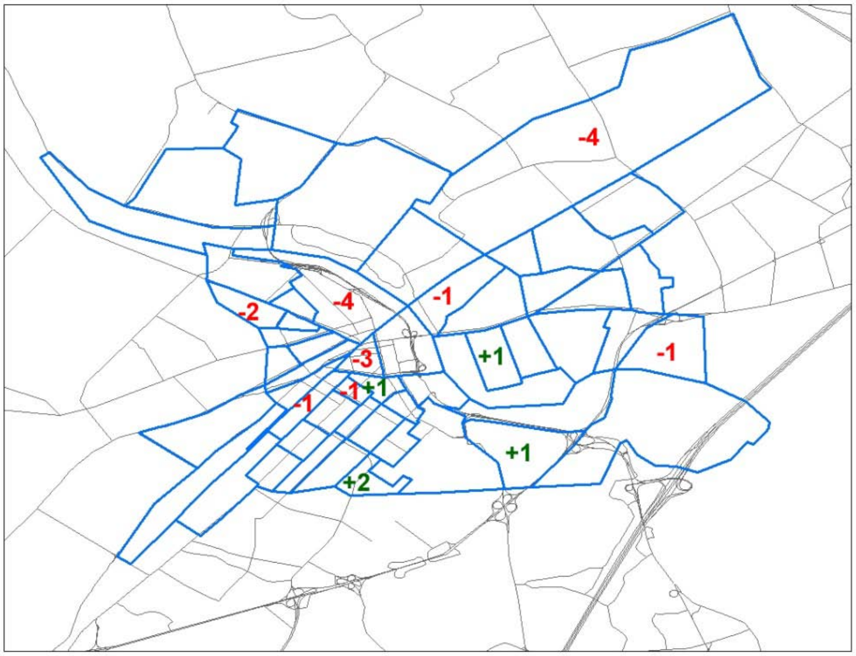

Figure 6.12 Zonal changes in employment, year 2010.

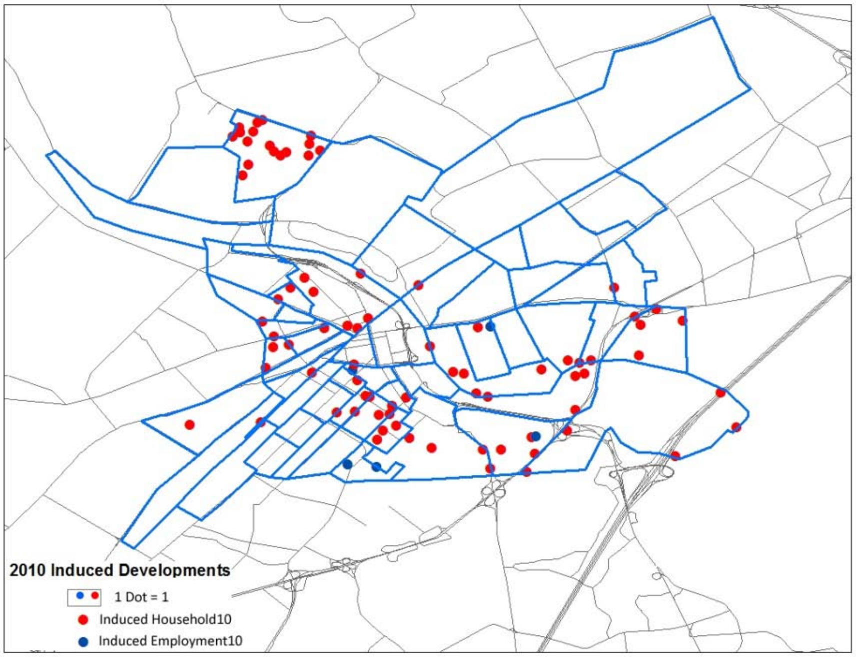

Figure 6.13 Induced households and employment, year 2010.

To identify the effects of changes in land use patterns on trip productions and attractions between the baseline and built scenarios, the following figures are generated.

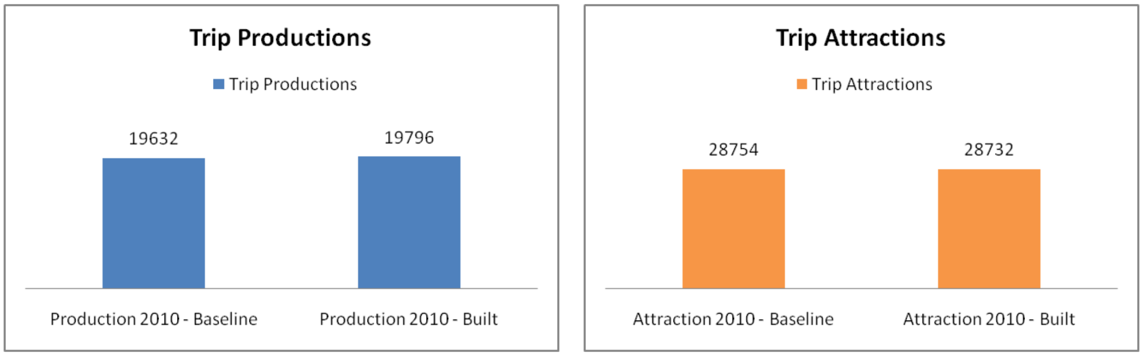

Figure 6.14 Changes in trip productions and attractions between the baseline and built scenarios, year 2010.

Based on the results above, the induced households and the loss in employment due to Route 18 improvements lead to 164 induced trip productions and a decrease in 22 trip attractions in the area.

6.4.2.2 Impacts on Traffic Conditions, Year 2010. Based on Tables 6.3 and 6.6, the improvements on Route 18 result in a total of 310 induced trips (or a 4.72%[44] increase in traffic volume). This additional traffic represents both components of induced demand: the rerouted trips and the trips resulted from induced developments.

Table 6.6 also shows that 31.75%[45] of the traffic is utilizing the local lanes (or outer roadway) while 68.25%[46] are utilizing the express lanes. The traffic in express lanes is 71.48%[47] of the baseline traffic (or 28.52%[48] less than that of the baseline traffic flow). This means that a portion of the baseline traffic is rerouted to the new outer

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[44] (6,873-6,563)/6,563

[45] 2,182/6,873

[46] 4,691/6,873

[47] 4,691/6,563

[48] 100-71.48

roadways. Thus, the outer roadway not only enhances the accessibility to the city of New Brunswick, but also improves the traffic circulation on Route 18.

Figures 6.15 and 6.16 are generated to display the comparison of simulated average speed and V/C ratios on Route 18 express lanes during the AM peak period between the baseline and built scenario with year 2010 demand. The blue line represents the baseline scenario results, and the red line represents the built scenario results.

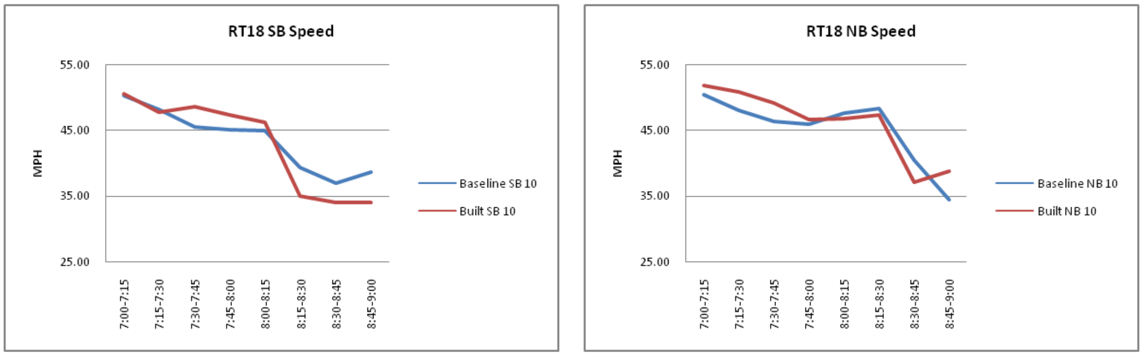

Figure 6.15 Route 18 southbound and northbound speed comparison, year 2010.

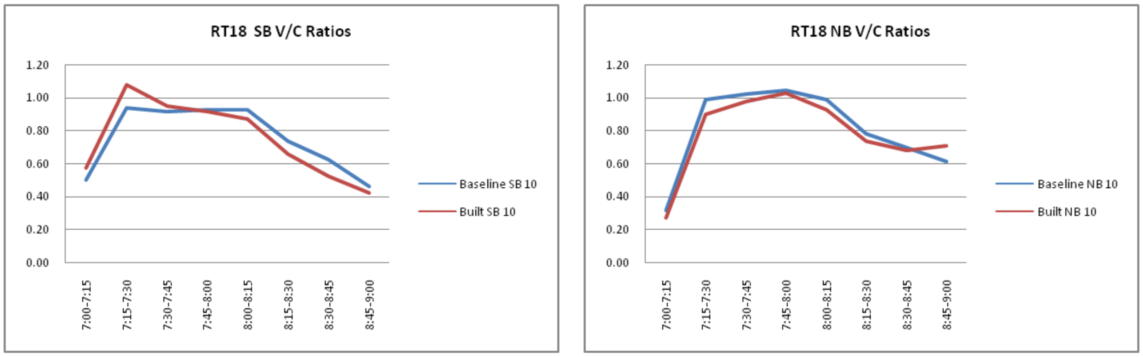

Figure 6.16 Route 18 southbound and northbound V/C ratios comparison, year 2010.

Based on Figure 6.15, the average speed on the southbound direction in the built scenario is decreasing at a higher rate compared to the baseline scenario. For the northbound, the average speed of the built scenario also declines rapidly after 8:30 AM.

By observing the simulation results, it can be noticed that the spillback congestion from the neighboring facilities, namely Route 27 and Route 1, are causing a major delay on Route 18 traffic operations in 2010. To visualize the spillback, Transims ArcDelay program is used to generate the average queue (in vehicles) between 8:00 and 9:00 AM. Figure 6.17 displays the spillback from Route 27 eastbound on to Route 18 northbound and Figure 6.18 displays the heavy merge from Route 1 northbound to Route 18 southbound.

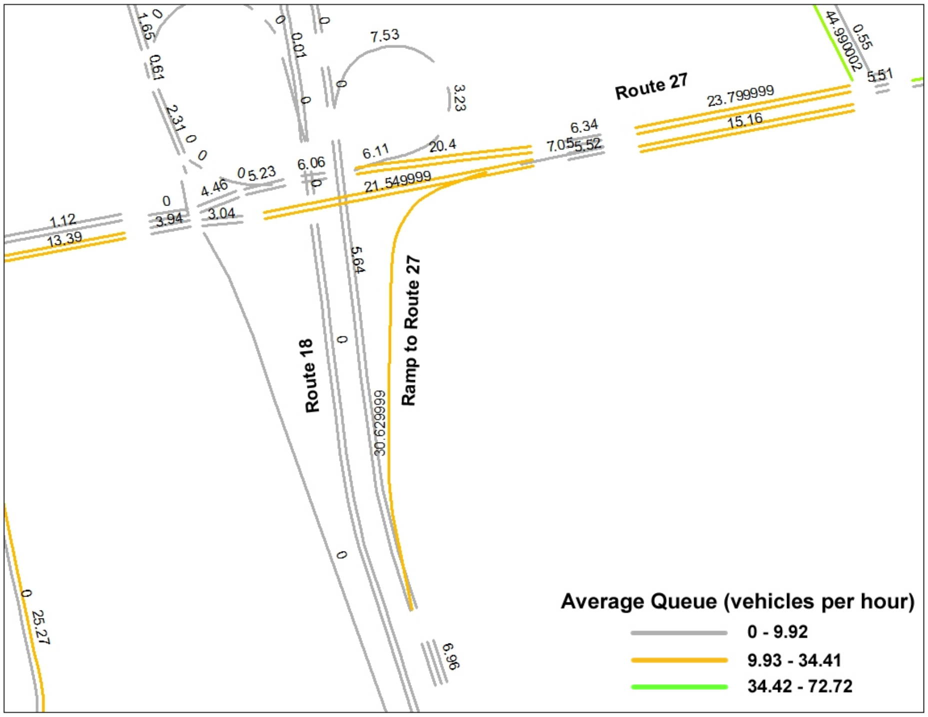

Figure 6.17 Average queue on Route 27, built scenario, year 2010.

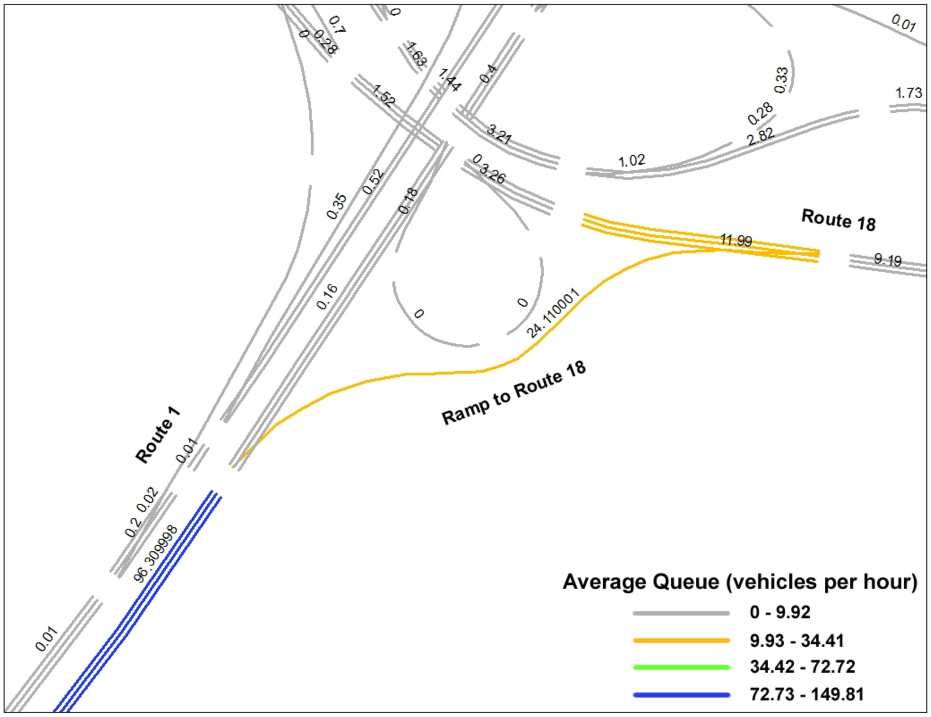

Figure 6.18 Average queue on Route 1, built scenario, year 2010.

6.5 Route 18 Reconstruction Area Analysis Summary

Based on the results discussed in this chapter, the integrated framework reveals a rather surprising outcome which challenges the validity of a widely accepted land use assumption. Although the improvement project is expected to have the greatest impact on the Route 18 reconstruction area and brings about substantial induced development to the area, only 41 households are attracted to the area between 2000 and 2010. Therefore, a question arises as to where the Route 18 improvement project induced development occurs.

In the next chapter, the model results are analyzed and evaluated at the regional level which will:

- Confirm the linkage between transportation system and land use

- Invalidate the widely accepted concept that the majority of induced development will occur in the vicinity of the improvement project

- Determine where the induced development will locate

- Identify the most crucial factor that influences such an anomaly in land use patterns

CHAPTER 7

THE REGIONAL ANALYSIS RESULTS

This chapter presents the analysis results for the entire region covering Middlesex and Monmouth Counties. It first summarizes the analysis results obtained from the baseline scenario and then the results obtained from the built scenario. The chapter concludes with the comparison between the two modeling scenarios' results. The impacts of the Route 18 reconstruction on the region are identified in terms of changes in land use patterns and traffic conditions.

7.1 Baseline Scenario Analysis Results

This section summarizes the regional analysis results for the baseline scenario for year 2000, 2005 and 2010, respectively. The results obtained from TELLUM model are summarized in terms of changes in land use patterns, and the results obtained from TRANSIMS model are summarized in terms of changes in traffic conditions.

7.1.1 Changes in Land Use

Table 7.1 displays the changes in land use patterns obtained from the baseline scenario for years 2000, 2005, and 2010.

Table 7.1 Regional Baseline Scenario Changes in Land Use Patterns

	Baseline Scenario		
	Year 2000	**Year 2005**	**Year 2010**
Households	266,402	270,007	276,539
Employment	369,221	377,960	386,920

According to Table 7.1, without the Route 18 reconstruction project, in 2005, Middlesex County experiences a 1.35%[49] and 2.37%[50] increase in households and employment, respectively, and increases of 2.42%[51] and 2.37%[52] in 2010.

7.1.2 Changes in Traffic Condition

Table 7.2 displays the changes in traffic conditions obtained from the baseline scenario for years 2000, 2005, and 2010.

Table 7.2 Regional Baseline Scenario Changes in Traffic Conditions

	Baseline Scenario		
	Year 2000	**Year 2005**	**Year 2010**
VMT	6,040,286.07	6,146,538.74	6,461,428.10
VHT	166,794.57	172,681.16	261,902.50
VHD	67,641.24	71,980.36	155,930.51
AV Travel Time (minutes)	12.67	13.02	21.00

In 2005, the region experiences a 1.76%[53], 3.53%[54], and 6.41%[55] increase in VMT, VHT, and VHD, respectively. This results in a 2.76%[56] increase in the average travel time. In 2010, the region continues to experience traffic growth. The VMT, VHT and, VHD increase by 5.12%[57], 51.67%,[58] and 116.63%[59], respectively. This leads to a 61.29%[60] increase in the average travel time in 2010.

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[49] (270,007-266,402)/ 266,402
[50] (377,960-369,221)/ 369,221
[51] (276,539-270,007)/ 270,007
[52] (386,920-377,960)/ 377,960
[53] (6,146,538.74-6,040,286.07)/ 6,040,286.07
[54] (172,681.16-166,794.57)/ 166,794.57
[55] (71,980.36-67,641.24)/ 67,641.24
[56] (13.02-12.67)/ 12.67
[57] (6,461,428.10-6,146,538.74)/ 6,146,538.74
[58] (261,902.50-172,681.16)/ 172,681.16
[59] (155,930.51-71,980.36)/ 71,980.36
[60] (21.00-13.02)/ 13.02

7.2 Built Scenario Analysis Results

This section summarizes the regional analysis results for the built scenario for years 2000, 2005 and 2010, respectively. It first summarizes the changes in land use patterns, and then the changes in traffic conditions.

7.2.1 Changes in Land Use

Table 7.3 displays the changes in land use patterns obtained from the built scenario for years 2000, 2005, and 2010.

Table 7.3 Regional Built Scenario Changes in Land Use Patterns

	Built Scenario		
	Year 2000	**Year 2005**	**Year 2010**
Households	266,402	270,116	276,643
Employment	369,221	378,051	387,024

According to Table 7.3, as a result of the Route 18 reconstruction project, in 2005, Middlesex County experiences a 1.39%[61] and 2.39%[62] increase in households and employment, respectively, and increases of 2.42%[63] and 2.37%[64] in 2010.

7.2.2 Changes in Traffic Conditions

Table 7.4 displays the changes in traffic conditions obtained from the built scenario for years 2000, 2005, and 2010.

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[61] (270,116-266,402)/ 266,402
[62] (378,051-369,221)/ 369,221
[63] (276,643-270,116)/ 270,116
[64] (387,024-378,051)/ 378,051

Table 7.4 Regional Built Scenario Changes in Traffic Conditions

	Built Scenario		
	Year 2000	**Year 2005**	**Year 2010**
VMT	6,063,328.53	6,150,959.03	6,567,254.46
VHT	165,012.99	172,348.24	260,999.61
VHD	65,803.12	71,601.77	153,188.69
AV Travel Time (minutes)	12.53	12.95	19.99

Due to the Route 18 reconstruction project, in year 2005, the region experiences a 1.45%[65], 4.45%[66], and 8.81%[67] increase in VMT, VHT, and VHD, respectively. This results in a 3.35%[68] increase in the average travel time. In 2010, the region continues to experience traffic growth. The VMT, VHT and VHD increase by 6.77%[69], 51.44%[70], and 113.95%[71], respectively. This leads to a 54.36%[72] increase in the average travel time in 2010.

7.3 Regional Analysis Result Conclusion

This section concludes the analysis results for the entire region. The impacts of the Route 18 reconstruction on regional land use patterns and traffic conditions are identified by comparing the results obtained from the baseline and built scenarios. The comparison is done for years 2005 and 2010.

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[65] (6,150,959.03-6,063,328.53)/ 6,063,328.53
[66] (172,348.24-165,012.99)/ 165,012.99
[67] (71,601.77-65,803.12)/ 65,803.12
[68] (12.95-12.53)/ 12.53
[69] (6,567,254.46-6,150,959.03)/ 6,150,959.03
[70] (260,999.61-172,348.24)/ 172,348.24
[71] (153,188.69-71,601.77)/ 71,601.77
[72] (19.99-12.95)/ 12.95

7.3.1 Year 2005 Conclusion

7.3.1.1 Impacts on Land Use Patterns, Year 2005. The results shown in Tables 7.1 and 7.3 suggest that the improvements on Route 18 lead to 0.04%[73] and 0.02%[74] increase in households and employment in Middlesex County in 2005.

The results of TELUM in Middlesex County are analyzed by comparing the difference in zonal allocation of employment and households between the baseline and built scenarios for 2005. The impacts are demonstrated by showing both the absolute and the relative (percentage) changes in the allocated number of households and jobs (employment) in each zone.

The maps of Middlesex County are generated to display zonal absolute and percentage changes in employment and households relative to the baseline scenario for 2005. Blue color represents a net increase; red color represents a net decrease, and white color indicates no change in the number of jobs or households by zone. Darker shades indicate greater difference in the number of allocated jobs or households between the two scenarios.

Figures 7.1 to 7.4 display the zonal absolute and percentage changes in households and employment for 2005 in Middlesex County. In Figure 7.1, the lighter shades of blue and red on the map suggest that the Route 18 improvements generally caused moderate relative shifts in household location patterns, compared to the baseline scenario (ranging between -5% and +5%). However, it can be noted that the southern part of the County generally experiences increase in the number of households, with zone #572 gaining 15.09% and zone #571 gaining 9.72% more households due to the highway

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[73] (270,116 - 270,007) / 270,007

[74] (378,051 - 377,960) / 377,960

improvement. In the northern parts, this is reversed: more zones seem to experience relative loss in attractiveness for households, especially zones #239 and #208 with 25% and 8.33% decrease in the number of households, respectively. Figure 7.2 shows the absolute change in the number of households. The southern part of Middlesex County appears to be the area that is most effected by the Route 18 improvements. The dark red areas indicate the largest absolute decrease, and the dark blue areas indicate the largest absolute increase in households in the area when comparing the two scenarios. A significant absolute decrease in households in the zones north and east to the Route 18 reconstruction area can be observed. One may infer that the Route 18 improvements reallocate the households from those areas to the south.

