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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

FEASIBILITY AND BENEFITS OF ADVANCED FOUR-STEP AND ACTIVITY-BASED TRAVEL DEMAND MODELS FOR MARYLAND

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16. Abstract

This research identifies current and emerging transportation planning policy issues faced by the Maryland State Highway Administration (SHA) and other State agencies. After reviewing the recently-developed Maryland Statewide Transportation Model (MSTM), the UMD research team summarizes the capability of the MSTM to analyze these planning and policy issues and prioritizes various model improvement needs. Based on identified planning and policy analysis needs, a thorough synthesis of existing transportation data sources, and proposed MSTM applications in Maryland, a Strategic MSTM Improvement Plan (SMIP) is developed to guide short- and long-run MSTM improvement and applications. This research also explores the feasibility of incorporating departure time choices into the MSTM by developing a prototype time-of-day choice model.

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EXECUTIVE SUMMARY

Maryland is facing a number of historical and emerging transportation planning and policy issues including: (1) Highway congestion management; (2) System performance measurement and monitoring; (3) Multimodal transportation planning and operations; (4) Capital investment needs; (5) Land use scenario analysis; (6) Promoting smart growth; (7) Accommodating increased freight traffic on multimodal and intermodal facilities; (8) Supporting and stimulating economic development via transportation investment and system enhancement; and (9) Reducing pollution and green house gas emissions. Decision-makers in Maryland need reliable information on the relative effectiveness of alternative plans and policies in addressing these issues.

These planning and policy analysis needs have led to the development of the Maryland Statewide Transportation Model (MSTM), which is a powerful travel demand analysis tool that enables efficient transportation decision-making across multiple transportation modes (highway, transit, rail, air, etc.) and at various geographical scales (project, corridor, city, county, statewide, and even regional levels). The usefulness of the MSTM is currently being demonstrated in several applications, such as the MDOT Scenario Analysis project and the I-95/US 301 corridor studies.

While the development of MSTM should greatly enhance the ability of decision makers in Maryland to make informed transportation decisions, the amplitude of multimodal transportation issues faced by decision-makers in Maryland cannot be fully addressed by the current version of MSTM. Improving MSTM and applying it to address an even broader range of issues in Maryland will contribute to a more effective transportation system that supports economic development, enhance livability standards, and promote sustainable growth in Maryland.

This Maryland State Highway Administration (SHA) research project had four main objectives:

1. Summarizing current and emerging planning and policy issues in Maryland that the MSTM needs to address, and identifying how MSTM, in its present form or with certain improvements, can be applied to address these issues.

2. Identifying cost-effective approaches for improving MSTM based on SHA's planning and policy analysis needs; in close cooperation with SHA, developing a strategic plan for MSTM improvement.

3. Determining the feasibility and benefit of activity-based, tour-based, and advanced four-step modeling approaches for travel demand forecasting in Maryland
4. Developing a prototype time-of-day choice model. If SHA plans to improve the time-of-day aspects of the MSTM, this prototype model may be further developed in a subsequent project with a larger behavior dataset and incorporated into MSTM.

Based on these research objectives, a team of researchers at the University of Maryland – College Park that have worked closely with SHA technical liaisons and research office staff members have identified current and emerging transportation planning and policy issues in six broad categories: (1) Performance measuring and monitoring; (2) Congestion management; (3) Multimodal transit; (4) Freight transportation; (5) Socio-economic and land use scenario analysis; and (6) Planning and policy analysis needs beyond the MDOT and SHA. Subsequently, the capability and limitation of the current MSTM are discussed and analyzed, which provides input to the development of the Strategic MSTM Improvement Plan detailed in Chapter 4.

To ensure the proposed MSTM Improvement Plan is built upon the best practices and prior lessons from other states, the research team has conducted a comprehensive review of statewide transportation models in other states, their model development strategies and phases and any notable applications. It is apparent from this review that investment in state-of-the-practice statewide transportation models is a necessary step toward rational and effective transportation decision-making at the statewide and corridor levels. Several states, such as Oregon and Ohio, have invested in state-of-the-art statewide transportation models that go beyond the traditional four-step demand modeling paradigm. Many applications that are unique to these more advanced statewide transportation models, such as pricing studies and multimodal freight analysis, are relevant to important planning needs in Maryland. In addition to the model review, the research team has also reviewed, and in many cases, collected available data for MSTM development and improvement. Data items reviewed include both demand-side (e.g. travel surveys) and supply-side (e.g. modal network, intermodal facilities) data; both Maryland data and data in the surrounding states (Virginia, Delaware, etc.); and both state-specific data and national data. While available data would support future MSTM improvement, it is necessary to synthesize them into a consistent format for model development purposes. For certain advanced applications (e.g. peak spreading analysis), it is desirable to base model improvement tasks on additional data collected in Maryland (e.g. behavior response data collected from revealed, stated preference, or GPS-enabled surveys).