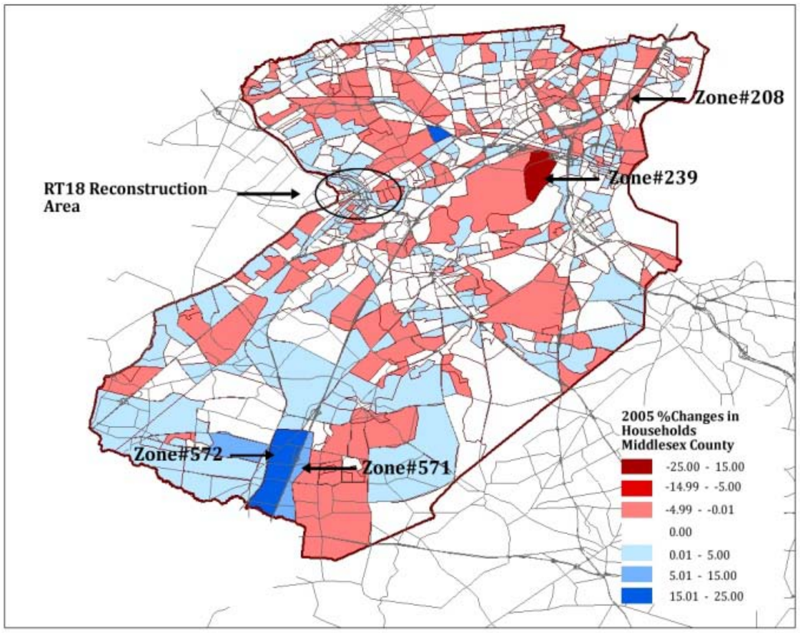

Figure 7.1 Zonal percentage change in households in built scenario relative to the baseline scenario, year 2005.

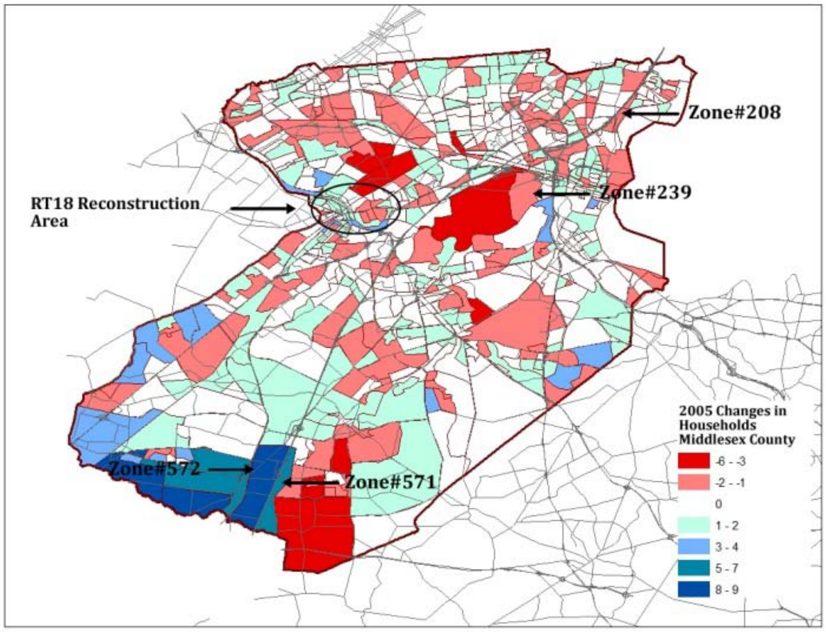

Figure 7.2 Zonal absolute change in households in built scenario relative to the baseline scenario, year 2005.

Figure 7.3 shows the change in location of jobs between the two scenarios in 2005. The zones in the south-west and far north-east parts of the county experienced gains as shown by the pale blue color. However, several zones in the southern part of the county experienced a loss of jobs (red colors in Figures 7.3 and 7.4), most likely gravitating toward zones further south. Zones in the central part of the county, north and east of the Route 18 improvement area, show a decrease in employment. This means that the Route 18 improvements resulted in increased attractiveness for jobs in the zones in the south-west and the north-east of the county. Interestingly, the zones in close proximity to the Route 18 reconstruction area show almost no change in job location patterns resulting from the reconstruction (most of the zones are in white color in both Figures 7.3 and 7.4).

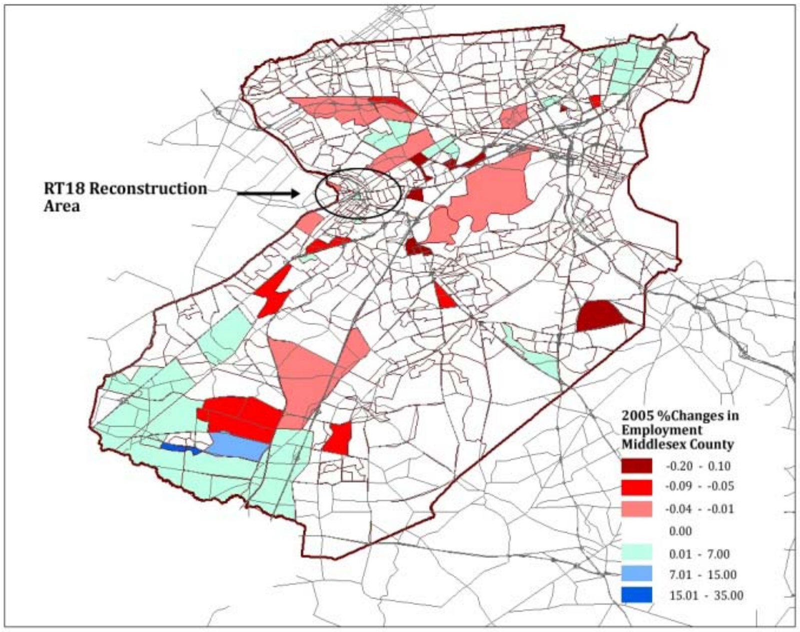

Figure 7.3 Zonal percentage change in employment in built scenario relative to the baseline scenario, year 2005.

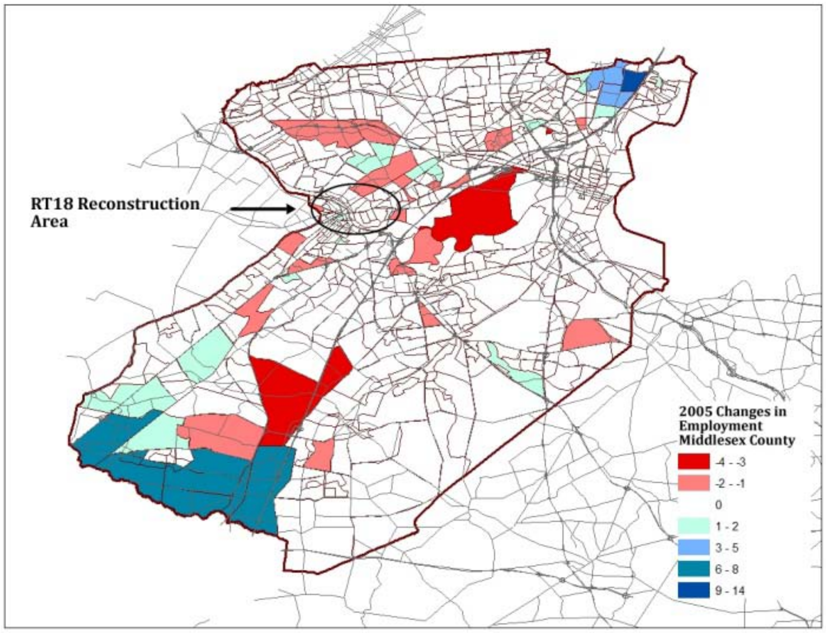

Figure 7.4 Zonal absolute change in employment in built scenario relative to the baseline scenario, year 2005.

7.3.1.2 Impacts on Traffic Conditions, Year 2005. Based on Tables 7.2 and 7.4, although the region experiences a 0.07%[75] increase in VMT in the built scenario compared to the baseline scenario, the regional VHT and VHD decrease by 0.19%[76] and 0.53%[77], respectively. The improvement in traffic flows resulting from the Route 18 improvements brings the regional average travel time down from 13.02 minutes to 12.95 minutes or a 0.54%[78] decrease in travel time from the baseline scenario.

7.3.2 Year 2010 Conclusion

7.3.2.1 Impacts on Land Use Patterns, Year 2010. The results shown in Tables 7.1 and 7.3 suggest that the improvements on Route 18 lead to a 0.04%[79] and 0.03%[80] increase in households and employment in Middlesex County in 2010.

The results from TELUM in Middlesex County are analyzed by comparing the difference in zonal allocations of employment and households between the baseline and built scenarios for 2010. The impacts are demonstrated by showing both the absolute and relative (percentage) changes in the allocated number of households and jobs (employment) in each zone.

The maps of Middlesex County are generated to display zonal absolute and percentage changes in employment and households relative to the baseline model for 2010. Blue color represents a net increase; red color represents a net decrease, and white color indicates no change in the number of jobs or households by zone. Darker shades

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[75] (6,150,959.03 - 6,146,538.74) / 6,146,538.74
[76] (172,348.24 - 172,681.16) / 172,681.16
[77] (71,601.77 - 71,980.36) / 71,980.36
[78] (12.95 - 13.02) / 13.02
[79] (276,643 – 276,539)/276,539
[80] (387,024 – 386,920)/386,920

indicate greater difference in the number of allocated jobs or households between the two models.

Figures 7.5 to 7.8 show the zonal absolute and percentage change in households and employments for 2010 in Middlesex County. According to Figures 7.5 and 7.6, while the impact of the Route 18 improvements in the immediate area of reconstruction remains marginal, the southern part of Middlesex County continues to have greater attractiveness for households in the built scenario as compared to the baseline scenario. The maps also show a household shift from the northern part to the eastern and southern parts of Middlesex County. In other words, Route 18 improvements continue to have a positive effect on the attractiveness of eastern and southern parts of the County in 2010 and shift the households from the northern part of the County to the eastern and southern parts.

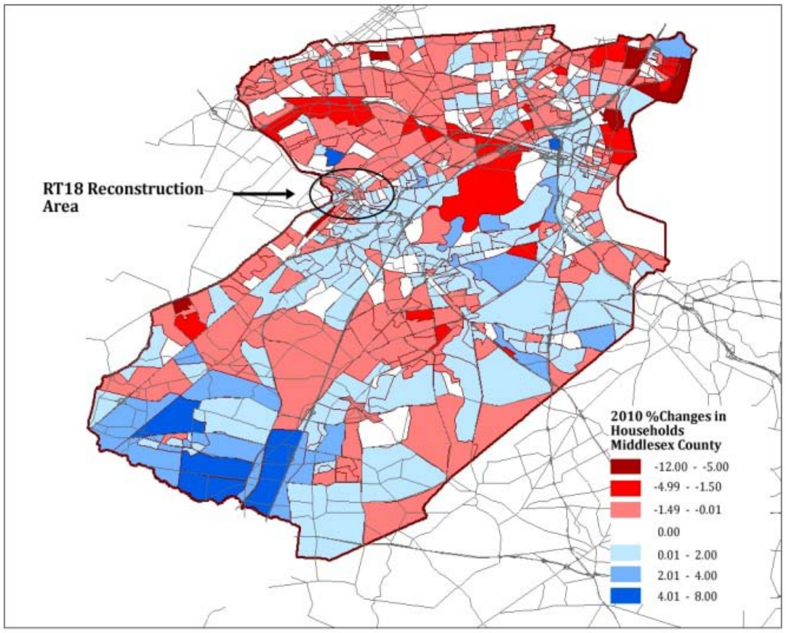

Figure 7.5 Zonal percentage change in households in built scenario relative to the baseline scenario, year 2010.

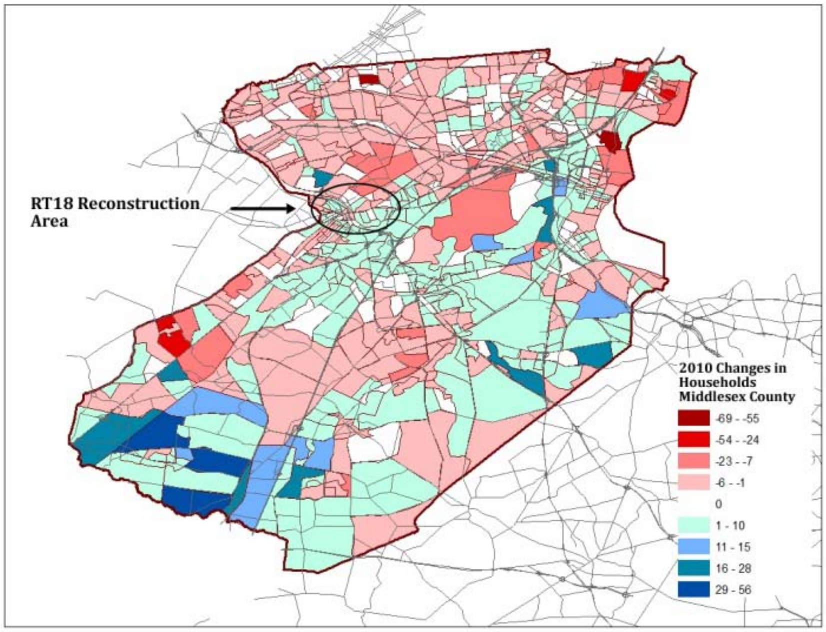

Figure 7.6 Zonal absolute change in households in built scenario relative to the baseline scenario, year 2010.

Figures 7.7 and 7.8 show that the impact of the Route 18 improvements on the location of jobs in Middlesex County in 2010 is relatively similar to that of year 2005. The impact on zones in the reconstruction area is marginal, zones in the south-west and north-east fringes of the region continue to gain attractiveness. Also, the larger areas in blue color in the south and north of the county suggest that those zones become more attractive for jobs to locate there in 2010 compared with 2005.

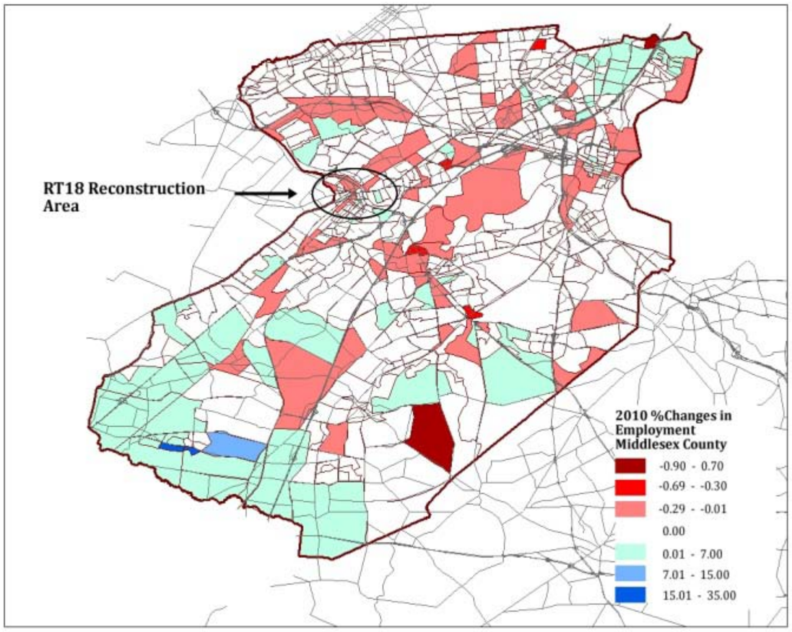

Figure 7.7 Zonal percentage change in employment in built scenario relative to the baseline scenario, year 2010.

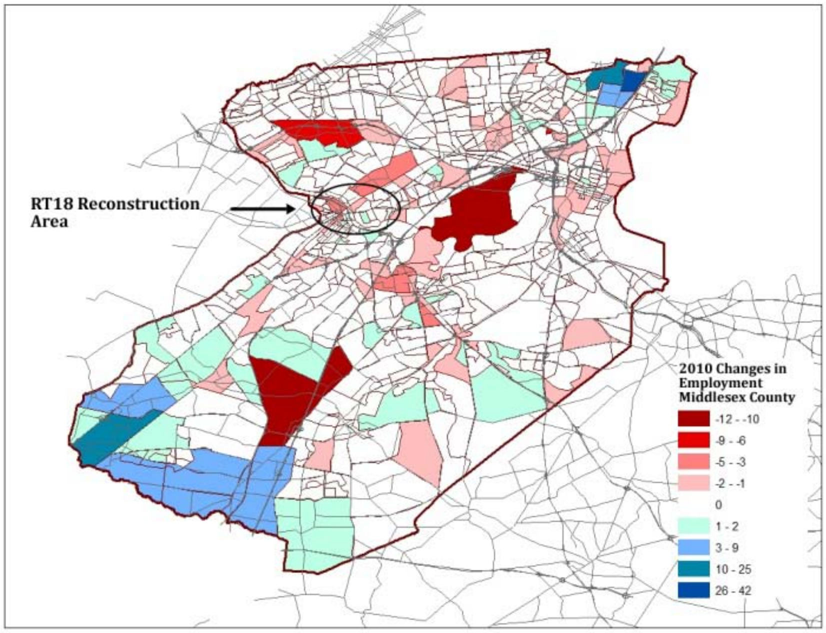

Figure 7.8 Zonal absolute change in employment in built scenario relative to the baseline scenario, year 2010.

7.3.2.2 Impacts on Traffic Conditions, Year 2010. Based on Tables 7.2 and 7.4, although the region experiences in 2010 a 1.64%[81] increase in VMT, the Route 18 improvements allow the overall traffic in the regional network to move more efficiently. The regional VHT and VHD in the built scenario decrease by 0.34%[82] and 1.76%[83], respectively compared to the baseline scenario. The reduction in VHT and VHD result in a decrease in travel time from 21 minutes to 19.99 minutes or a 4.81%[84] decrease from the baseline scenario.

7.4 Regional Analysis Summary

The analysis results discussed in this chapter shed new light on the extent and impact of transportation system changes on land use patterns. The results obtained from the case study suggest that the interactions between transportation system and land use are complex and that experiences in one location cannot be used to explain the effects on others. In the case study, although the majority of induced development is anticipated in the Route 18 reconstruction area, the land use, however, responds unexpectedly to the changes in transportation system. Due to the lack of vacant land in the vicinity of the improved area, the induced developments are spreading outward and gravitating toward the vacant land in the southern part of Middlesex County, thus, extending the affected area beyond what is first anticipated.

The results also highlight the fact that the interrelationship between the two systems changes constantly and continues to evolve over time. For example, given the

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[81] (6,567,254.46 - 6,461,428.10) / 6,461,428.10
[82] (260,999.61 - 261,902.50) / 261,902.50
[83] (153,188.69 - 155,930.51) / 155,930.51
[84] (19.99 - 21.00)/ 21.00

forecasted household patterns in 2005, it is reasonable to expect the southern part of Middlesex County to be the dominant area of attraction of future households, yet the eastern part of Middlesex County starts to gain momentum and attracts more households in 2010.

CHAPTER 8

COST BENEFIT ANALYSIS

This chapter presents a methodology used to calculate the economic viability of a transportation improvement. The methodology compares the costs of construction to the estimated benefits (or savings) in various user cost categories, including travel time, fuel consumption, and vehicle emissions. They are defined as follows:

- Travel time: overall savings in travel time on the regional network (and corresponding cost) resulting from the improvement.
- Fuel consumption: expected reduction due to improved ability of vehicles to operate in more efficient regimes on highways.
- Vehicle emissions: expected reductions in pollutants such as NOx, HC, and CO, as well as reduction in carbon footprint.

The main sources of data for this analysis are the outputs from the TRANSIMS model. The changes in VMT and VHT on each link of the regional network, resulting from the Route 18 improvements, are recorded. The benefits are expressed as the cost savings stemming from reductions in road users' costs, including travel time cost, vehicle emissions mitigation cost, and fuel cost. All of the savings are accrued across the model network on an annual basis and are calculated using VMT and VHT outputs from the model, and cost parameters specific to each cost category. Using the "Baseline" (or "no-build") and "Built" scenario results, the benefits of the Route 18 improvement project are estimated as a reduction in various user costs between the "Built" and "Baseline" scenarios. The calculation of road users' costs for each cost category is described next.

8.1 Calculation of Travel Time Cost Savings

Travel time savings (ΔVHT) are calculated as the difference between the total travel time (expressed in vehicle-hours traveled or VHT) in the Baseline scenario and the total travel time in the Built scenario. To obtain the monetary value of the travel time savings, total travel time savings are calculated for passenger cars and trucks, and then multiplied by the appropriate value of travel time, respectively. Travel time cost per driver/passenger and cost of one hour of operating a truck are obtained from the Bureau of Labor Statics (BLS)[85] and the American Transportation Research Institute (ATRI) report[86], respectively.

8.2 Calculation of Fuel Consumption Savings

Vehicle fuel consumption savings are calculated as a function of vehicle flow parameters derived from the results of VMT, which are disaggregated by vehicle type, fuel type, and speed bins (in 5 mph increments from 0 to 105 mph). The vehicle and fuel types in New Jersey are classified using Mobile 6 data[87], and the percentage of each vehicle type. The average price of gasoline and diesel in New Jersey, used to calculate the monetary value of fuel savings, was obtained from the U.S. Energy Information Administration (EIA) report[88].

With the classified vehicle type (i.e., auto and truck) and fuel type (i.e., gas and diesel) data, the average fuel consumption rate was obtained using IDAS (see Table J.2,

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[85] Average New Jersey wage from BLS Occupational Employment and Wages (http://www.bls.gov/oes/current/oes_nj.htm)

[86] Katherine J. Fender and David A. Pierce. "An Analysis of the Operational Costs of Trucking: A 2011 Update," ATRI, June 2011

[87] http://www.epa.gov/otaq/models/mobile6/420r03010.pdf

[88] http://www.eia.gov/petroleum/gasdiesel/

Appendix J). Therefore, the total fuel consumption amount for auto and truck can be computed as:

$$\Delta F_{Auto} = (\Delta VMT_{SOV} + \Delta VMT_{HOV}) \times \; g_{Auto}^{Speed} \tag{8.1}$$

$$\Delta F_{Truck} = \Delta VMT_{Truck} \times \; g_{Truck}^{Speed} \tag{8.2}$$

where

$\Delta F_{Auto}, \Delta F_{Truck}$ = Total fuel consumption change of passenger cars and trucks, respectively (gallons),

ΔVMT_{SOV}, $\Delta VMT_{HOV}, \Delta VMT_{Truck}$= Total VMT change of SOVs, HOVs, and trucks, respectively (vehicle-miles), and

$g_{Auto}^{Speed}, g_{Truck}^{Speed}$ = Average fuel consumption rate of passenger cars and trucks per speed bin (gallon/vehicle-miles).

The estimated fuel economy of passenger cars and trucks is given in Table J.2, Appendix J.

8.3 Calculation of Vehicle Emissions Savings

The emission rates and unit costs for HC, CO, and NOx (dependent on vehicle type and speed) were obtained from IDAS and used to calculate the monetary value of savings in vehicle emissions as a difference between the Baseline and the Built scenario. The vehicle emissions savings are also calculated based on the results of VMT, which are disaggregated by vehicle type, fuel type, and speed bins (in 5 mph increments from 0 to 105 mph). The emission rates per speed and vehicle type for HC, CO, and NOx are shown in Appendix J Tables J.3, J.4, and J.5, respectively.

8.4 Calculation of the Total Road User Cost Savings

To calculate a benefit/cost ratio on the modeled New Jersey roadway network, it is necessary to express all of the benefits in monetary values. To obtain the total savings in dollar amounts, the savings in travel time, vehicle emissions, and fuel must be multiplied by the appropriate unit costs.

8.4.1 Travel Time

$$\Delta C_{VHT} = (\Delta VHT_{SOV} \times C_{Pass}) + (\Delta VHT_{HOV} \times C_{Pass} \times VOR) + (\Delta VHT_{Turck} \times C_{Truck}) \tag{8.3}$$

where

ΔC_{VHT} = Total travel time cost savings due to transportation improvements (in $),

ΔVHT_{SOV}, ΔVHT_{HOV}, ΔVHT_{Truck} = Total VHT change of SOVs, HOVs, and trucks, respectively (vehicle-hours),

C_{pass}, C_{Truck} = Average value of time for passenger car and truck ($/person-hour) as indicated in Table 8.1, and

VOR = Vehicle occupancy rate (persons/vehicle).

Table 8.1 Dollar Value of Parameters Used in Calculations

Parameter	Value	Measure	Source
Travel Time Cost per driver or passenger	18.34, 21.09, and 24.39 per hour for year 2000, 2005, and 2010, respectively	$/hour	Average NJ wage from BLS Occupational Employment and Wages (50% of the average NJ hourly wage)[89]

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[89] Based on the congestion costs studies conducted by Apogee Research (Apogee Research 1994) and USDOT (USDOT 1997).

8.4.2 Fuel Consumption

$$\Delta C_{Fuel} = [(\Delta VMT_{SOV} + \Delta VMT_{HOV}) \times C_{Gas}] + (\Delta VMT_{Turck} \times C_{Diesel}) \qquad (8.4)$$

where

ΔC_{Fuel} = Total fuel consumption savings due to transportation improvements ($), and

C_{Gas}, C_{Diesel}= Market price at the pump of gasoline and diesel ($/gallon).

8.4.3 Vehicle Emission

$$\Delta C_{Emission} = (\Delta E_{HC} \times C_{HC}) + (\Delta E_{CO} \times C_{CO}) + (\Delta E_{NO_x} \times C_{NO_x}) \qquad (8.5)$$

where

$\Delta C_{Emission}$ = Total vehicle emission cost savings due to transportation improvements ($),

C_{HC}, C_{CO}, C_{NO_x} = Unit cost savings from the reduction of emissions of HC, CO, and NO_x, respectively ($/ton).

The dollar value of the parameters used is shown in Table 8.2.

Table 8.2 Dollar Value of Parameters Used in Fuel and Emission Savings Calculations

Parameter	Value	Measure	Source
HC emissions per hour of delay	0.000025676	tons	Guin *et al.*, 2007
CO emissions per hour of delay	0.00033869	tons	Guin *et al.*, 2007
NOx emissions per hour of delay	0.000036064	tons	Guin *et al.*, 2007
Cost savings because of HC reduction	6,700	$/ton	Guin *et al.*, 2007
Cost savings because of CO reduction	6,360	$/ton	Guin *et al.*, 2007
Cost savings because of NOx reduction	12,875	$/ton	Guin *et al.*, 2007
Average price of gasoline in NJ	2.654	$/gallon	U.S. Department of Energy, Energy Information Administration (EIA)
Average price of diesel in NJ	2.918	$/gallon	

The regional annual road user costs and benefits of the Route 18 reconstruction project are estimated and shown in Tables 8.3, 8.4 and 8.5.

Table 8.3 Estimated Annual Road User Costs and Benefits, 2000

	Year 2000			
	Travel Time Cost	**Environmental Cost**	**Fuel Cost**	**Total**
Baseline Scenario	382,376,552	64,546,540	208,883,531	655,806,623
Built Scenario	378,292,280	60,608,076	189,780,763	628,681,119
Savings[90]	**4,084,272**	**3,938,464**	**19,102,768**	**27,125,504**

Table 8.4 Estimated Annual Road User Costs and Benefits, 2005

	Year 2005			
	Travel Time Cost	**Environmental Cost**	**Fuel Cost**	**Total**
Baseline Scenario	455,230,708	65,956,096	213,231,035	734,417,839
Built Scenario	454,352,942	61,941,372	194,962,781	711,257,095
Savings	**877,766**	**4,014,724**	**18,268,254**	**23,160,744**

Table 8.5 Estimated Annual Road User Costs and Benefits, 2010

	Year 2010			
	Travel Time Cost	**Environmental Cost**	**Fuel Cost**	**Total**
Baseline Scenario	798,475,247	71,589,221	231,262,968	1,101,327,436
Built Scenario	795,722,561	69,068,172	218,550,995	1,083,341,728
Savings	**2,752,686**	**2,521,049**	**12,711,973**	**17,985,708**

8.4.4 The Construction Cost

The construction cost of the project is estimated at $200 million, and the total operating and maintenance cost, covering the period of 25 years, is estimated at 10% of the construction cost[91].

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[90] Baseline - Built

8.4.5 The Cost Benefit Ratio

Tables 8.3 to 8.5 show that the annual regional benefits attributable to Route 18 reconstruction project are approximately \$27.13 million, \$23.16 million and \$18 million, for years 2000, 2005, and 2010, respectively. The net present value of the total benefits, assuming a 1.7% discount rate[92], is calculated as \$329.09 million in year 2000 dollars[93].

The benefit-cost ratio (BCR) of this project is 1.50[94].

Thus, the project is considered to be an efficient investment, in that, each present value dollar invested in the project yields \$1.50 in present value of benefits.

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[91] Based on the value suggested by National Cooperative Highway Research Program (NCHRP) report, 345.

[92] Based on the real Interest Rate for 20-year maturity obtained from OMB Circular No.A-94, Appendix C.

[93] The benefit are assumed to linearly decrease to zero at the end of the 25th year due to the expected increase in traffic based on the standard utilized by USDOT and Iowa DOT.

[94] \$329.09 million in benefits divided by \$220 million on costs

CHAPTER 9

CONCLUSION AND THE RECOMMENDATIONS FOR FUTURE RESEARCH

In this dissertation, a developed framework integrates TRAMSIMS (a travel demand model) and TELUM (a land use model). A methodology is applied to determine the change in land use patterns that result from improvements in a transportation system. The framework also identifies changes in roadway network performance (travel time, speed, volume, delay) as a result of transportation improvement projects. In addition, the developed model can assist urban planners identify which transportation improvement projects should be undertaken, and at which locations, in order to achieve desired land use patterns.

This dissertation makes several contributions to the field of transportation policy and planning. The main contribution is the planning tool which allows planning agencies to utilize transportation improvement projects as mechanisms to encourage desired land use patterns and stimulate economic development in the targeted communities. A second contribution is the guidelines which enable MPOs to achieve compliance with federal mandates. And a third contribution is the technical information in regards to TRANSIMS model development, the feedback process, and the convergence statistics.

9.1 Results and Findings

Since the passage of ISTEA and TEA-21, MPOs, state DOTs, and other planning agencies have come under intense pressure to respond to federal mandates which require the integration of land use and transportation into their project prioritization process. However, neither ISTEA nor TEA-21 specifies how the transportation-land use integration is to be achieved. The absence of the guideline, the lack of resources and the fact that most MPOs are not equipped with planning models designed for this task make it nearly impossible for MPOs to comply with these requirements.

Currently, the integration process at the MPO is based on basic microeconomics which assumes that the decrease in travel cost will only affect and induce future development in the vicinity of the improved area.

Based on the model results, although the majority of induced developments are expected to take place in the Route 18 reconstruction area, only a few can be observed. The improvement induces only 22 and 19 developments into the area in year 2005 and 2010, respectively. The anomaly in expected impacts of the reconstruction project is amplified in the regional analysis where the results obtained from the integrated framework reveal change in future land use patterns occurring far from the reconstruction area. Although the greatest impact is expected to take place in the Route 18 reconstruction area, the southern part of Middlesex County, unexpectedly, experiences the highest gain in developments. This raises the question whether the invested funds fully help the targeted community achieve expected transportation and land use goals.

This dissertation provides a step-by-step guideline which MPOs and other planning agencies can follow to develop a framework which integrates transportation systems and land use. Recognizing the time and budget constraints most states and MPOs face, the integrated models are constructed based on data that are readily available to the planning agencies. The framework is developed based on interactions between TRANSIMS and TELUM models. Through the use of TRANSIMS in conjunction with TELUM, a planning agency can accurately capture and incorporate the impacts of their proposed transportation improvement projects on land use into the project prioritization process as mandated by law.

The dissertation described in detail data requirements, model development, and convergence statistics. The dissertation also explained how the integration between the two systems can be achieved through the use of multiple regression models which are built upon regional socioeconomic factors. Also, since the integrated framework has the ability to pinpoint exactly what the impacts of the transportation improvement project are, where the changes take place, and when they occur, planning agencies can utilize the framework to evaluate their transportation decisions based on modeling results which depict actual regional-specific travel and land use patterns. This approach greatly reduces the need for simplifying assumptions that tend to undermine the complexity of the interrelationship between the two systems.

Through the use of the framework, not only can the planning agency gain a better understanding in regards to how their transportation policies/decisions affect land use and vice versa, but the agency can also utilize the framework to fast-track and select projects listed in TIP which will result in desired land use patterns in the intended areas. Thus, transportation improvements can be used as mechanisms to guide the region toward sustainable land use futures.

9.2 Research Contributions

The methodological framework presented in this dissertation can be utilized as a powerful tool in project prioritization and transportation planning processes. The contributions of this dissertation to the field of transportation policy and planning are as follows:

- This dissertation discussed in detail how to develop an integrated transportation-land use model from data that are readily available to planning agencies.

- A planning tool was developed which allows planning agencies to utilize transportation improvement projects to guide future development patterns, densities and intensities of land use as well as encourage infill developments in an area of particular interest.

- A framework was provided which allows planning agencies to trace anomaly in land use patterns and identify crucial factors that influences such changes in land developments.

- Guidelines were established which enable planning agencies to achieve compliance with federal mandates.

- Appendices A, B, F, and G provide technical information in regards to TRANSIMS model development, the feedback process, and the convergence statistics. These appendices provide planning agencies and transportation modelers technical insights about the utilization of different programs in TRAMSIMS model. The different selection criteria that applied in each module in order to nudge TRANSIMS model toward convergence is also explained and discussed.

9.3 Future Research

The findings discussed in this dissertation suggest the following potential topics for future research:

- An immediate extension of this study is to extend the boundary of the study area. Since the majority of induced developments are forecasted to take place in the Southern part of Middlesex County, the study area defined in both TRANSIMS and TELUM models should be extended to include Mercer and Monmouth Counties. This extension should reveal the extent of the impacts on future land use patterns as a result of the Route 18 reconstruction project.

- The extension of the study area can cause the distribution and redistribution of the population and employment within the study area. The possible change in jobs yields economic impact for the study area but also adds vehicles to the roadway network that can alter the user road cost. This can further improve the planning process and enable transportation planners to have an even better estimate of the impacts of the project locally and regionally.

- In the case study, the framework was utilized to evaluate the impact of a single transportation improvement project. However, the framework can also be utilized to assess the impacts of multiple transportation improvement projects concurrently. This would allow planners to assess the combined effects of their transportation priorities. Thus, a set of priorities which yields the highest benefits, in terms of future traffic conditions and land use patterns, can be identified and implemented.

- Improve TRANSIMS model by developing an activity-based TRANSIMS model which uses information from household activity surveys to simulate changes in individual travel patterns. In the activity-based model, planners will have the ability to trace all activities that are carried out by every single synthetic traveler in the network. Thus, not only a more accurate assessment of transportation improvement projects can be achieved, but planners can also gain an insight into how changes in transportation system and land use patterns influence and/or alter the trip patterns and schedules of individuals' activities.

APPENDIX A

DYNAMIC USER EQUILIBRIUM AND SKIM FILE GENERATING PROCESS

The process of reaching dynamic user equilibrium in TRANSIMS consists of an iterative feedback process with the TRANSIMS Router[95] and MicroSimulator[96] programs. The user equilibrium is achieved thru these following processes:

- Router Stabilization
- Microsimulator Stabilization
- Equilibrium Convergence

A.1 Router Stabilization Process

Router Stabilization is a feedback process that involves TRANSIMS Router Program. Router is used repeatedly to adjust travel plans to generate realistic estimates of traffic volume. The approach is to reroute a subset of the travelers and combine their travel plans with the rest of the travel plans in a new simulation or travel time estimate. The travelers selected for rerouting are those that are traveling trough congested locations. Focusing on congested locations helps in refining the network travel times and diverting travelers from congested locations using the fewest number of feedback iterations. The Router Stabilization process is presented in Figure A.1.

If the initial set of travel plans is based on all-or-nothing paths using free-flow speeds. This may result in cascading queues and gridlock situations that misrepresent link travel times. Thus, travel plans are refined based on estimated travel time calculated

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[95] Build travel plans from specified origins to specified destinations at specified times of day using a specified travel mode

[96] Simulate the second-by-second movements of vehicles through the network

by TRANSIMS PlanSum program. TRANSIMS PlanSum program estimates the demand for each link in 15-minute increments. This demand is divided by the 15-minute link capacity and read into a volume-delay equation that estimates the loaded travel time. The results are stored in a link delay file that is read by the Router to refine the travel plans. The TRANSIMS PlanSelect program selects households for rerouting using four basic criteria:

- Volume-to-Capacity Ratio
- Time of Day
- Select Link or Node
- Travel Time Difference

The criteria based on travelers are selected and presented in Appendices for each scenario. The selected travelers are then rerouted based on link delay file. TRANSIMS PlanPrep program merges the rerouted plans with the full plan set. This iterative process should continue until the criterion, based on the selection, is achieved and satisfied.

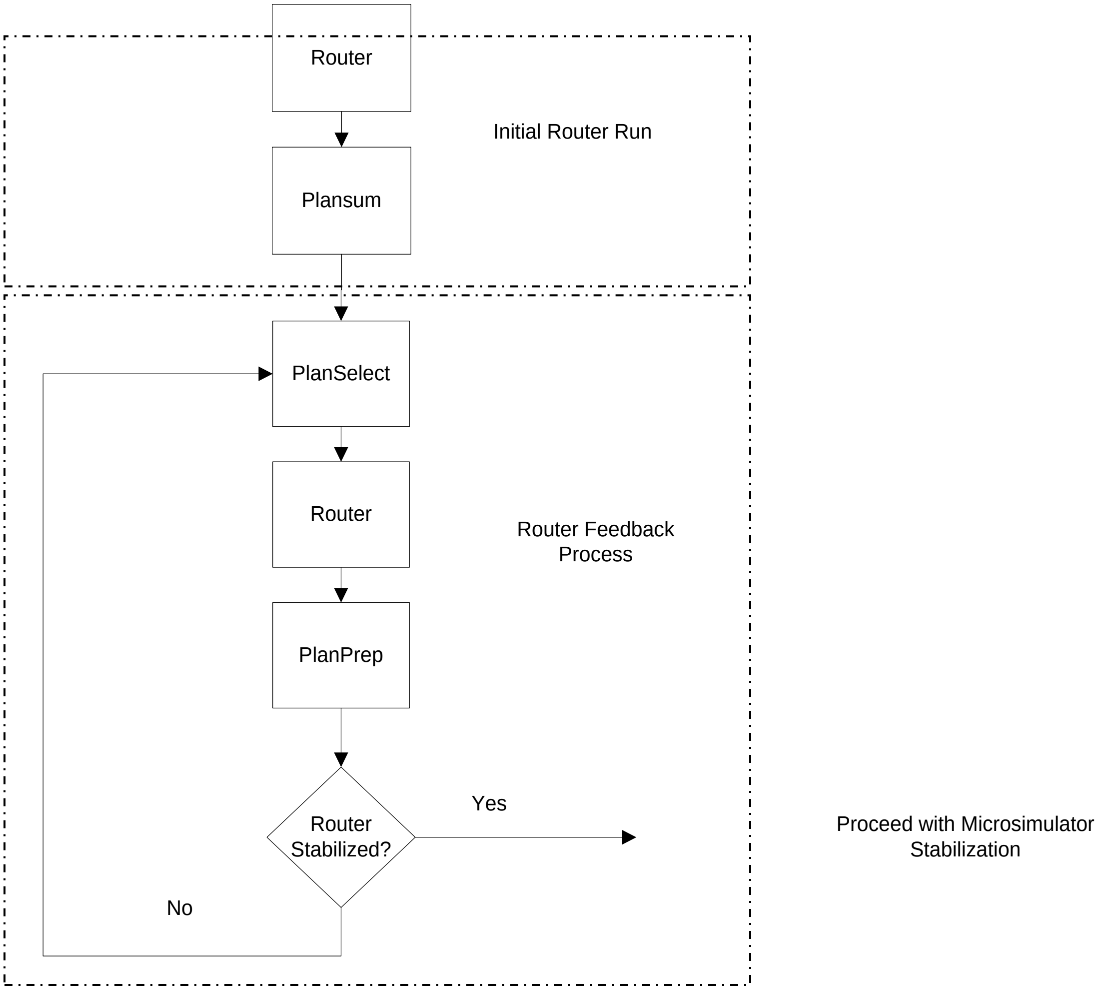


Figure A.1 Router stabilization process.

A.2 Microsimulator Stabilization Process

The Microsimulator feedback concept is similar to the one described in the Router Stabilization process. The difference is that the feedback process is using simulated travel times to calculate link travel times instead of travel times obtained from the Router. The process of selecting travelers for rerouting described in the Router Stabilization section is also here applied with the link delay file generated by the Microsimulator. After the Router Stabilization process is completed, the initial TRANSIMS Microsimulator program run is performed (Figure A.2). The TRANSIMS PlanSelect program, for rerouting selects travelers whose total trip travel time is significantly different from their previous travel plan. The criteria for traveler selection are presented in Appendices for each scenario. The selected travelers are rerouted and merged with the full plan set. The Microsimulator performs another run.

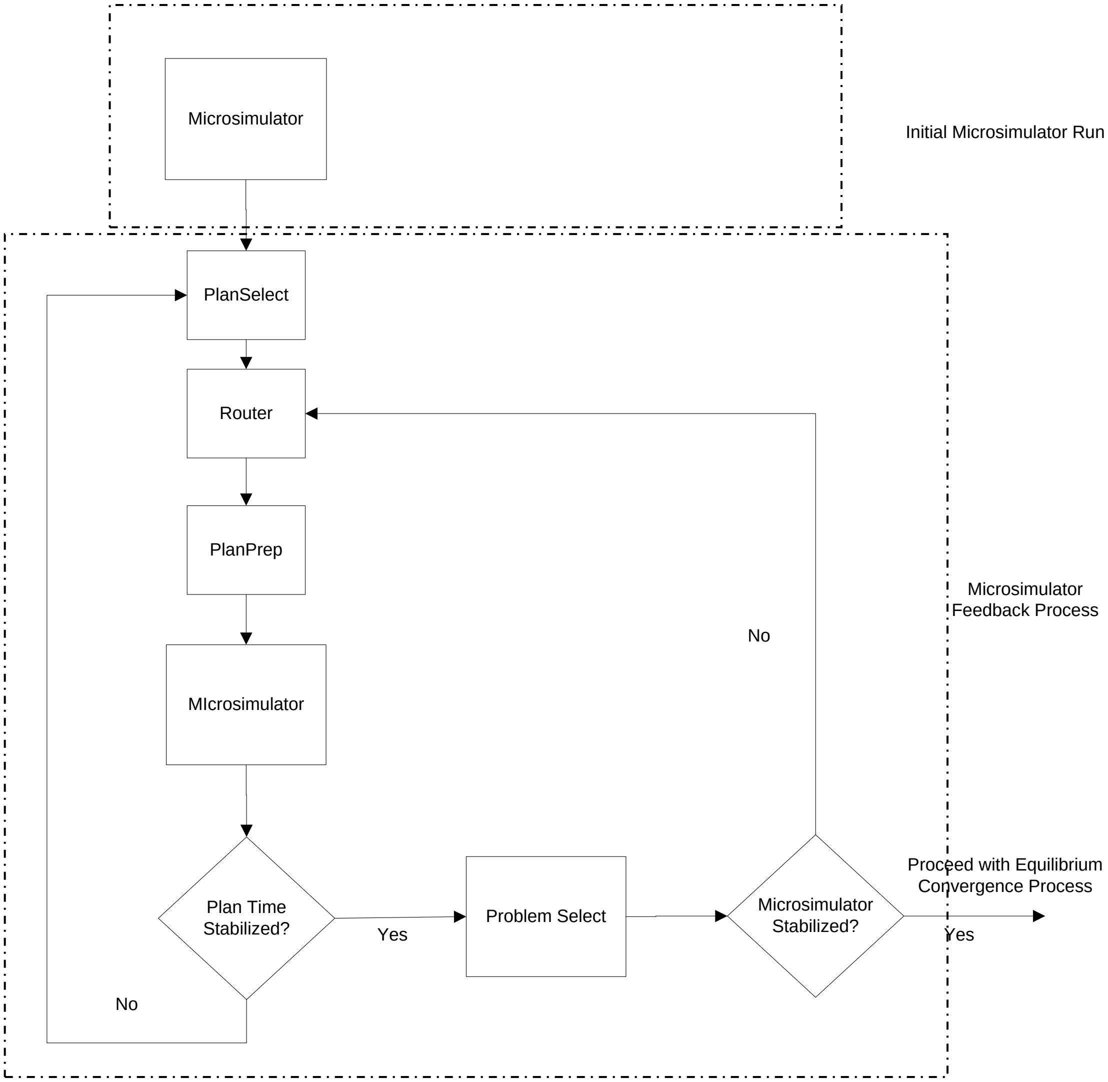


Figure A.2 Microsimulator stabilization process.

Once the difference in travel time meets the selected criteria, the TRANSIMS ProblemSelect Program is instructed to select travelers based on:

- Wait time problem. A wait time problem is defined as any situation in which a vehicle does not move its position for more than a predetermined number of seconds (in our case 120 sec)
- Departure Time Problem. When a vehicle cannot start its trip at the time specified in the trip file plus an amount of slack time is defined as a departure time problem

A TRANSIMS Microsimulator is typically considered to be stabilized when the percentage of selected travelers with a problem cannot be reduced any further.