While the model and data review findings suggest a state-of-the-art statewide transportation model in Maryland would be valuable for decision-makers, feasible in terms of data availability, and could be justified by application needs, the research team recommends a phased multi-stage approach for gradually improving the current MSTM based on planning and policy analysis priorities in Maryland in view of the likely higher cost of developing advanced statewide transportation models. This vision is reflected in the proposed Strategic MSTM Improvement Plan (SMIP), which incorporates four phases of model improvement activities: (1) 2010-2011 ongoing MSTM improvement tasks already funded by various sponsors; (2) 2012-2015 short-term MSTM improvement tasks; (3) 2016-2020 mid-term MSTM improvement tasks; and (4) Beyond 2020 long-term MSTM improvement tasks. Individual tasks are also identified for each of the four phases and documented in Chapter 4 of the report.

Finally, to both demonstrate how individual MSTM improvement tasks may be accomplished and to address the high priority of peak spreading considerations in the proposed MSTM improvement plan, the research team has also developed a prototype time-of-day choice model. The prototype model aims to explore departure time shifts and peak spreading effects corresponding to different time-of-day traffic conditions. The model is estimated from simulated data for the morning commute on the I-270 corridor in 2010. Results indicate that travel delay and scheduling delay both have significant impact on individuals' departure time choices. In term of scheduling delay for morning commute trips, arriving late at work has more severe negative effect than early arrival. To supplement the simulated data, the research team also collected dedicated survey data along the I-495 and Inter-County Connector corridors for peak-spreading modeling in Maryland. While this joint web-based revealed-/stated preference survey is currently funded by non-SHA sources, it is still documented in this report to demonstrate how additional behavior data may be collected to complement existing data and improve the policy sensitivity of MSTM.

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INTRODUCTION

The Maryland State Highway Administration (SHA) has recently invested in the development of the Maryland Statewide Transportation Model (MSTM), which provides a valuable tool for statewide transportation planning decision-making in Maryland. MSTM is an essential tool in helping SHA meet a broad range of transportation planning and policy analysis needs (e.g. forecasting future levels of congestion, analyzing inter-regional traffic flow patterns, evaluating tolling and pricing strategies, assessing highway corridor improvements, estimating green house gas emissions, among many others). Improved planning decisions and smarter transportation investment, resulting from applications and improvement of MSTM, lead to a more effective transportation system that supports continual economic development, enhances livability standards, and promotes sustainable growth in Maryland.

This research identifies current and emerging policy issues faced by SHA. The current MSTM is reviewed and the capability of the MSTM to analyze these policies is discussed; then strategies for the continuous improvement of the MSTM both in the short and long run are proposed. The strategies are designed to be cost effective; strategies with the lowest cost and greatest benefit are clearly identified. This research report is organized as follows:

Chapter 1 synthesizes current and emerging transportation planning and policy analysis needs in Maryland. The Chapter aims to help SHA and the research team to determine how the current version of MSTM can be applied to address important planning and policy issues in Maryland, and how it can be further improved.

Chapter 2 reviews the existing modeling practices in the U.S. focusing on three aspects of the statewide travel models including methodology, data needs, and applications. For each modeling methodology, the selected representative statewide models are explored in great depth. The chapter aims to help the research team and SHA evaluate different options for improving the MSTM. The chapter also includes various application examples of different statewide models that address issues similar to transportation planning and policy issues in Maryland.

Chapter 3 assesses data availability for the development of the MSTM Improvement Plan. The existing data sources for travel modeling in Maryland are summarized. Then based on transportation planning and policy analysis needs in Maryland in Chapter 1, and on advanced statewide travel demand models successfully implemented in other states (reviewed in Chapter 2), the development of more advanced four-step and activity/tour-based models in Maryland are discussed.