A.3 Equilibrium Convergence Process

The equilibrium convergence process is presented in Figure A.3. The selection process in this step focuses on those travelers whose total trip travel time is significantly different from their previous travel plan. When the number of travelers for which the meaningful travel time differences is relatively small (below 2 percent), the process ends and the user-equilibrium is approximated.

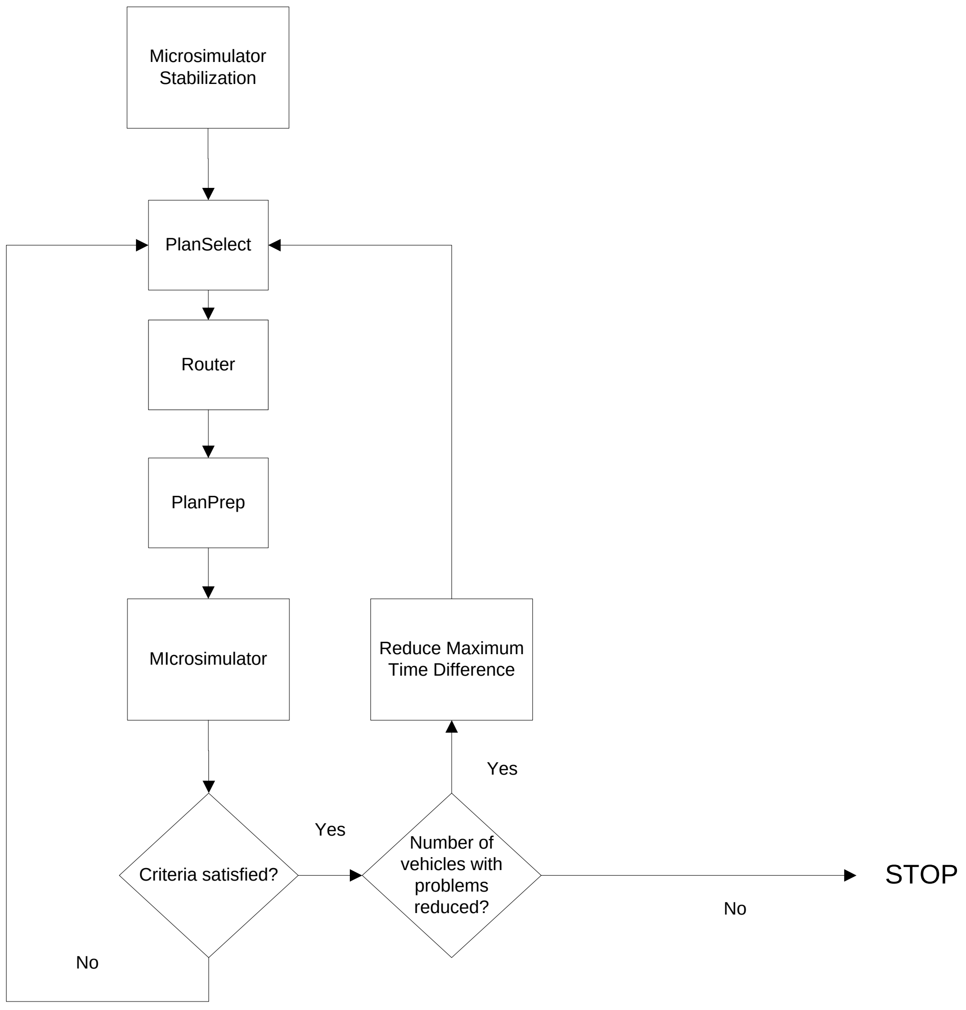


Figure A.3 Equilibrium convergence process.

APPENDIX B

TRANSIMS SKIM FILE GENERATION PROCESS

Figure B.1 below displays the iterative process of TRANSIMS modules required to reach user equilibrium and generate the skim file. It begins with the Router stabilization, followed by the Microsimulator stabilization and ends with the User Equilibrium Process. After the traffic flow equilibrium is approximated, the TRANSIMS PlanSum program is used to generate the zone-to-zone skim file.

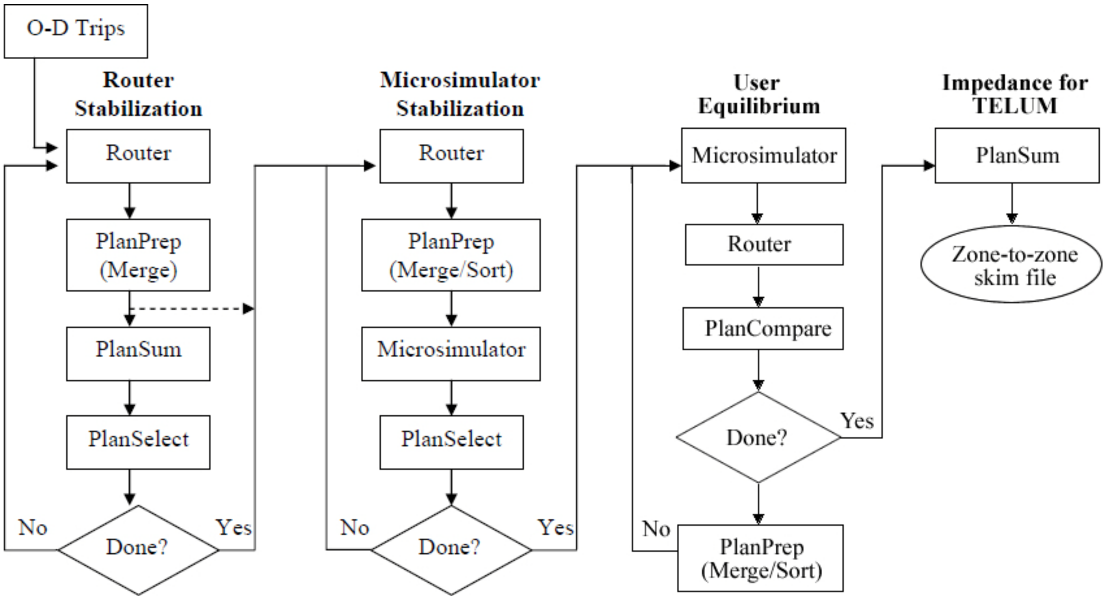


Figure B.1 TRANSIMS modules feedback process.

APPENDIX C

TELUM MODEL – DATA AND SOURCES

Other data used for TELUM model and their sources:

- U.S. Census Bureau:
    - Households by income group on a census block group level
    - Employment by industry type on a census block group level
    - Total population on a census block group level
    - Total employed residents on a census block group level
    - Group quarters population on a census block group level
    - Total households on a census block group level
    - Households by income group on a census block group level
    - Employment by industry type on a census block group level
    - Total population on a census block group level
    - Total employed residents on a census block group level
    - Group quarters population on a census block group level
    - Total households on a census block group level
    - Regional Householders by Industry and Income Matrix (PUMS)
    - Regional Employees per Household by Income Category Matrix (PUMS)
- New Jersey Department of Environmental Protection (NJDEP):
    - Land area occupied by basic employment
    - Land area occupied by commercial employment
    - Residentially occupied land
    - Land used for streets and highways

    a. Total usable land (developed + vacant developable)
    - Unusable land

- Census Bureau Transportation Planning Package:
    - Employment by place of residence on a census block group level
    - Employment by place of work on a census block group level
- U.S. Department of Labor. Identified data items include:
    - Percentage of multiple job holding on a state level
    - Regional unemployment rate by industry

APPENDIX D

TRIP PRODUCTION MODELS

This appendix discusses the results of trip production models for vehicle classes SOVS, HOV2, HOV3&4, and TRKS.

D.1 SOVS Production Model

Table D.1 summarizes the production models for vehicle class SOVS in detail.

Table D.1 SOVS Production Model Results

SOVS PRODUCTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.1499	$O_{vi} = 0.1858H_{i1} + 0.0214H_{i2} - 0.7563H_{i3} + 0.1669H_{i4} + 0.9157H_{i5} + 0.3373H_{i6} + 0.6848H_{i7} + 139.1987$
	EXP	0.1083	$O_{vi} = 129.2155 * (1.001{}^\wedge H_{i1}) * (0.9998{}^\wedge H_{i2}) * (0.9997{}^\wedge H_{i3}) * (0.9996{}^\wedge H_{i4}) * (1.001{}^\wedge H_{i5}) * (1.0008{}^\wedge H_{i6}) * (1.0024{}^\wedge H_{i7})$
CENSUS TRACT	**LINEAR**	**0.8177**	$\mathbf{O_{vi} = 0.311H_{i1} - 0.264H_{i2} - 1.5011H_{i3} + 3.1736H_{i4} + 2.1135H_{i5} + 0.4689H_{i6} + 0.6573H_{i7} - 24.2362}$
	EXP	0.7523	$O_{vi} = 482.616 * (0.9997{}^\wedge H_{i1}) * (1.0007{}^\wedge H_{i2}) * (0.9988{}^\wedge H_{i3}) * (1.0019{}^\wedge H_{i4}) * (1.0009{}^\wedge H_{i5}) * (1.0007{}^\wedge H_{i6}) * (1{}^\wedge H_{i7})$

Based on the model results, the census tract dataset on household income is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.8177 comparing to 0.1499 of the block group model for linear regression. For the exponential regression, the R^2 of the census tract model is 0.7523 compared to 0.1083 for the block group model. The results also suggest that the relationship between the existing household income and trip productions is better explained by the linear model than by the exponential model (R^2 of 0.8177 comparing to 0.7523 for the census tract model). Thus, the linear multiple regression equation based on census tract household income will be utilized to estimate the future trip productions for vehicle class SOVS.

D.2 HOV2 Production Model

Table D.2 summarizes the production models for vehicle class HOV2 in detail.

Table D.2 HOV2 Production Model Results

HOV2 PRODUCTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.1147	$O_{vi} = 0.0822H_{i1} + 0.0403H_{i2} - 0.064H_{i3} + 0.049H_{i4} + 0.0626H_{i5} + 0.0563H_{i6} + 0.0604H_{i7} + 27.3671$
	EXP	0.0807	$O_{vi} = 23.8675 * (1.0023^{\wedge}H_{i1}) * (1.0008^{\wedge}H_{i2}) * (1.0001^{\wedge}H_{i3}) * (0.9994^{\wedge}H_{i4}) * (1.0002^{\wedge}H_{i5}) * (1.001^{\wedge}H_{i6}) * (1.0014^{\wedge}H_{i7})$
CENSUS TRACT	**LINEAR**	**0.8717**	$\mathbf{O_{vi} = 0.1416H_{i1} + 0.1167H_{i2} - 0.0096H_{i3} + 0.5922H_{i4} - 0.1784H_{i5} + 0.0113H_{i6} + 0.1312H_{i7} + 20.9395}$
	EXP	0.7236	$O_{vi} = 112.0869 * (1.0003^{\wedge}H_{i1}) * (1.0005^{\wedge}H_{i2}) * (0.9995^{\wedge}H_{i3}) * (1.0018^{\wedge}H_{i4}) * (0.9999^{\wedge}H_{i5}) * (1.0003^{\wedge}H_{i6}) * (1.0001^{\wedge}H_{i7})$

Based on the model results, the census tract dataset on household income is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.8717 compared to 0.1147 of the block group model for linear regression. For the exponential regression, the R^2 of the census tract model is 0.7236 compared to 0.0807 of the block group model. The results also suggest that the relationship between the existing household income and trip productions is better explained by the linear model than by the exponential model (R^2 of 0.8717 compared to 0.7236 for the census tract model). Thus, the linear multiple regression equation based on census tract household income will be utilized to estimate the future trip productions for vehicle class HOV2.

D.3 HOV3&4 Production Model

Table D.3 summarizes the production models for vehicle class HOV3&4 in detail.

Table D.3 HOV3&4 Production Model Results

HOV3&4 PRODUCTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.1216	$O_{vi} = 0.0317H_{i1} + 0.0134H_{i2} + -0.0249H_{i3} + 0.0242H_{i4} + 0.0321H_{i5} + 0.0218H_{i6} + 0.0287H_{i7} + 11.7149$
	EXP	0.0829	$O_{vi} = 10.2146 * (1.0022{}^\wedge H_{i1}) * (1.0006{}^\wedge H_{i2}) * (1.0001{}^\wedge H_{i3}) * (0.9999{}^\wedge H_{i4}) * (1.0003{}^\wedge H_{i5}) * (1.0008{}^\wedge H_{i6}) * (1.0015{}^\wedge H_{i7})$
CENSUS TRACT	**LINEAR**	**0.8897**	$\mathbf{O_{vi} = 0.0541H_{i1} + 0.0416H_{i2} + 0.009H_{i3} + 0.2663H_{i4} - 0.0717H_{i5} - 0.0055H_{i6} + 0.0619H_{i7} + 6.8987}$
	EXP	0.7383	$O_{vi} = 47.5801 * (1.0002{}^\wedge H_{i1}) * (1.0005{}^\wedge H_{i2}) * (0.9995{}^\wedge H_{i3}) * (1.0019{}^\wedge H_{i4}) * (1{}^\wedge H_{i5}) * (1.0003{}^\wedge H_{i6}) * (1.0001{}^\wedge H_{i7})$

Based on the model results, the census tract dataset on household income is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.8897 compared to 0.1216 of the block group model for linear regression. For the exponential regression, the R^2 of the census tract model is 0.7383 compared to 0.0829 of the block group model. The results also suggest that the relationship between the existing household income and trip productions is better explained by the linear model than by the exponential model (R^2 of 0.8897 compared to 0.7383 for the census tract model). Thus, the linear multiple regression equation based on census tract household income will be utilized to estimate the future trip productions for vehicle class HOV3&4.

D.4 TRKS Production Model

Table D.4 summarizes the production models for vehicle class TRKS in details.

Table D.4 TRKS Production Model Results

TRKS PRODUCTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.0314	$O_{vi} = 0.0293H_{i1} - 0.0163H_{i2} - 0.0763H_{i3} + 0.0439H_{i4} + 0.0427H_{i5} + 0.0354H_{i6} - 0.0041H_{i7} + 9.9786$
	EXP	N/A	N/A
CENSUS TRACT	**LINEAR**	**0.4702**	$\mathbf{O_{vi} = 0.1873H_{i1} - 0.1363H_{i2} - 0.215H_{i3} + 0.1946H_{i4} + 0.1257H_{i5} + 0.1566H_{i6} - 0.041H_{i7} + 6.3581}$
	EXP	0.4231	$O_{vi} = 20.4074 * (1.0009\text{^}H_{i1}) * (1.0004\text{^}H_{i2}) * (0.9977\text{^}H_{i3}) * (1.0015\text{^}H_{i4}) * (1.0008\text{^}H_{i5}) * (1.0018\text{^}H_{i6}) * (0.9997\text{^}H_{i7})$

To describe the relationship of variables by exponential regression, the values of dependent variables must be greater than zero. Since TRKS trips do not originate from every block group in the study area, it is infeasible to define the exponential relationship. Based on the model results, the census tract dataset on household income is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.4702 compared to 0.0314 of the block group model for linear regression. For the census tract model, the results indicate that the relationship between the existing household income and trip productions is better explained by the linear regression than by the exponential regression (R^2 of 0.4702 compared to 0.4231). Thus, the linear multiple regression equation based on census tract household income will be utilized to estimate the future trip productions for vehicle class TRKS.

APPENDIX E

TRIP ATTRACTION MODELS

The following discusses the results of trip attraction models for vehicle classes SOVS, HOV2, HOV3&4, and TRKS.

E.1 SOVS Attraction Model

Table E.1 summarizes the attraction models for vehicle class SOVS in details.

Table E.1 SOVS Attraction Model Results

SOVS ATTRACTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.4398	$D_{vj} = - 0.026E_{j1} + 0.0418E_{j2} + 0.4124E_{j3} + 0.498E_{j4} + 0.2341E_{j5} - 0.3436E_{j6} + 0.1931E_{j7} + 138.1335$
	EXP	0.2328	$D_{vj} = 96.2902 * (1^{\wedge}E_{j1}) * (1.0002^{\wedge}E_{j2}) * (1.001^{\wedge}E_{j3}) * (1.0016^{\wedge}E_{j4}) * (0.9999^{\wedge}E_{j5}) * (1.0032^{\wedge}E_{j6}) * (0.9995^{\wedge}E_{j7})$
CENSUS TRACT	**LINEAR**	**0.6389**	$\mathbf{D_{vj} = - 0.1411E_{j1} + 0.121E_{j2} + 0.3656E_{j3} + 0.8788E_{j4} + 0.4396E_{j5} - 0.7848E_{j6} + 0.4708E_{j7} + 579.865}$
	EXP	0.5232	$D_{vj} = 446.9109 * (1^{\wedge}E_{j1}) * (1.0001^{\wedge}E_{j2}) * (1.0005^{\wedge}E_{j3}) * (1.0008^{\wedge}{}_{Ej4}) * (0.9999^{\wedge}E_{j5}) * (1.001^{\wedge}E_{j6}) * (0.9997^{\wedge}E_{j7})$

Based on the model results, the census tract dataset on employment type is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.6389 compared to 0.4398 of the block group model for linear regression. For the exponential regression, the R^2 of the census tract model is 0.5232 compared to 0.2328 of the block group model. The results also suggest that the relationship between the existing employment types and trip attractions is better explained by the linear model than by the exponential model (R^2 of 0.6389 compared to 0.5232 for the census tract model). Thus, the linear multiple regression equation based on census tract employment types will be utilized to estimate the future trip attractions for vehicle class SOVS.

E.2 HOV2 Attraction Model

Table E.2 summarizes the attraction models for vehicle class HOV2 in details.

Table E.2 HOV2 Attraction Model Results

HOV2 ATTRACTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.3969	$D_{vj} = 8.242E\text{-}06E_{j1} - 0.0044E_{j2} + 0.0305E_{j3} + 0.1587E_{j4} + 0.0033E_{j5} - 0.0612E_{j6} + 0.0192E_{j7} + 31.4899$
	EXP	0.1971	$D_{vj} = 22.4603 * (0.9999\text{^}E_{j1}) * (1.0001\text{^}E_{j2}) * (1.0006\text{^}E_{j3}) * (1.002\text{^}E_{j4}) * (0.9999\text{^}E_{j5}) * (1.0023\text{^}E_{j6}) * (0.9995\text{^}E_{j7})$
CENSUS TRACT	**LINEAR**	**0.6492**	$\mathbf{D_{vj} = - 0.0082E_{j1} + 0.0213E_{j2} + 0.0279E_{j3} + 0.4205E_{j4} - 0.0022E_{j5} - 0.2398E_{j6} - 0.064E_{j7} + 153.4793}$
	EXP	0.5318	$D_{vj} = 119.1181 * (1\text{^}E_{j1}) * (1\text{^}E_{j2}) * (1.0002\text{^}E_{j3}) * (1.0011\text{^}E_{j4}) * (0.9999\text{^}E_{j5}) * (1.0003\text{^}E_{j6}) * (0.9996\text{^}E_{j7})$

Based on the model results, the census tract dataset on employment type is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.6492 compared to 0.3969 of the block group model for linear regression. For the exponential regression, the R^2 of the census tract model is 0.5318 compared to 0.1971 of the block group model. The results also suggest that the relationship between the existing employment types and trip attractions is better explained by the linear model than by the exponential model (R^2 of 0.6492 compared to

0.5318 for the census tract model). Thus, the linear multiple regression equation based on census tract employment types will be utilized to estimate the future trip attractions for vehicle class HOV2.

E.3 HOV3&4 Attraction Model

Table E.3 summarizes the attraction models for vehicle class HOV3&4 in details.

Table E.3 HOV3&4 Attraction Model Results

HOV3&4 ATTRACTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.3843	$D_{vj} = - 0.0006E_{j1} - 0.0035E_{j2} + 0.0155E_{j3} + 0.0693E_{j4} - 0.0012E_{j5} - 0.0291E_{j6} + 0.0071E_{j7} + 14.0951$
	EXP	N/A	N/A
CENSUS TRACT	**LINEAR**	**0.6459**	$\mathbf{D_{vj} = - 0.0053E_{j1} + 0.0077E_{j2} + 0.0249E_{j3} + 0.1873E_{j4} - 0.0082E_{j5} - 0.1054E_{j6} - 0.0381E_{j7} + 67.7581}$
	EXP	0.5016	$D_{vj} = 51.7126 * (1\text{^}E_{j1}) * (1\text{^}E_{j2}) * (1.0003\text{^}E_{j3}) * (1.0011\text{^}E_{j4}) * (0.9999\text{^}E_{j5}) * (1.0004\text{^}E_{j6}) * (0.9996\text{^}E_{j7})$

To describe the relationship of variables by exponential regression, the values of dependent variables must be greater than zero. Since HOV3&4 trips do not terminate in every block group in the study area, it is infeasible to define the exponential relationship. Based on the model results, the census tract dataset on employment type is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.6459 compared to 0.3843 of the block group model for linear regression. For the census tract model, the results indicate that the relationship between the existing employment types and trip attractions is better explained by the linear regression than by the exponential regression (R^2 of 0.6459 compared to 0.5016). Thus, the linear multiple regression equation based on census tract employment types will be utilized to estimate the future trip attractions for vehicle class HOV3&4.

E.4 TRKS Attraction Model

Table E.4 summarizes the attraction models for vehicle class TRKS in details.

Table E.4 TRKS Attraction Model Results

TRKS ATTRACTION MODELS			
		R2	**EQUATIONS**
BLOCK GROUP	**LINEAR**	0.5442	$D_{vj} = 0.0024E_{j1} + 0.004E_{j2} + 0.0179E_{j3} + 0.0371E_{j4} - 0.0005E_{j5} - 0.0281E_{j6} + 0.0136E_{j7} + 6.4302$
	EXP	N/A	N/A
CENSUS TRACT	**LINEAR**	**0.7209**	$\mathbf{D_{vj} = 0.0092E_{j1} + 0.0101E_{j2} + 0.0349E_{j3} + 0.0838E_{j4} - 0.0177E_{j5} - 0.0851E_{j6} + 0.0068E_{j7} + 24.7171}$
	EXP	0.5402	D_{vj} = 22.8102 * (1.0001^E_{j1}) * (1^E_{j2}) * (1.0005^E_{j3}) * (1.0009^E_{j4}) * (0.9998^E_{j5}) * (1.0009^E_{j6}) * (0.9996^E_{j7})

To describe the relationship of variables by exponential regression, the values of dependent variables must be greater than zero. Since TRKS trips do not terminate in every block group in the study area, it is infeasible to define the exponential relationship. Based on the model results, the census tract dataset on employment type is a better descriptor than the block group dataset. The coefficient of determination (R^2) of the census tract model is 0.7209 compared to 0.5442 of the block group model for linear regression. For the census tract model, the results indicate that the relationship between the existing employment types and trip attractions is better explained by the linear regression than by the exponential regression (R^2 of 0.7209 compared to 0.5402). Thus, the linear multiple regression equation based on census tract employment types will be utilized to estimate the future trip attractions for vehicle class TRKS.

APPENDIX F

TRANSIMS MODEL VALIDATION

This appendix summarizes the TRANSIMS model simulation and validation results. It discusses the convergence statistics and illustrates the impact of Router feedback iterations in terms of travel time. The model is based on the regional network, covering Middlesex and Monmouth Counties, prior to the Route 18 improvements with the current demand (year 2000).

F.1 Convergence Statistics

In Appendix A, the process of reaching user equilibrium in TRANSIMS was described. The process starts with the Router stabilization, is followed by the Microsimulator stabilization, and ends with the Equilibrium Convergence Process.

A total of 220 feedback iterations are run for the regional network with the current demand (year 2000). The following section discusses the convergence process and the simulation results in detail.

F.1.1 Router Stabilization

The Router Stabilization process starts with the initial loading of the network. After this initial loading, the Transims PlanSelect program is instructed to select trips based on the V/C ratio. For the first 20 iterations, all trips traversing thru links with V/C ratios greater than 2.0 are selected for rerouting. After these initial 20 iterations, the routing of travelers is improved and there are no travelers that are traversing through the links with a V/C ratio larger than 2.0. Thus, the criterion for rerouting is changed and the following 20 iterations select the trips that are traveling through links with a V/C ratio greater than 1.5. This results in a better distribution of vehicles on the network and reduced congestion. The last 30 iterations (iteration 31-60 in Table F.1) select travelers based on minimum time difference between the two consecutive plan sets. The criteria during these iterations is that all trips with a minimum time difference between two plan sets of 2 minutes and a maximum time difference of 60 minutes will be eligible for rerouting. Table F.1 displays the selection criteria used for the Router Stabilization.

Table F.1 Selection Criteria for Router Stabilization – Baseline 2000

Variables	**Iterations**		
	2-10	**11-30**	**31-60**
Select V/C Ratios	2.0	1.5	-
Percent Time Difference	-	-	10
Minimum Time Difference	-	-	2
Maximum Time Difference	-	-	60
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Select Time Periods	All	All	All

After 60 feedback iterations, the Router has stabilized with 58.40% of trips being selected. Figure F.1 displays the Router Stabilization results.

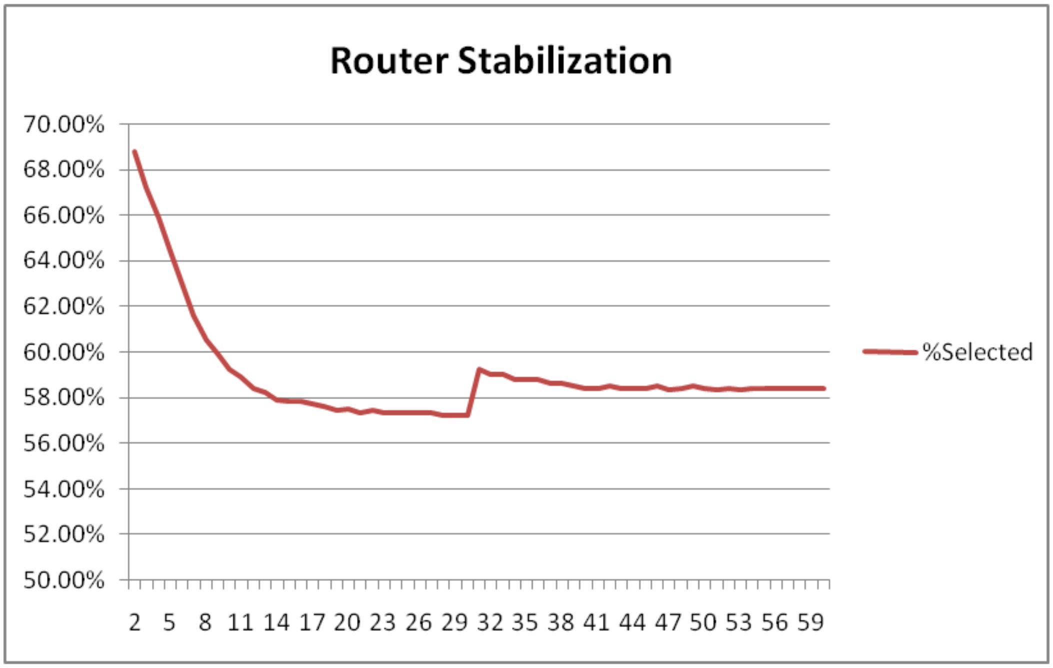


Figure F.1 Percentage of trips selected for rerouting – router stabilization baseline, year 2000.

F.1.2 Microsimulator Stabilization

After the Router Stabilization process is completed the improvements in routing of travelers in the network are achieved through Microsimulator Stabilization process. During the initial 15 Microsimulator feedback runs, TRANSIMS PlanSelect program is instructed to select the subsets of travelers based on the difference in travel time between the last two consecutive plans. The criterion used to select a trip for rerouting was that the trip will be rerouted if the minimum (maximum) time difference between plan sets is 2 minutes (60 minutes). After the plan time stabilization reached acceptable limits, the TRANSIMS ProblemSelect program is then utilized to select trips with specific problems (wait time and departure time). The wait time problem is generated when a vehicle remains in the same position, and it is unable to advance for a specific amount of time. The trip with a departure time problem is registered when a vehicle cannot start its trip at the time specified in the trip file plus an amount of slack time. Trips with a wait time or departure time problem were selected for rerouting in the remaining feedback runs. Table F.2 shows the selection criteria for Microsimulator Stabilization.

Table F.2 Selection Criteria for Microsimulator Stabilization – Baseline 2000

Variables	**Iterations**			
	61-75	**76-80**	**81-100**	**101-120**
Percent Time Difference	10	-	-	-
Minimum Time Difference	2	-	-	-
Maximum Time Difference	60	-	-	-
Problem Select	-	Wait Time	Wait Time, Departure Time	Wait Time
Selection Percentage	50	50	50	50
Maximum Percent Selected	10	10	10	10
Msim Run Time	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM

After 60 feedback microsimulation iterations, the Microsimulator is stabilized with only 1.30% of travelers having problems. Figure F.2 displays the Microsimulator Stabilization results.

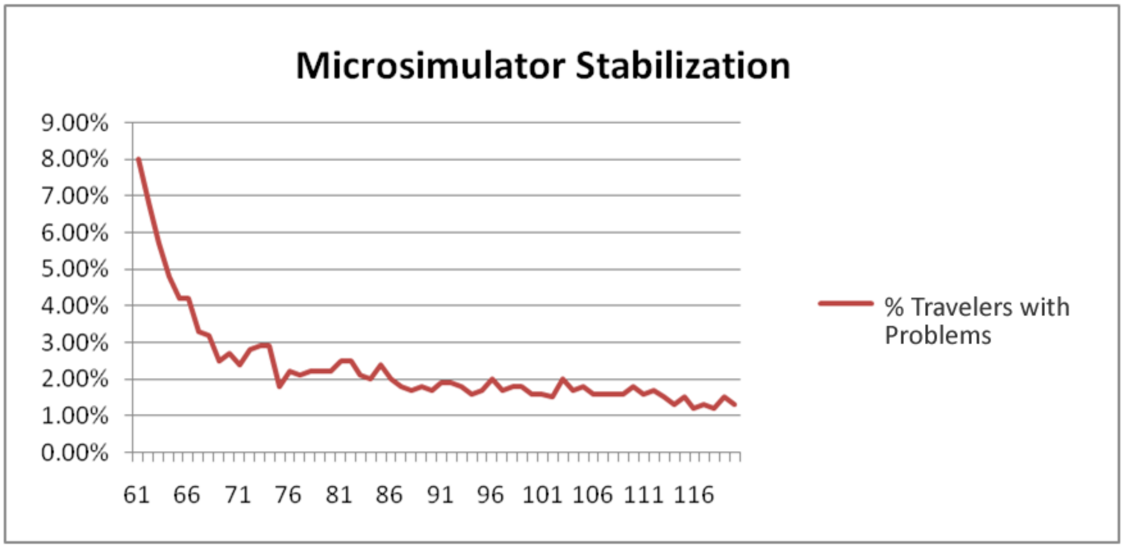


Figure F.2 Percentage of travelers with problems – microsimulator stabilization baseline, year 2000.

F.1.3 Equilibrium Convergence

The final step is the Equilibrium Convergence Stabilization process. The TRANSIMS PlanCompare program is instructed to select trips based on plan time difference, depending on the iteration number (Table F.3). The process starts with selecting travelers with minimum time difference of 2 minutes and maximum time difference of 30 minutes for rerouting. When there are no travelers selected based on this criterion, the maximum time difference is being reduced and an attempt is made to reroute travelers to a more efficient path that will improve their travel time. Table F.3 shows the change in criteria based on the iteration number.

Table F.3 Selection Criteria for User Stabilization – Baseline 2000

Variables	**Iterations**			
	121-135	**136-145**	**146-155**	**156-220**
Percent Time Difference	10	10	10	50
Minimum Time Difference	2	2	2	3
Maximum Time Difference	30	20	15	15
Selection Percentage	50	50	50	50
Maximum Percent Selected	10	5	3	3

After 100 feedback iterations, convergence is reached with 1.70% of travelers being selected. Figure F.3 displays the percent of travelers being selected based on the iteration number.

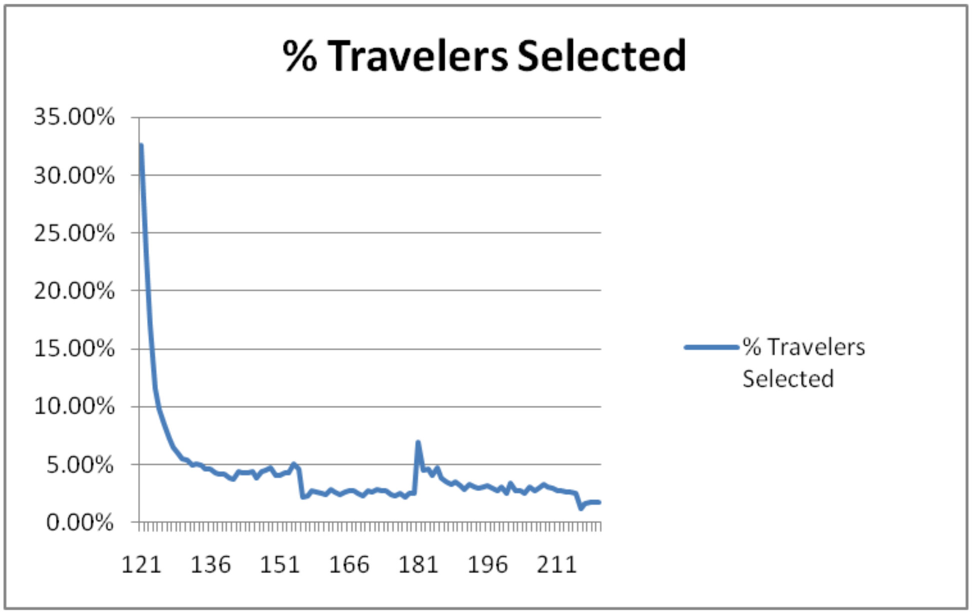


Figure F.3 Percentage of travelers selected for rerouting – equilibrium convergence baseline, year 2000.

In the process of reaching user equilibrium the Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT) and Vehicle Hours of Delay (VHD) are observed as the model moves toward convergence. As the model converges, the TRANSIMS model achieves better traffic assignment, hence, higher VMT and lower VHT and VHD. The Vehicle Miles of Travel (VMT) increases from 5,966,014.40 in iteration 1 to 6,040,286.07 in iteration 220. The Vehicle Hours of Travel (VHT) decrease from 313,187.7 to 166,794.57. The Vehicle Hours of Delay (VHD) decrease from 235,491.62 to 67,641.24 (Figure F.4).

The Microsimulator Stabilization and the Equilibrium Converge Process (in Table F.3 variable "Percent Time Difference") considered the difference in travel times between the two traveler plan sets. The average absolute travel time difference decreases from 2.44 minutes to 0.85 minutes. The gap between the simulated travel time and the equilibrium, for each iteration, is calculated and plotted. At the last iteration, the gap is 0.058 (Figure F.5).

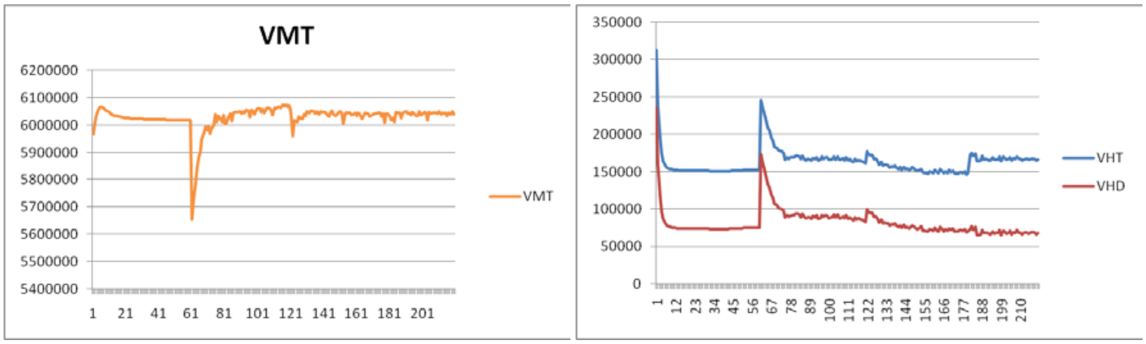


Figure F.4 VMT, VHT and VHD – baseline, year 2000.

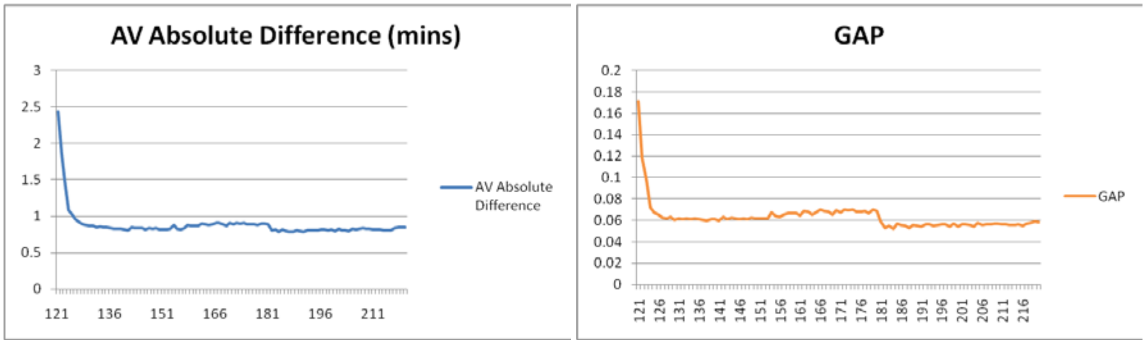
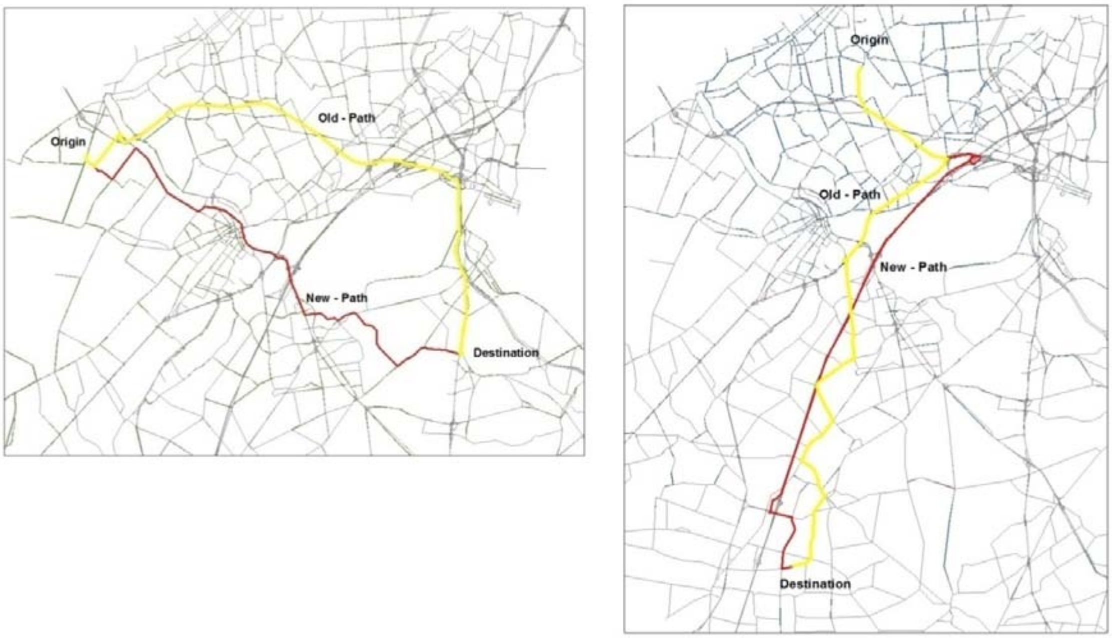


Figure F.5 Average absolute travel time difference and travel time gap – baseline, year 2000.

F.2 The Impact of Router Stabilization on Route Choice

The impact of the Router stabilization process on route choice is analyzed by selecting random travelers at certain selected iterations and observing their paths. The difference in paths that may exist is recorded and analyzed. The random traveler paths are selected (Figure F.6) and compared in order to ascertain the impact of Router feedbacks on route choice.

After the system is stabilized, the TRANSIMS ArcPlan[97] utility is used to generate the paths of randomly selected travelers for Router iterations 121 and 180. By observing their travel time, the travelers are rerouted to more direct and faster routes which resulted in decreased travel time. Figures F.6 and F.7 display the paths of selected travelers from two iterations. The original path is shown in yellow. The final path is shown in purple.



a. Impact of Router Parameters on Traveler 13101

b. Impact of Router Parameters on Traveler 125101

Figure F.6 The impact of router stabilization on selected travelers, iteration 121.

Figure F.6a indicates that traveler 13101 is rerouted to avoid the congested freeways (I-287SB and Garden State Parkway SB) to the less congested arterial (Route

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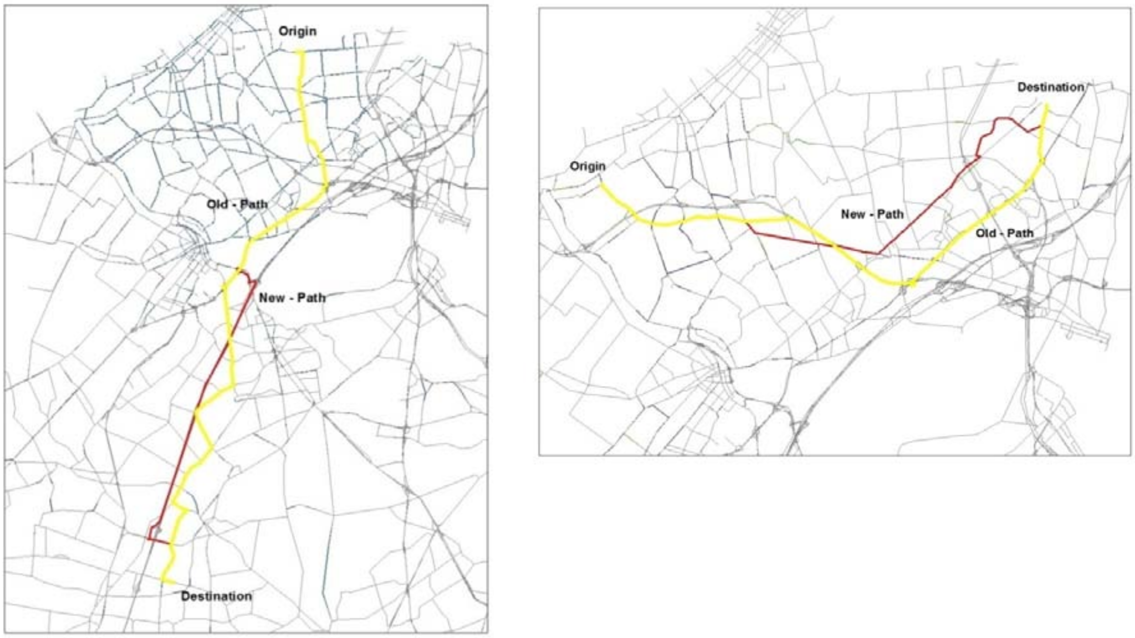
[97] Creates ArcView shapefiles showing the paths from selected records in TRANSIMS plan files

18SB). This rerouting resulted in a decrease in travel time from 33.53 minutes to 28.14 minutes.

Figure F.6b displays the shift of the traveling path of traveler 125101 to the freeway (I-95SB) that has a higher free flow speed. This rerouting resulted in a decrease in travel time from 33.10 minutes to 23.26 minutes.



a. Impact of Router Parameters on Traveler 191001

b. Impact of Router Parameters on Traveler 6101

Figure F.7 The impact of router stabilization on selected travelers, iteration 180.

Figure F.7a shows the shift in traveling path of traveler 191001 to the freeway (I-95SB) with higher free flow speed that resulted in a decrease in travel time from 41.04 minutes to 29.09 minutes.

Figure F.7b illustrates that traveler 6101 is rerouted from I-287SB and Route 1&9NB to Route 27. Traveling on less congested roadways results in a decrease in travel time from 26.37 minutes to 23.21 minutes.

F.3 TRANSIMS Model Validation

The TRANSIMS model is validated against the existing traffic counts obtained from the New Jersey Department of Transportation for the roadways within Middlesex County, New Jersey. These traffic counts are collected between the years 2006 and 2008. A total of 305 Automated Traffic Recorder (ATR) records are available for the study area and are used for model validation. Table F.4 shows the peak period link traffic volumes which are classified by volume level. The total TRANSIMS-estimated volume is 70,187 vehicles (or 9.2%) less than the observed volume. In other words, the TRANSIMS model underestimates the existing traffic volumes. Also, the volume is underestimated on roadway facilities with volume level of 5,000 vehicles and greater.