Chapter 4 develops a long-range plan for continual improvement of the MSTM. The emerging planning and policy issues with high priorities for the SHA from Chapter 2 are identified. Then, the improvement options for these issues are described in detail with focus on their data requirements, other feasibility considerations, value added to the MSTM, and relative priorities according to the importance of the planning issues they address. Finally, a timeline for MSTM Improvement is proposed. It incorporates four groups of model improvement tasks: (1) 2010-2011 ongoing tasks already funded by various sponsors; (2) 2012-2015 short-term MSTM improvement tasks; (3) 2016-2020 mid-term MSTM improvement tasks; and (4) Beyond 2020 long-term MSTM improvement tasks.

Chapter 5 proposes a prototype time-of-day choice model for the state of Maryland. This model aims to account for departure time shift and peak spreading, corresponding to different time-of-day traffic conditions. The chapter summarizes literature reviews related to departure time choice models and focuses on data requirements, methodology, and applications. Based on the review findings, the appropriate methodology is selected and a prototype departure time choice model is proposed. The model is estimated from simulated data for the morning commute on I-270 corridor in 2010. The ongoing effort in collecting dedicated survey data for departure time choice is outlined, which will supplement any existing data for the departure time choice model. The survey is designed to investigate travelers' departure time due to time-of-day traffic conditions and hypothetical congestion pricing schemes on the Capital Beltway (I-495) and the Inter-County Connector corridors.

Chapter 6 offers conclusions and recommendations for future research.

CHAPTER 1: PLANNING AND POLICY NEEDS

1.1 INTRODUCTION

This Chapter synthesizes current and emerging transportation planning and policy analysis needs in Maryland. This synthesis should help SHA and the research team to determine how the current version of MSTM can be applied to address important planning and policy issues in Maryland, and how it can be further improved to meet other emerging planning and policy analysis needs.

Our research efforts in Task 1 focus on four general categories of planning and policy issues that are directly relevant to the MSTM development: (1) Performance measures; (2) Corridor forecasts and congestion management; (3) Freight analysis; and (4) Land use, economic, and investment scenario analysis.

This Chapter is organized as follows: Section 1.2 highlights different performance measures that characterize the transportation system in Maryland. The performance measures considered include recurrent congestion quantified herein terms of delay and total cost, non-recurrent congestion caused mainly by accidents, safety, freight efficiency, sustainability, and other indicators. In terms of future planning and policy analysis needs, we have reviewed various planning documents and discussed initiatives such as the Smart, Green & Growing initiative with a focus on sustainability and environmental impacts. The success of these initiatives often requires strategic planning and demand modeling analysis at the state level.

Section 1.3 discusses the current and future traffic conditions on major highway corridors in Maryland. The highest-priority transportation planning and policy analysis needs in this regard pertain to corridor-level traffic forecasts and congestion management. Promising congestion management strategies that deserve further analysis with the MSTM and other related modeling tools include advanced traffic operations and management, incident management, HOV/HOT operations, tolling and congestion pricing, peak spreading incentives, and multimodal transit improvements. For instance, the Maryland Statewide Express Toll Lanes Initiative considers the implementation of pricing schemes on several existing and new highway facilities in Maryland. Multimodal transportation improvements, such as bus rapid transit and light rail, are also under consideration as a more sustainable and feasible alternative for alleviating congestion on major highway corridors.

Section 1.4 focuses on the increasing freight travel demand in Maryland, and the resulting statewide freight demand modeling and multimodal freight planning needs. In particular, several important freight transportation issues are identified and discussed: (1) Increasing truck travel demand along major highway corridors and the resulting congestion effects; (2) Demand increase in other non-highway freight transportation modes such as rail, water, and air transportation; and (3) Growing capacity and service needs for intermodal freight transfer facilities. A multimodal statewide transportation model is necessary both for the efficient management and the operations of existing freight facilities in Maryland, and for the strategic planning of freight policies including freight transportation system improvements, modal shifts from highway to non-highway freight modes, and diversion of freight traffic to less congested corridors.