Table F.4 Model Validation Results - Highway Link Traffic Volumes Classified by Volume Level

Summary Statistics by Link Traffic Volume Level

	No of Obs	Volume		Difference		Abs. Error		Std.	%	R	V/C	
Volume Level		**Est**	**Obs**	**Volume**	**%**	**Avg.**	**%**	**Dev**	**RMSE**	**Sq**	**Avg**	**Max**
0 to 100	3	763	161	602	373.9	201	373.9	307	598.5	0.384	0.18	0.37
100-250	14	4,202	2,606	1,596	61.2	186	99.8	191	140.4	0.289	0.3	0.81
250-500	29	20,739	10,915	9,824	90	437	116.2	379	152.6	0.024	0.54	1.39
500-750	23	23,374	14,869	8,505	57.2	502	77.7	555	114.4	0.01	0.71	2.08
750-1,000	45	46,972	38,842	8,130	20.9	381	44.2	323	57.6	0.005	0.62	1.65
1,000 - 2,500	86	132,422	127,752	4,670	3.7	575	38.7	465	49.7	0.043	0.62	2.58
2,500-5,000	55	190,845	202,924	-12,079	-6	725	19.6	761	28.4	0.246	0.71	1.71
5,000-7,500	28	144,409	170,067	-25,658	-15.1	1410	23.2	1239	30.7	0.175	0.77	1.25
7,500-10,000	18	97.738	153,258	-55,520	-36.2	3152	37	1835	42.5	0.185	0.47	1.4
10,000-50,000	4	34,958	45,215	-10,257	-22.7	3144	27.8	2028	31.9	0.974	0.55	0.7
TOTAL	**305**	**696,422**	**766,609**	**-70,187**	**-9.2**	**796**	**31.7**	**1,047**	**52.3**	**0.747**	**0.63**	**2.58**

Table F.5 shows the peak period link traffic volumes classified by highway facility type. It can be observed that the TRANSIMS underestimates the volume on the higher class roadways, namely freeway and major arterials compared to the observed volumes. For the lower class roadways, TRANSIMS overestimates the traffic volume. The underestimation of the volume, however, is not a result of the routing problem. Since the trip table is based on year 2000 it can be assumed that the under-assignment is due to the traffic growth in years 2006 to 2008 and the under-assignment of the external trips that is carried over from the New Jersey Regional Transportation Model into the TRANSIMS network.

Table F.5 Validation Results of Traffic Link Volume by Facility Type

Summary Statistics by Facility Type

Facility Type	No of Obs	Volume		Difference		Abs. Error		Std. Dev	% RMSE	R Sq	V/C	
		Est	Obs	Volume	%	Avg	%				Avg	Max
Freeway	24	136,843	200,855	-64,012	-31.9	3,203	38.3	1,650	42.9	0.16	0.43	1.08
Major Arterial	128	411,464	428,685	-17,221	-4	763	22.8	681	30.5	0.74	0.73	1.71
Minor Arterial	76	87,584	82,969	4,615	5.6	529	48.5	773	85.5	0.01	0.68	2.08
Collector	68	51,909	44,495	7,414	16.7	352	53.7	320	72.4	0.30	0.72	2.58
Local Street	2	410	327	83	25.4	47	28.4	59	38.1	1	0.2	0.25
Ramp	7	8,212	9,278	-1,066	-11.5	566	42.7	352	49.3	0.28	0.39	0.65
TOTAL	**305**	**696,422**	**766,609**	**-70,187**	**-9.2**	**796**	**31.7**	**1,047**	**52.3**	**0.75**	**0.63**	**2.58**

APPENDIX G

TRANSIMS MODEL SIMULATION SUMMARY

This appendix summarizes the TRANSIMS model simulation results and the convergence statistics for baseline and built scenarios. It is divided into two parts. The first part discusses the baseline scenario for years 2005 and 2010 (see Appendix F for year 2000 baseline scenario). The second part discusses the results from the built scenario for years 2000, 2005, and 2010.

G.1 Baseline Scenario TRANSIMS Simulation Summary

G.1.1 Baseline Scenario – Year 2005

A total of 100 feedback iterations are run for the baseline scenario with the forecasted demand (year 2005). The following section discusses the convergence process and results for the AM period in detail.

G.1.1.1 Router Stabilization. The PlanSelect program is instructed to select trips based initially on V/C ratios. For the first 10 iterations all trips that are traveling via links with v/c ratio greater than 2.0 were selected for rerouting. The criterion value for the v/c ratio is reduced to 1.5 for the next ten iterations. The plan time difference was the final criterion based on last 10 iterations were performed. The trips that had a minimum travel time difference of 2 minutes and a maximum time difference of 60 minutes were selected for rerouting. Table G.1 shows the selection criteria used for Router Stabilization.

Table G.1 Selection Criteria for Router Stabilization – Baseline 2005

Variables	**Iterations**		
	2-10	**11-20**	**21-30**
Select VC Ratios	2.0	1.5	-
Percent Time Difference	-	-	10
Minimum Time Difference	-	-	2
Maximum Time Difference	-	-	60
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Select Time Periods	All	All	All

After 30 feedback iterations, the Router is stabilized with 57.20% of trips being selected. Figure G.1 displays the Router Stabilization results.

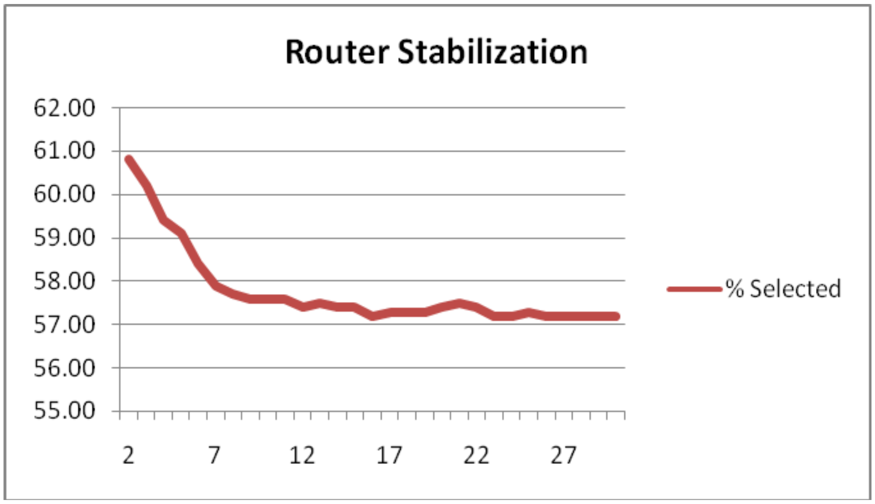


Figure G.1 Percentage of trips selected for rerouting – router stabilization baseline, year 2005.

G.1.1.2 Microsimulator Stabilization. Transims PlanSelect program is instructed to select the subsets of travelers based on travel timer difference criteria. A minimum time difference of 2 minutes and a maximum time difference of 60 minutes are the selection criteria for the first 10 iterations. After the plan time stabilization has reached acceptable limits, the Transims ProblemSelect program is then utilized to select trips with specific problems (wait time and departure time). The trips with a wait time problem were selected for rerouting for the next 5 iterations. The final 15 iterations selected vehicles based on the wait time and departure time criteria. Table G.2 shows the selection criteria for Microsimulator Stabilization.

Table G.2 Selection Criteria for Microsimulator Stabilization – Baseline 2005

Variables	**Iterations**		
	31-40	**41-45**	**46-50**
Percent Time Difference	10	-	-
Minimum Time Difference	2	-	-
Maximum Time Difference	60	-	-
Problem Select	-	Wait Time	Wait Time, Departure Time
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Msim Run Time	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM

After 20 feedback microsimulation iterations, the Microsimulator is stabilized with 1.70% of travelers with problems. Figure G.2 displays the Microsimulator Stabilization results.

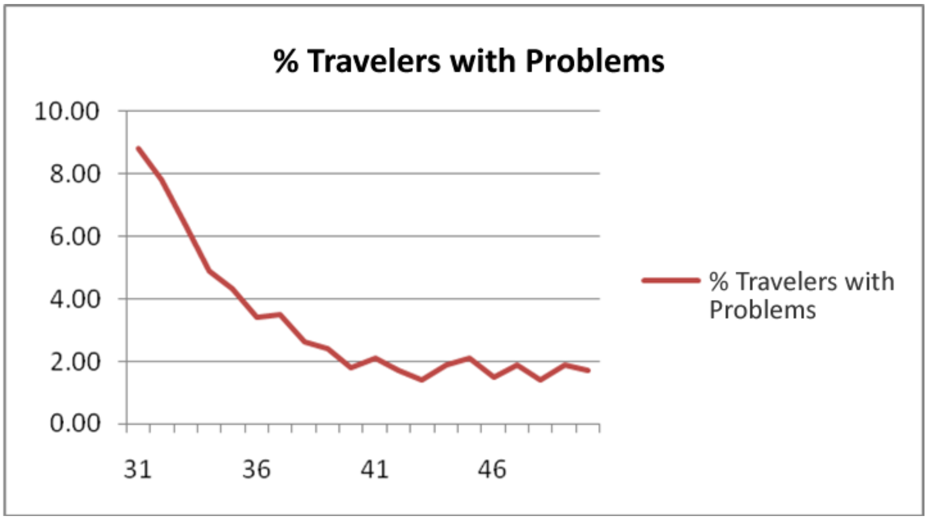


Figure G.2 Percentage of travelers with problems – microsimulator stabilization baseline, year 2005.

G.1.1.3 Equilibrium Convergence. Equilibrium Convergence is achieved through the iterative feedback process of running the Router, PlanCompare, PlanPrep, and Microsimulator programs. The PlanCompare program is instructed to select trips based on plan time difference, depending on the iteration number. In this feedback process the maximum time difference between two plan sets was reduced from 60 minutes to 30 minutes for the first 15 iterations, then to 20 minutes for the next 25 iterations and finally to 15 minutes for the last 5 iterations. Table G.3 shows the selection criteria used for User Equilibrium.

Table G.3 Selection Criteria for User Stabilization – Baseline 2005

Variables	**Iterations**		
	51-65	**66-85**	**86-90**
Percent Time Difference	10	10	10
Minimum Time Difference	2	2	3
Maximum Time Difference	30	20	15
Selection Percentage	50	50	50
Maximum Percent Selected	10	5	3

After 40 feedback PlanCompare iterations, convergence is reached with 2.3% of travelers being selected. Figure G.3 displays the User Equilibrium results.

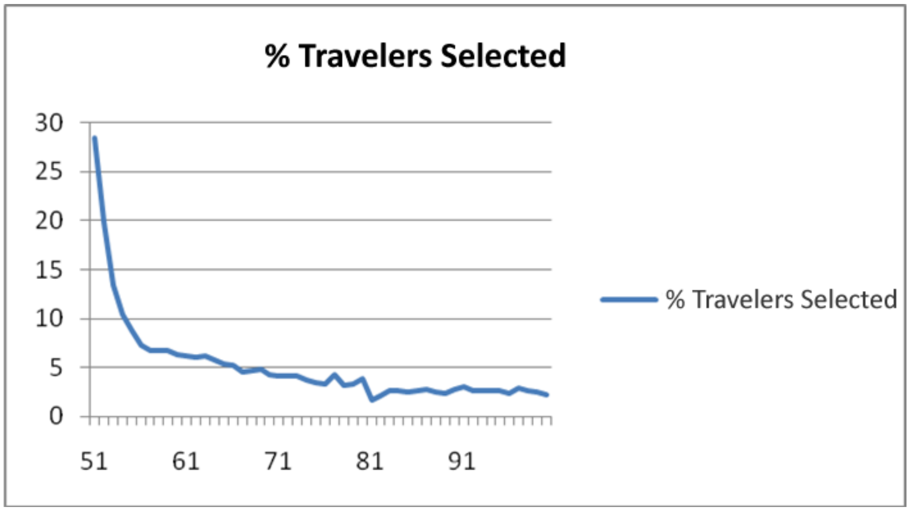


Figure G.3 Percentage of travelers selected for rerouting – equilibrium convergence baseline, year 2005.

The Vehicle Miles of Travel (VMT) in the last iteration is 6,146,538.74. The Vehicle Hours of Travel (VHT) decrease from 230,593.63 to 172,681.16 between the first and last iterations. The Vehicle Hours of Delay (VHD) decrease from 129,638.02 to 71,980.36 between the first and last iteration. Figure G.4 shows VMTs, VHTs and VHDs.

The average absolute travel time difference decreases from 2.33 minutes to 0.85 minutes between the first and last iteration. The gap between the simulated travel times is calculated and plotted. At the last iteration, the gap is 0.057. Figure G.5 shows the travel time and gap.

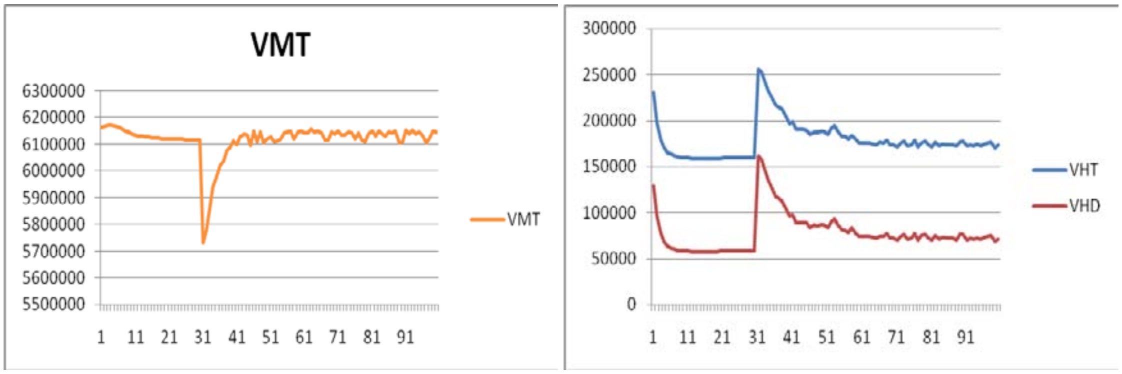


Figure G.4 VMT, VHT and VHD – baseline, year 2005.

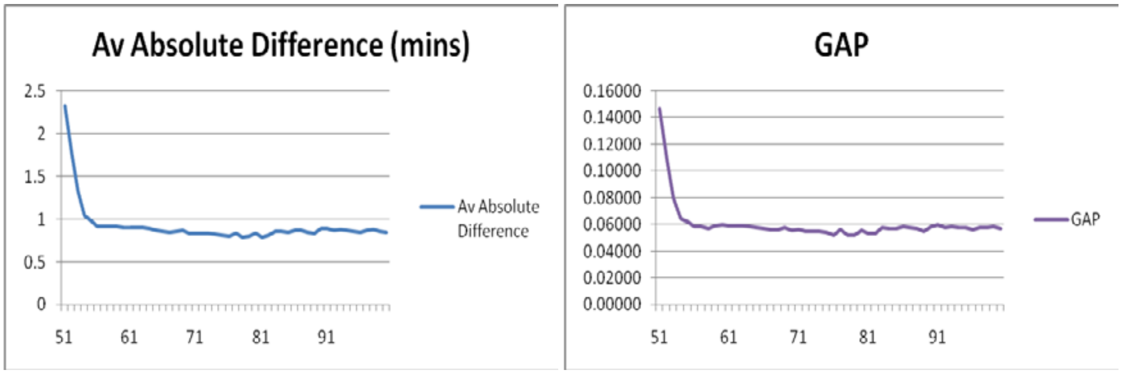


Figure G.5 Average absolute travel time difference and travel time gap – baseline, year 2005.

G.1.2 Baseline Scenario – Year 2010

A total of 135 feedback iterations are run for the baseline scenario with the forecasted demand (year 2010). The following section discusses the convergence process and results for the AM period in detail.

G.1.2.1 Router Stabilization. Table G.4 shows the selection criteria used for Router Stabilization.

Table G.4 Selection Criteria for Router Stabilization – Baseline 2010

Variables	**Iterations**		
	2-10	**11-20**	**21-30**
Select VC Ratios	2.0	1.5	-
Percent Time Difference	-	-	10
Minimum Time Difference	-	-	2
Maximum Time Difference	-	-	60
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Select Time Periods	All	All	All

After 30 feedback iterations, the Router is stabilized with 62.70% of trips being selected. Figure G.6 displays the Router Stabilization results.

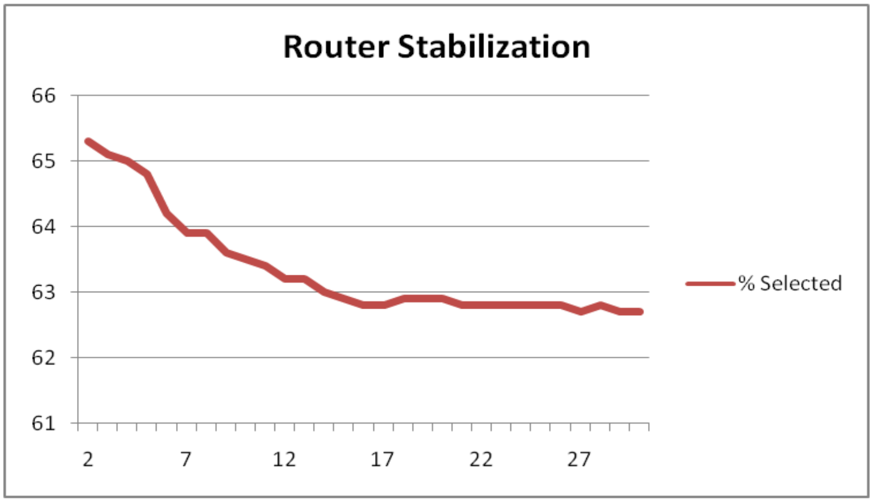


Figure G.6 Percentage of trips selected for rerouting – router stabilization baseline, year 2010.

G.1.2.2 Microsimulator Stabilization. Table G.5 shows the selection criteria for Microsimulator Stabilization.

Table G.5 Selection Criteria for Microsimulator Stabilization – Baseline 2010

Variables	**Iterations**			
	31-45	**46-60**	**61-70**	**71-80**
Percent Time Difference	10	-	-	-
Minimum Time Difference	2	-	-	-
Maximum Time Difference	60	-	-	-
Problem Select	-	Wait Time	Wait Time, Departure Time	Wait Time
Selection Percentage	50	50	50	50
Maximum Percent Selected	10	10	10	10
Msim Run Time	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM

After 50 feedback microsimulation iterations, the Microsimulator is stabilized with 3.60% of travelers with problems. Figure G.7 displays the Microsimulator Stabilization results.

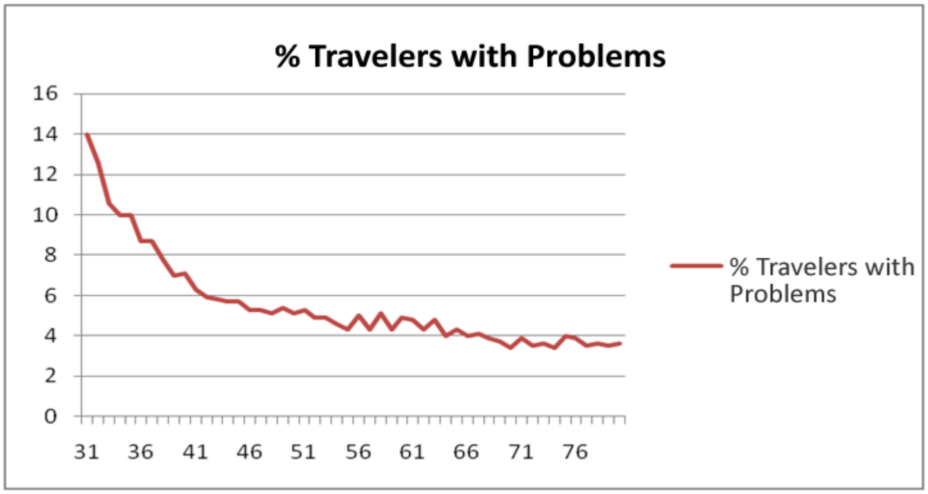


Figure G.7 Percentage of travelers with problems – microsimulator stabilization baseline, year 2010.

G.1.2.3 Equilibrium Convergence. Table G.6 shows the selection criteria used for Equilibrium Convergence Stabilization.

Table G.6 Selection Criteria for User Stabilization – Baseline 2010

Variables	Iterations			
	91-105	106-115	116-125	126-145
Percent Time Difference	10	10	10	50
Minimum Time Difference	2	2	2	3
Maximum Time Difference	30	20	15	15
Selection Percentage	50	50	50	50
Maximum Percent Selected	10	5	3	3

After 55 feedback Transims PlanCompare iterations, convergence is reached with 6.90% of travelers being selected. Figure G.8 displays the User Stabilization results.

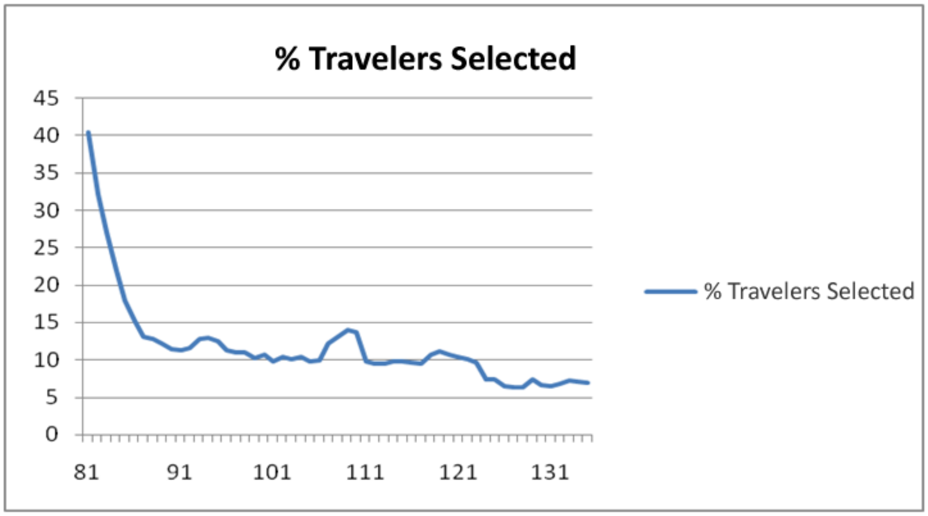


Figure G.8 Percentage of travelers selected for rerouting – equilibrium convergence baseline, year 2010.

The results deal with the impact of the number of iterations on the quality of solution expressed in terms of Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT) and Vehicle Hours of Delay (VDT).

Figure G.9 shows the VMTs, VHTs and VHDs as a function of the number of iterations. A total of 135 feedback iterations are run for the baseline with year 2010 demand. The figure shows that the Vehicle Miles of Travel (VMT) increase to 6,461,428.1 in iteration 135. The Vehicle Hours of Travel (VHT) decrease from 431,927.73 in the first to 261,902.50 in the last iteration. The Vehicle Hours of Delay (VHD) started at 321,862.32 and ended at 155,930.51.

Figure G.10 shows the travel time difference as a function of the number of iterations. The average absolute travel time difference decreases from 4.00 minutes to 1.67 minutes. The gap between the simulated travel times is calculated and plotted. At the last iteration, the gap is 0.08.

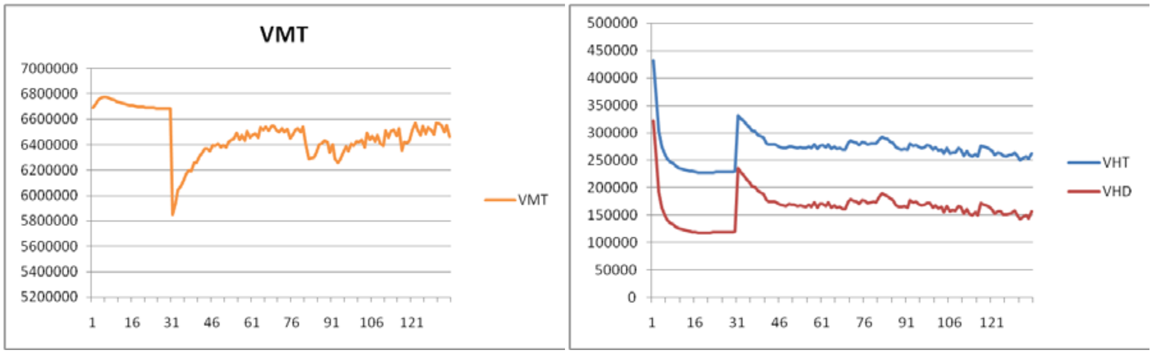


Figure G.9 VMT, VHT and VHD – baseline, year 2010.

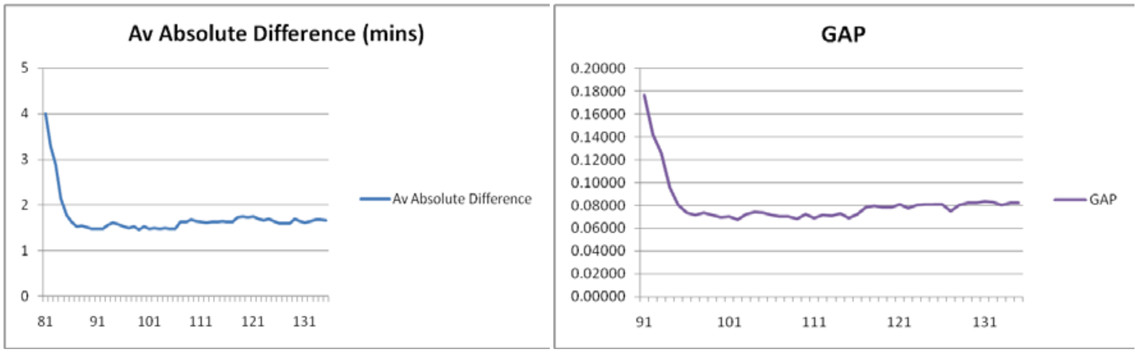


Figure G.10 Average absolute travel time difference and travel time gap – baseline, year 2010.

G.2 Built Scenario TRANSIMS Simulation Summary

G.2.1 Built Scenario – Year 2000

A total of 90 feedback iterations are run for the built scenario with current year 2000 demand. The following discusses the convergence process and results for the AM peak period (7:00 – 9:00) in detail.

G.2.1.1 Router Stabilization. During the first 20 iterations, the Transims PlanSelect program is instructed to select trips based on the V/C ratio and for the last 10 iteration based on traveler time difference between two consecutive plan sets. Table G.7 shows the selection criteria used for Router Stabilization.

Table G.7 Selection Criteria for Router Stabilization – Built 2000

Variables	**Iterations**		
	2-10	**11-20**	**21-30**
Select VC Ratios	2.0	1.5	-
Percent Time Difference	-	-	10
Minimum Time Difference	-	-	2
Maximum Time Difference	-	-	60
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Select Time Periods	All	All	All

After 30 feedback iterations, the Router was stabilized with 56.60% of trips being selected. Figure G.11 displays the Router Stabilization results.

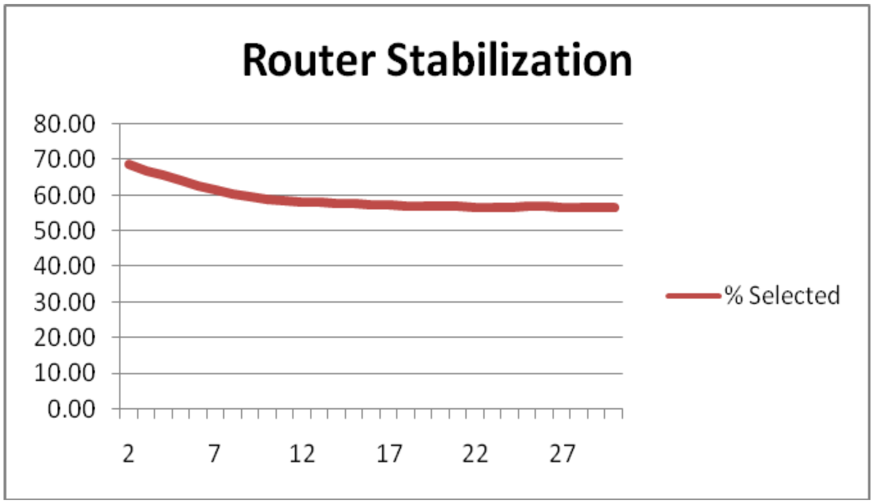


Figure G.11 Percentage of trips selected for rerouting – router stabilization built, year 2000.

G.2.1.2 Microsimulator Stabilization. During the first 10 Microsimulator feedback runs, the Transims PlanSelect program is instructed to select the subsets of travelers based on plan time criteria. After the plan time stabilization has reached acceptable limits, the Transims ProblemSelect program is then subsequently utilized to select trips with specific problems (wait time and departure time). Table G.8 shows the selection criteria for Microsimulator Stabilization.

Table G.8 Selection Criteria for Microsimulator Stabilization – Built 2000

Variables	Iterations		
	31-40	41-45	46-50
Percent Time Difference	10	-	-
Minimum Time Difference	2	-	-
Maximum Time Difference	60	-	-
Problem Select	-	Wait Time	Wait Time, Departure Time
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Msim Run Time	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM

After 20 feedback microsimulation iterations, the Microsimulator is stabilized with 1.40% of travelers with problems. Figure G.12 displays the Microsimulator Stabilization results.

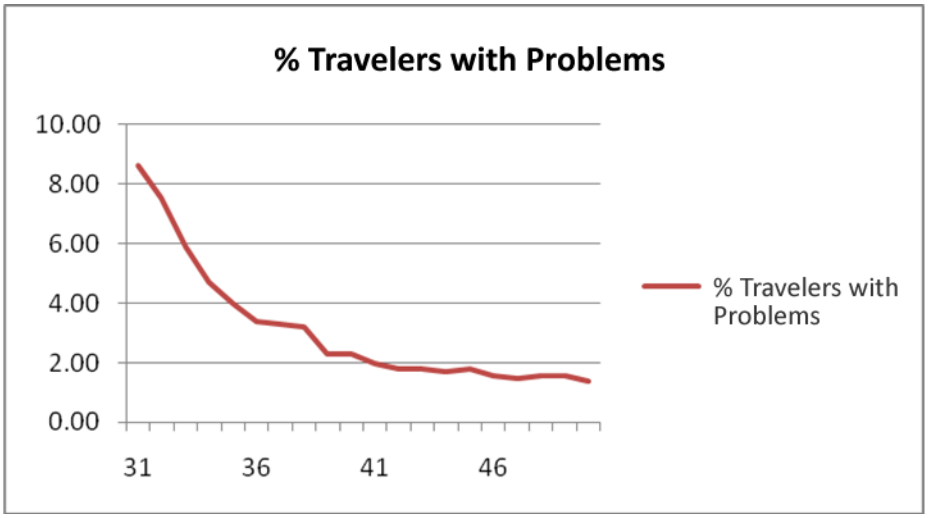


Figure G.12 Percentage of travelers with problems – microsimulator stabilization built, year 2000.

G.2.1.3 Equilibrium Convergence.

Table G.9 shows the selection criteria used for Equilibrium Convergence Stabilization.

Table G.9 Selection Criteria for User Stabilization – Built 2000

Variables	**Iterations**		
	51-65	**66-80**	**81-90**
Percent Time Difference	10	10	10
Minimum Time Difference	2	2	3
Maximum Time Difference	30	20	15
Selection Percentage	50	50	50
Maximum Percent Selected	10	5	3

After 40 feedback PlanCompare iterations, convergence is reached with 2.3% of travelers being selected. Figure G.13 displays the User Equilibrium results.

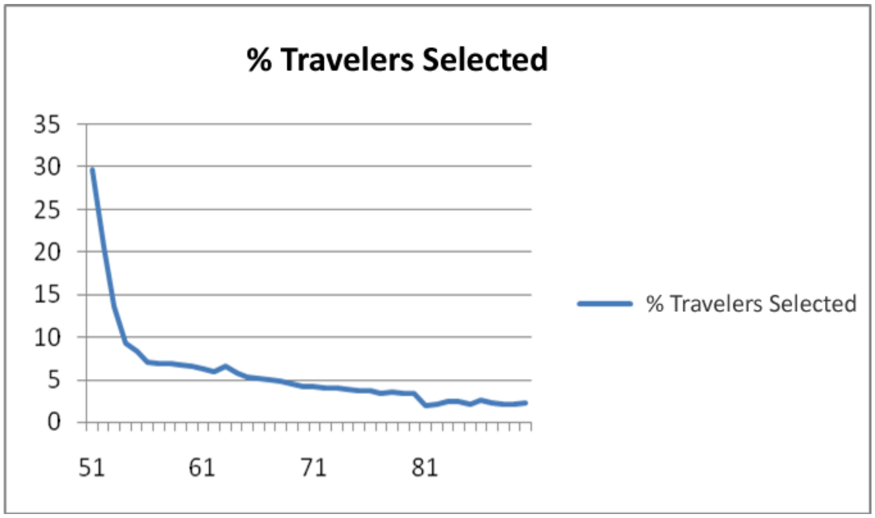


Figure G.13 Percentage of travelers selected for rerouting – equilibrium convergence built, year 2000.

Figure G.14 shows the VMTs, VHTs and VHDs as a function of the number of iterations. The figure shows that the Vehicle Miles of Travel (VMT) increase from 5,976,933.96 in iteration 1 to 6,063,328.53 in iteration 90. The Vehicle Hours of Travel (VHT) decrease from 315,058.52 to 165,012.99. The Vehicle Hours of Delay (VHD) decrease from 216,242.16 to 65,803.12.

Figure G.15 shows the travel time difference as a function of the number of iterations. The average absolute travel time difference decreases from 2.28 minutes to 0.91 minutes. The gap between the simulated travel times is calculated and plotted. At the last iteration, the gap is 0.06.

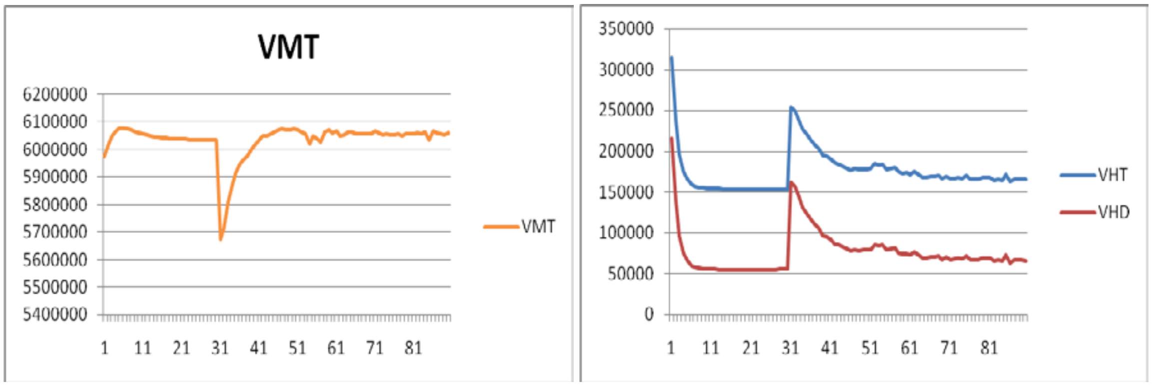


Figure G.14 VMT, VHT and VHD – built, year 2000.

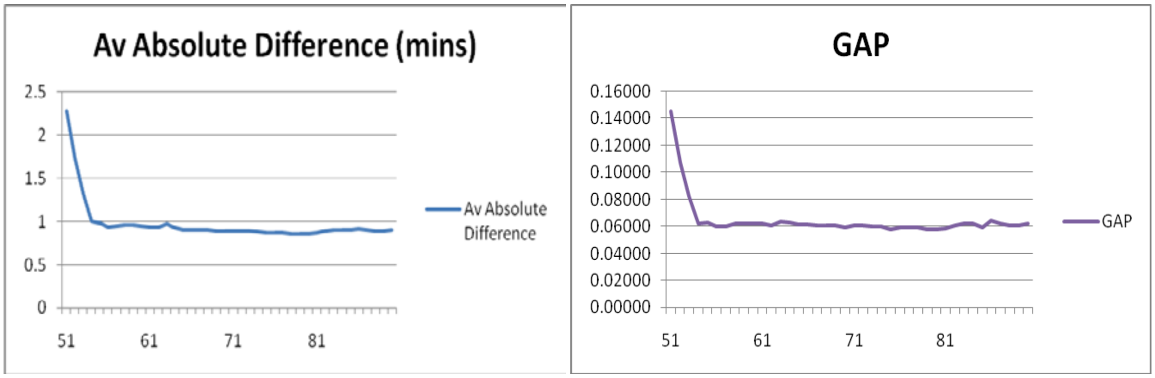


Figure G.15 Average absolute travel time difference and travel time gap – built, year 2000.

G.2.2 Built Scenario – Year 2005

A total of 90 feedback iterations are run for the built scenario with forecasted demand (year 2005). The following section discusses the convergence process and results for the AM period in detail.

G.2.2.1 Router Stabilization. Table G.10 shows the selection criteria used for Router Stabilization.

Table G.10 Selection Criteria for Router Stabilization – Built 2005

Variables	**Iterations**		
	2-10	**11-20**	**21-30**
Select VC Ratios	2.0	1.5	-
Percent Time Difference	-	-	10
Minimum Time Difference	-	-	2
Maximum Time Difference	-	-	60
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Select Time Periods	All	All	All

After 30 feedback iterations, the Router was stabilized with 58.0% of trips being selected. Figure G.16 displays the Router Stabilization results.

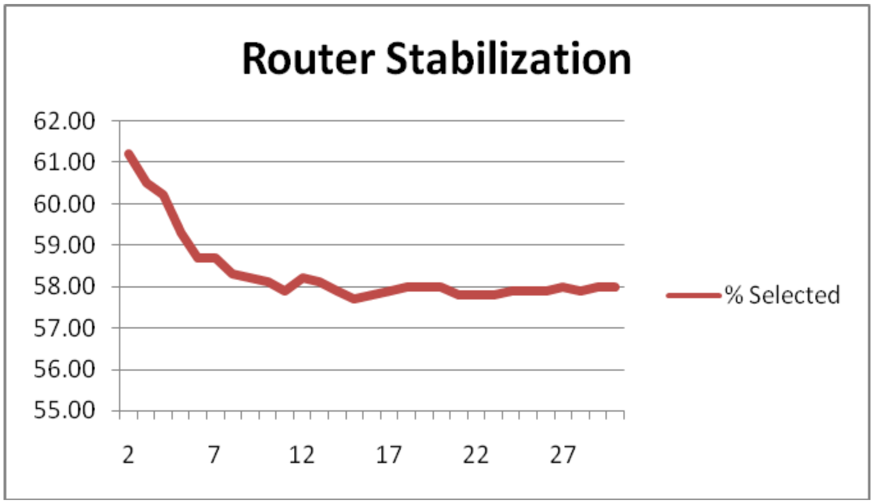


Figure G.16 Percentage of trips selected for rerouting – router stabilization built, year 2005.

G.2.2.2 Microsimulator Stabilization. Table G.11 shows the selection criteria for Microsimulator Stabilization.

Table G.11 Selection Criteria for Microsimulator Stabilization – Built 2005

Variables	Iterations		
	31-40	41-45	46-50
Percent Time Difference	10	-	-
Minimum Time Difference	2	-	-
Maximum Time Difference	60	-	-
Problem Select	-	Wait Time	Wait Time, Departure Time
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Msim Run Time	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM

After 20 feedback microsimulation iterations, the Microsimulator is stabilized with 1.60% of travelers with problems. Figure G.17 displays the Microsimulator Stabilization results.

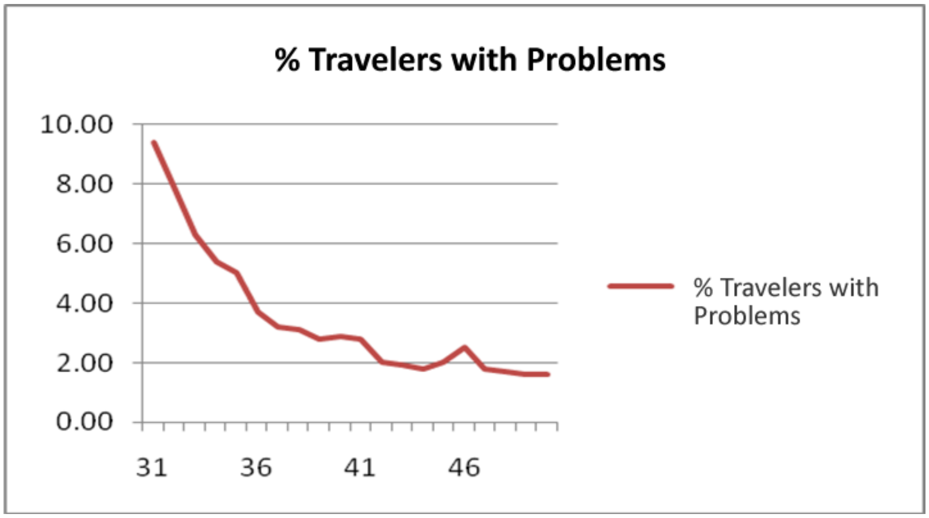


Figure G.17 Percentage of travelers with problems – microsimulator stabilization built, year 2005.

G.2.2.3 Equilibrium Convergence. Table G.12 shows the selection criteria used for User Equilibrium.

Table G.12 Selection Criteria for User Stabilization – Built 2005

Variables	Iterations		
	51-65	66-80	81-90
Percent Time Difference	10	10	10
Minimum Time Difference	2	2	3
Maximum Time Difference	30	20	15
Selection Percentage	50	50	50
Maximum Percent Selected	10	5	3

After 40 feedback Transims PlanCompare iterations, the User stabilization is reached with 2.2% of travelers being selected. Figure G.18 displays the User Equilibrium results.

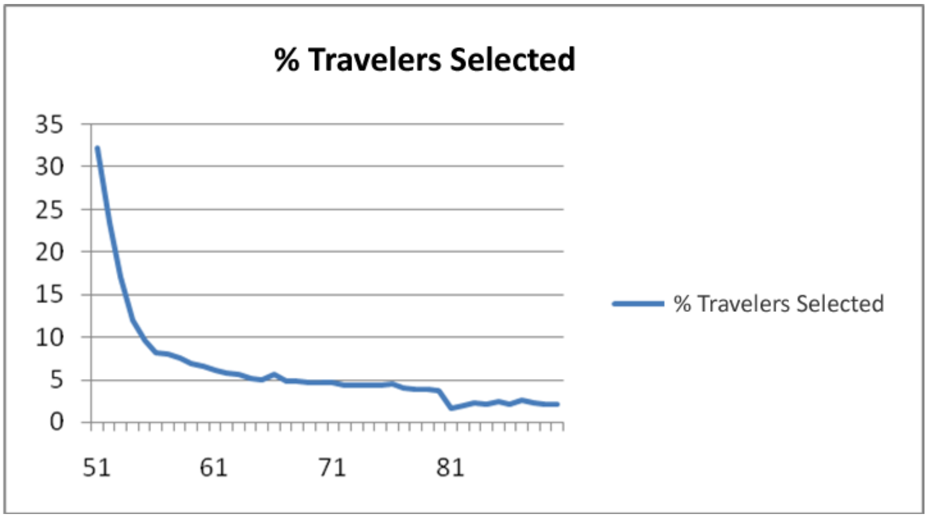


Figure G.18 Percentage of travelers selected for rerouting – equilibrium convergence built, year 2005.

The VMTs, VHTs and VHDs are plotted in Figure G.19 as a function of the number of iterations. The Vehicle Miles of Travel (VMT) in the last iteration was

6,150,959.03. The Vehicle Hours of Travel (VHT) decreased from 225,658.2 in the first iteration to 172,348.2 in the last iteration. The VHDs decreased from 124,817.09 in the first iteration to 71,601.77 in the last iteration.

The average absolute travel time change as a function of the number of iterations is shown in Figure G.20. The average absolute travel time difference decrease from 2.61 minutes to 0.83 minutes. The gap between the simulated travel times is also calculated and plotted. At the last iteration, the gap is 0.056 (Figure G.20).

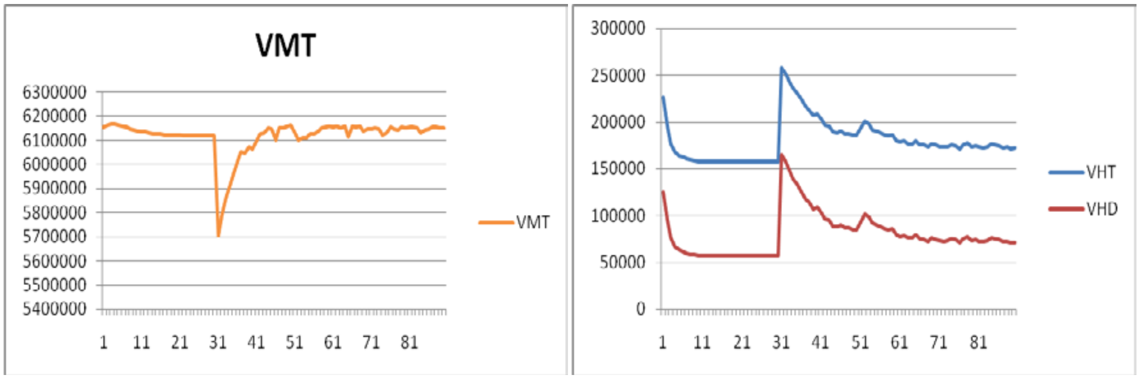


Figure G.19 Change in VMT, VHT and VHD – built, year 2005.

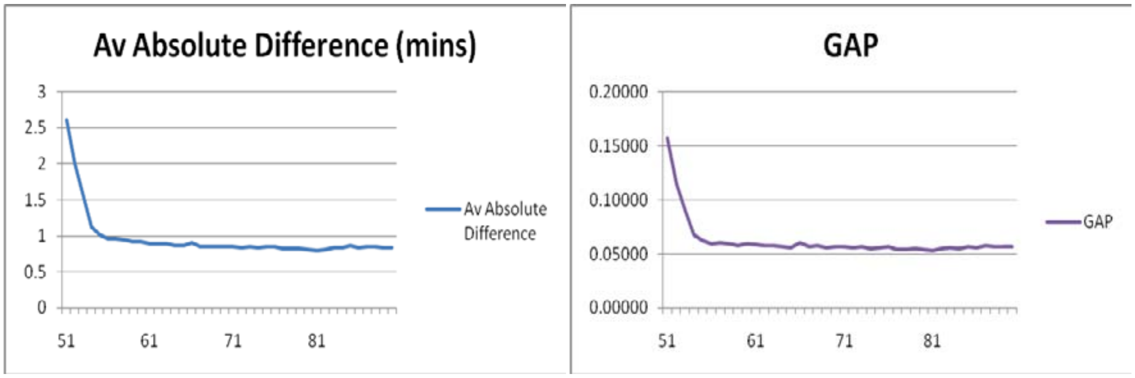


Figure G.20 Average absolute travel time difference and travel time gap – built, year 2005.

G.2.3 Built Scenario – Year 2010

A total of 150 feedback iterations are run for the built scenario with the forecasted demand (year 2010). The following section discusses the convergence process and results for the AM period in detail.

G.2.3.1 Router Stabilization. Table G.13 shows the selection criteria used for Router Stabilization.

Table G.13 Selection Criteria for Router Stabilization – Built 2010

Variables	**Iterations**		
	2-10	**11-20**	**21-30**
Select VC Ratios	2.0	1.5	-
Percent Time Difference	-	-	10
Minimum Time Difference	-	-	2
Maximum Time Difference	-	-	60
Selection Percentage	50	50	50
Maximum Percent Selected	10	10	10
Select Time Periods	All	All	All

After 30 feedback iterations, the Router is stabilized with 63.30% of trips being selected. Figure G.21 displays the Router Stabilization results.

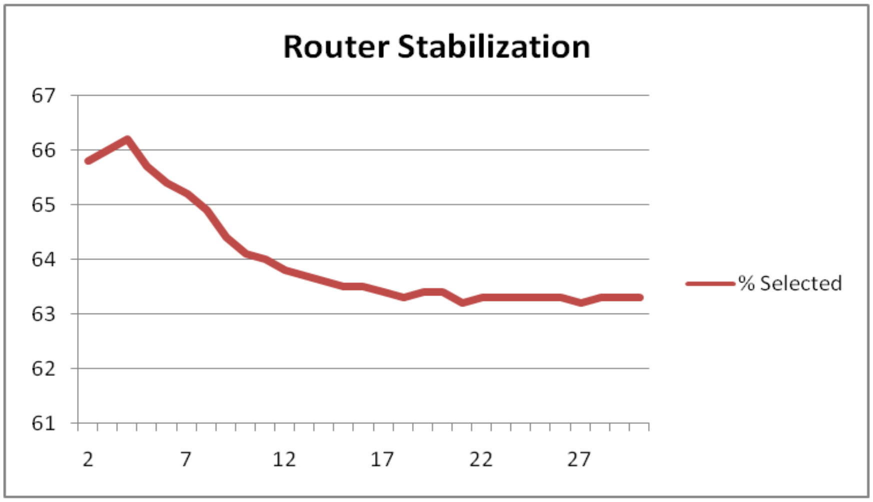


Figure G.21 Percentage of trips selected for rerouting – router stabilization built, year 2010.

G.2.3.2 Microsimulator Stabilization. For the first 15 Microsimulator feedback runs, the Transims PlanSelect program is instructed to select the subsets of travelers based on plan time criteria. After the plan time stabilization has reached acceptable limits, the ProblemSelect program is then utilized to select trips with specific problems (wait time and departure time). Table G.14 shows the selection criteria for Microsimulator Stabilization.

Table G.14 Selection Criteria for Microsimulator Stabilization – Built 2010

Variables	**Iterations**			
	31-45	**46-60**	**61-70**	**71-90**
Percent Time Difference	10	-	-	-
Minimum Time Difference	2	-	-	-
Maximum Time Difference	60	-	-	-
Problem Select	-	Wait Time	Wait Time, Departure Time	Wait Time
Selection Percentage	50	50	50	50
Maximum Percent Selected	10	10	10	10
Msim Run Time	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM	6:00-10:00 AM

After 60 feedback microsimulation iterations, the Microsimulator is stabilized with 4.50% of travelers with problems. Figure G.22 displays the Microsimulator Stabilization results.

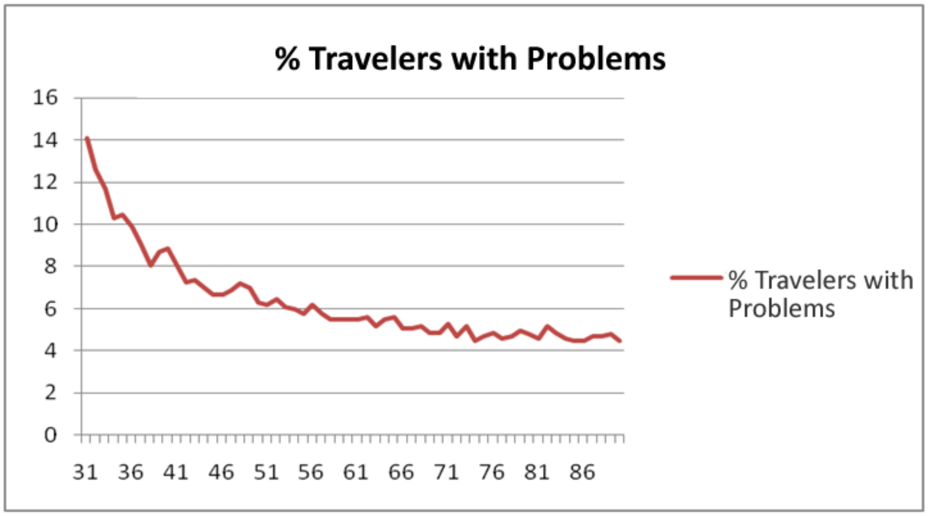


Figure G.22 Percentage of travelers with problems – microsimulator stabilization built, year 2010.

G.2.3.3 Equilibrium Convergence. Table G.15 shows the selection criteria used for Equilibrium Convergence Stabilization.

Table G.15 Selection Criteria for User Stabilization – Built 2010

Variables	**Iterations**			
	91-105	**106-115**	**116-125**	**126-150**
Percent Time Difference	10	10	10	50
Minimum Time Difference	2	2	2	3
Maximum Time Difference	30	20	15	15
Selection Percentage	50	50	50	50
Maximum Percent Selected	10	5	3	3

After 60 feedback PlanCompare iterations, convergence is reached with 3.50% of travelers being selected. Figure G.23 displays the User Stabilization results.

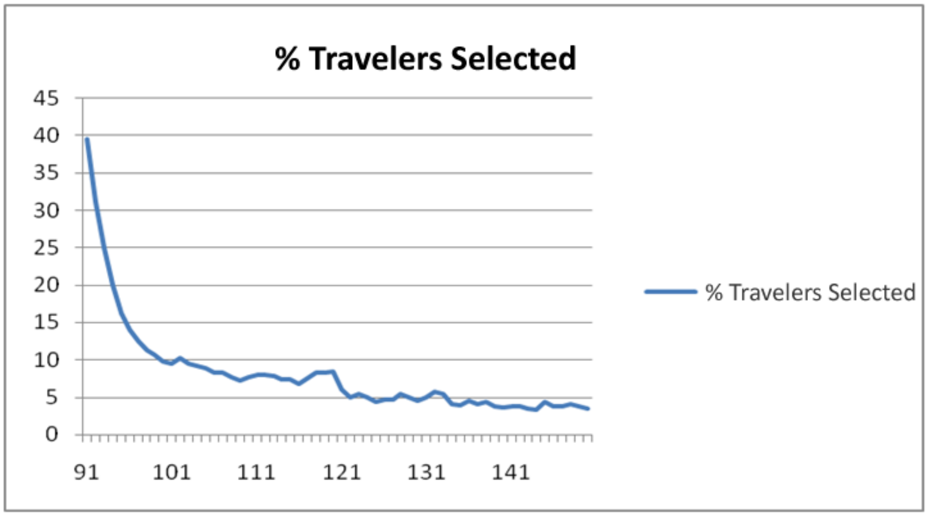


Figure G.23 Percentage of travelers selected for rerouting – equilibrium convergence built, year 2010.

The VMTs, VHTs and VHDs are plotted in Figure G.24 as a function of the number of iterations. The Vehicle Miles of Travel (VMT) in the last iteration was 6,567,254.46. The Vehicle Hours of Travel (VHT) decreased from 608,884.99 in the first iteration to 260,999.61 in the last iteration. The VHDs decreased from 496,142.2 in the first iteration to 153,188.69 in the last iteration.

The average absolute travel time change as a function of the number of iterations is shown in Figure G.25. The average absolute travel time difference decreases from 4.05 minutes to 1.35 minutes. The gap between the simulated travel times is also calculated and plotted. At the last iteration, the gap is 0.066 (Figure G.25).

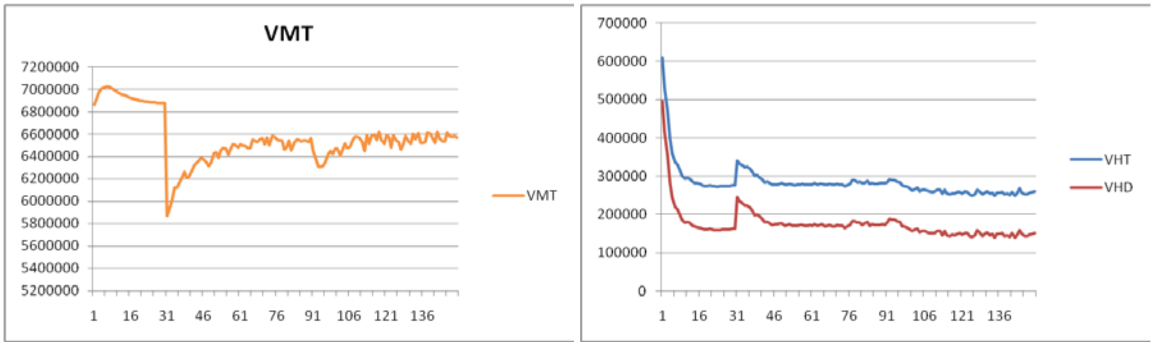


Figure G.24 VMT, VHT and VHD – built, year 2010.

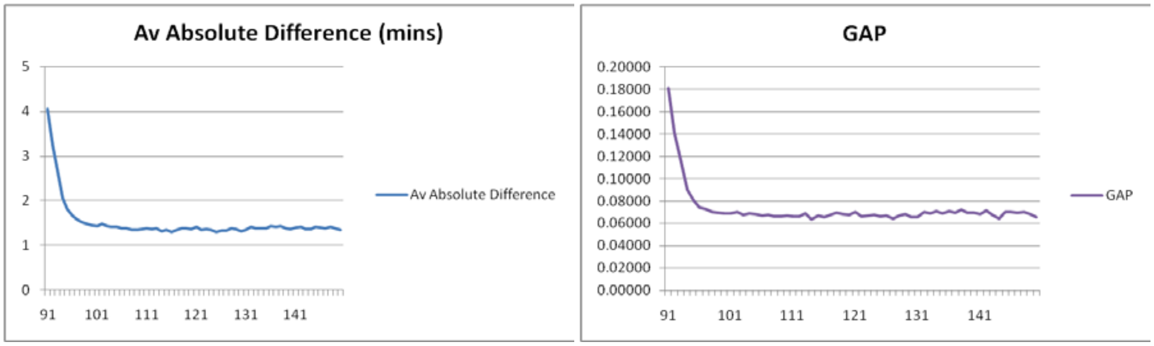


Figure G.25 Average absolute travel time difference and travel time gap – built, year 2010.

APPENDIX H

TRIP GENERATION MODELS

The goal of the trip generation process is to predict the total number of trips generated by and attracted to each zone of the study area based on zonal household and socioeconomic attributes. The commonly used socioeconomic attributes for estimating trip productions include household income, household size, number of workers, and auto ownership. The trip attraction characteristics include employment types, employment density, and accessibility to workforce. The following section reviews the trip generation models that are widely used in planning studies.

- **Growth Factor Model:** In this approach, the future traffic is forecasted by extrapolating the historical trends. This is the simplest approach for estimating trip generation. The accuracy of the model is based solely on the accuracy of the growth factor that is selected for extrapolation. This is a serious limitation of the model. If the wrong assumption was made in estimating the growth factor, the resulting error would propagate through the process.

- **Multiple Regression Model:** This model assumes that there is a relationship between the trip generation, as a dependent variable, and socioeconomic characteristics, as independent or explanatory variables. The independent variables are: household income, household size, number of workers in the household, number of vehicles per household, and number of employment per zone. Regression models are very easy and inexpensive to implement using the data that are typically available in the planning studies.

- **Cross-Classification Model:** In this approach, the explanatory variables are grouped according to common socioeconomic characteristics (i.e., auto ownership, income level, etc.) rather than spatially as in the regression models. The trip production/attraction rates are then computed for each discrete characteristic of observed data. The future trip production/attraction can be obtained by multiplying the forecasted socioeconomic values by the corresponding trip rate. Though the cross-classification model overcomes pitfalls inherent in regression models, it is considered to be more expensive and time consuming. The cross-classification model also requires more detailed data for model construction comparing to the typical regression model. It also assumed that the trip production/trip attraction will remain constant in the future.

APPENDIX I

TRIP DISTRIBUTION MODELS

Trip distribution model estimates the number of trips between production and attraction zones. Two general approaches exist for trip distribution, the growth and the synthetic models. They are listed as follows:

- **Growth Factor Approach:** In this approach, the future trip pattern is assumed to remain the same as in the base year while the traffic volume will increase/decrease according to the growth rate in the production zones and attraction zones. The examples of growth factor approach include:

    a. *Constant Factor Method:* This method assumes that the volume in all zones will increase in a uniform manner. In other words, the same growth rate is applied to an entire study area. Due to this assumption, this method tends to overestimate trips between densely populated zones and underestimate trips between underdeveloped zones.

    b. *Singly Constrained Growth Factor Method:* This method is used when information is available on the expected growth in trips either originating or terminating in each zone. The traffic flow to and from each zone is determined by applying either the origin-specific growth factors to the corresponding rows in the trip matrix or the destination-specific growth factors to the corresponding columns in the trip matrix.

    c. Furness Method (Doubly Constrained Growth Factor): This method is used when information is available on growth in the number of trips originating and terminating in each zone. Different growth rates are used for trips in and out of each zone resulting in two sets of growth factors for each zone. The traffic flow to and from each zone can be determined through the iterative process between applying the origin-specific growth factors to the corresponding rows and the destination-specific growth factors to the corresponding columns in the trip matrix. The iteration process will be repeated until the estimated matrix is within an acceptable range (e.g. 1%) of meeting the target trip ends.

- **Synthetic Methods:** In contrast to the growth factor approach, the synthetic methods allow the inclusion of travel impedance (i.e., travel time, distance, monetary out-of-pocket cost, etc.) in the model. The examples of synthetic methods include:

a. *Gravity Model:* Gravity model is the most commonly used trip distribution model. The gravity model assumes that the trips produced at an origin zone and attracted to a destination zone are directly proportional to the total trip productions at the origin and the total attractions at the destination and inversely proportional to the impedance between the zones. The impedance is described via a decay function. Developing a gravity model involves a trial-and-error process (calibration) to appropriately determine the decay function. The decay function is also known as friction factor (F) which represents the reluctance or impedance of persons to make trips of various duration or distance. The important consideration in developing a gravity model is to balance total productions and total attractions. The result of the balancing process is the equalization of the total productions and total attractions for the study area.

b. *Logit Model:* In this approach, the probability of travelers selecting a particular destination zone is based on the number of trip attractions estimated for that destination zone relative to the total attractions in all possible destination zones. The number of trips produced by zone *i* that will travel to zone *j* can be determined by multiplying the probability of traveling from zone *i* to zone *j* by the number of trips produced by zone *i*.

APPENDIX J

EMISSIONS AND FUEL CONSUMPTION SETTINGS

Table J.1 New Jersey Traffic Count Percentage based on Vehicle and Fuel Type

Mobile 6 Vehicle Type			Gasoline (%)	Diesel (%)
Light Duty Gasoline Vehicle	(LDGV)	Auto	52.73	
Light Duty Gasoline Truck 1	(LDGT1)	Auto	26.58	
Light Duty Gasoline Truck 2	(LDGT2)	Auto	8.75	
Heavy Duty Gasoline Vehicle	(HDGV)	Truck	2.79	
Light Duty Diesel Vehicle	(LDDV)	Auto		0.16
Light Duty Diesel Truck	(LDDT)	Auto		0.04
Heavy Duty Diesel Vehicle	(HDDV)	Truck		8.60
Motorcycle	(MC)	Auto	0.29	

Note: SOVs and HOVs are considered passenger cars (i.e., auto).

Table J.2 Fuel Consumption Rate by Vehicle Type

SPEED BIN		Average Fuel Consumption (gal/vehicle-mile)		
>=	<	**Auto (gas)**	**Truck(gas)**	**Truck(diesel)**
0	5	0.540000	0.650000	0.450000
5	10	0.182000	0.310000	0.696000
10	15	0.123000	0.181000	0.489000
15	20	0.089000	0.135000	0.297000
20	25	0.068000	0.118000	0.185000
25	30	0.054000	0.120000	0.131000
30	35	0.044000	0.133000	0.110000
35	40	0.037000	0.156000	0.112000
40	45	0.034000	0.185000	0.122000
45	50	0.033000	0.223000	0.136000
50	55	0.033000	0.264000	0.153000
55	60	0.034000	0.310000	0.170000
60	65	0.037000	0.374000	0.187000
65	70	0.043000	0.439000	0.204000
70	75	0.052000	0.511000	0.221000

Table J.3 Hydrocarbon (HC) Emission Rates (grams per mile)

Speed Range		**Vehicle Class**								
>=	<	**LDGV**	**LDGT1**	**LDGT2**	**LDGT**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**
0	5	7.0773	8.2920	9.9337	8.7847	10.3120	1.0950	1.5683	4.3963	11.6057
5	10	2.8982	3.4318	4.1086	3.6348	5.4950	0.9044	1.2952	3.6316	7.9760
10	15	1.8914	2.2176	2.6422	2.3452	3.7186	0.7160	1.0250	2.8750	6.2432
15	20	1.5142	1.7682	2.1008	1.8678	2.7752	0.5794	0.8298	2.3268	5.5900
20	25	1.2562	1.4786	1.7516	1.5606	2.1964	0.4794	0.6864	1.9248	5.2556
25	30	1.0604	1.2676	1.4948	1.3358	1.8324	0.4056	0.5806	1.6280	5.0318
30	35	0.9246	1.1220	1.3180	1.1808	1.5910	0.3506	0.5020	1.4076	4.8596
35	40	0.8240	1.0150	1.1884	1.0672	1.4270	0.3098	0.4436	1.2444	4.7296
40	45	0.7462	0.9330	1.0890	0.9798	1.3146	0.2800	0.4010	1.1242	4.6444
45	50	0.6852	0.8692	1.0122	0.9122	1.2378	0.2586	0.3704	1.0384	4.6002
50	55	0.6608	0.8432	0.9812	0.8846	1.1852	0.2442	0.3498	0.9808	4.5930
55	60	0.6808	0.8632	1.0064	0.9060	1.1556	0.2360	0.3376	0.9468	4.7352
60	65	0.7492	0.9348	1.0946	0.9828	1.1470	0.2326	0.3332	0.9340	5.0916
65	70	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
70	75	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
75	80	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
80	85	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
85	90	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050

Table J.4 Carbon Monoxide (CO) Emission Rates (grams per mile)

Speed Range		**Vehicle Class**								
>=	<	**LDGV**	**LDGT1**	**LDGT2**	**LDGT**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**
0	5	54.3420	58.7417	69.8430	62.0720	52.8050	4.3620	4.9317	32.9103	138.014
5	10	28.9404	31.9686	38.0100	33.7810	38.1226	3.2442	3.6682	24.4774	68.1184
10	15	19.7536	22.2862	26.4978	23.5498	25.8838	2.2750	2.5726	17.1658	36.9148
15	20	16.1586	18.4970	21.9926	19.5460	18.5720	1.6702	1.8884	12.6006	25.5384
20	25	13.0598	15.2100	18.0844	16.0724	14.0826	1.2832	1.4508	9.6818	19.7182
25	30	10.0958	12.0222	14.2942	12.7038	11.2850	1.0320	1.1670	7.7866	15.8836
30	35	8.0646	9.8380	11.6966	10.3952	9.5568	0.8686	0.9824	6.5548	13.0582
35	40	6.5854	8.2466	9.8050	8.7140	8.5528	0.7656	0.8656	5.7760	11.0046
40	45	5.4596	7.0358	8.3654	7.4346	8.0890	0.7062	0.7982	5.3274	9.6282
45	50	4.6038	6.1154	7.2710	6.4620	8.0852	0.6816	0.7706	5.1432	8.7950
50	55	4.4130	5.9100	7.0270	6.2450	8.5400	0.6890	0.7788	5.1974	8.6310
55	60	5.2210	6.8646	8.1620	7.2538	9.5328	0.7284	0.8240	5.4976	12.7880
60	65	7.2410	9.2516	10.9998	9.7760	11.2456	0.8070	0.9122	6.0872	23.1808
65	70	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
70	75	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
75	80	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
80	85	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
85	90	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170

Table J.5 Nitrogen Oxide (NO$_x$) Emission Rates (grams per mile)

Speed Range		**Vehicle Class**								
>=	<	**LDGV**	**LDGT1**	**LDGT2**	**LDGT**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**
0	5	1.7417	2.0820	2.5550	2.2243	3.1013	1.8387	2.1187	11.0553	0.8187
5	10	1.4190	1.6962	2.0814	1.8116	3.2240	1.5764	1.8164	9.4764	0.7198
10	15	1.3020	1.5566	1.9100	1.6626	3.3840	1.3258	1.5278	7.9706	0.6864
15	20	1.2564	1.5020	1.8432	1.6044	3.5446	1.1556	1.3314	6.9472	0.7246
20	25	1.2618	1.4812	1.8174	1.5820	3.7050	1.0434	1.2024	6.2744	0.7970
25	30	1.2904	1.4870	1.8248	1.5884	3.8650	0.9766	1.1254	5.8722	0.8746
30	35	1.3098	1.4914	1.8300	1.5928	4.0250	0.9472	1.0914	5.6950	0.9414
35	40	1.3242	1.4942	1.8336	1.5962	4.1850	0.9522	1.0968	5.7234	0.9896
40	45	1.3350	1.4966	1.8362	1.5986	4.3452	0.9914	1.1424	5.9604	1.0226
45	50	1.3512	1.5094	1.8522	1.6122	4.5060	1.0700	1.2330	6.4322	1.0588
50	55	1.4992	1.7210	2.1118	1.8384	4.6660	1.1964	1.3786	7.1930	1.1982
55	60	1.6918	1.9988	2.4526	2.1350	4.8260	1.3862	1.5974	8.3346	1.3710
60	65	1.8842	2.2768	2.7936	2.4316	4.9860	1.6648	1.9182	10.0082	1.5438
65	70	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
70	75	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
75	80	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
80	85	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
85	90	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470

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