Section 1.5 describes future scenarios of land use change, economic growth, and transportation investment in Maryland. Different land use and transportation investment policies lead to alternative future growth scenarios, and the relative effectiveness and performance of these scenarios should be analyzed with rigorous modeling tools for policy decision-making. The projected population, income, and employment growth trends in Maryland is first presented, which clearly imply increased demand for land development and for all types of transportation facilities. The focus then shifts to land use policies and transportation investment scenarios. Smart growth policies, such as Transit-Oriented Development (TOD), mixed-use development, in-fill development, higher density, and Priority Funding Areas (PFA), can in theory reduce excess travel demand. A statewide transportation model, such as the MSTM, can greatly enhance the design, implementation, and positive impact of smart growth and other sustainable land use policies. Another important application of the MSTM is ensuring the effectiveness of multimodal transportation investments through investment scenario analysis and informed project prioritization.

Section 1.6 summarizes this Chapter, and discusses how findings from Task 1 can be incorporated into future project tasks.

1.2 PERFORMACE MEASURES

1.2.1 Highway System Performance in Maryland

Maryland is ranked 5th in the nation in terms of population density with an estimated population of more than 5.6 million residents in 2007. Projections for 2030 indicate a growth in population rate to 6.7 million and an increase in the annual vehicle miles traveled to 85.6 billion (MDOT, 2009a). From 1990 to 2006, vehicle miles traveled have increased more than twice the rate of the population while the roadway and transit systems have seen limited expansion. This trend has caused increased levels of congestion in the transportation system (MDOT, 2009a). Figure 1 shows vehicle miles traveled in correspondence with highway lane miles from 1998 to 2006 in Maryland. Vehicle miles traveled increased by 17.0 percent (approximately 8.2 billion miles traveled) while total lane miles in the state increased only 4.0 percent (2,500 lane miles).

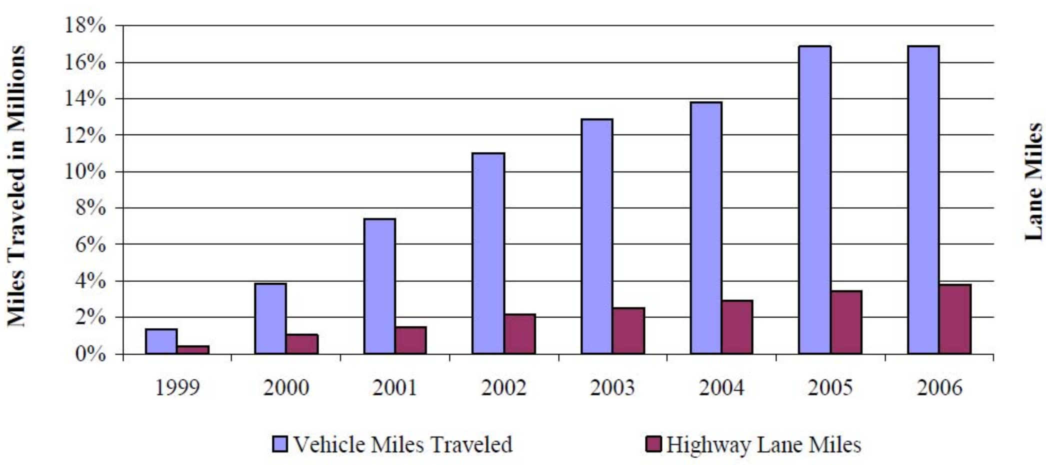


Figure 1. Percent change in Vehicle lane miles and Highway lane miles from 1998 to 2006
(Source: *Congestion in Maryland A Bumper to Bumper Analysis*, Department of Legislative Services, 2008)

Figure 2 shows the percentage of lane miles with average annual volumes at or above congestion levels. This measure provides insight into whether congestion is improving or worsening across the state. The measure looks at the percentage of roadways with vehicle volumes greater than 10,000 per day on arterial roads and 20,000 on highways. Based on this measure, the rate of growth in congestion on major freeways had leveled off between 2002 and 2008, while the percentage of congested arterial lane miles has been declining since 2005. These improvements are caused mainly by the opening of the new routes: MD 30 that allows traffic to bypass the historic town of Hampstead in Carroll County, the completion of the first phase of the I-95/I-495 access to the Branch Avenue Metro Station in Prince George's County, and the completion of the I-95/I-495 Woodrow Wilson Bridge improvement project. The recent economic downturn has also caused travel demand to decrease nationally, resulting in lower VMT in 2008and 2009 compared to previous years.

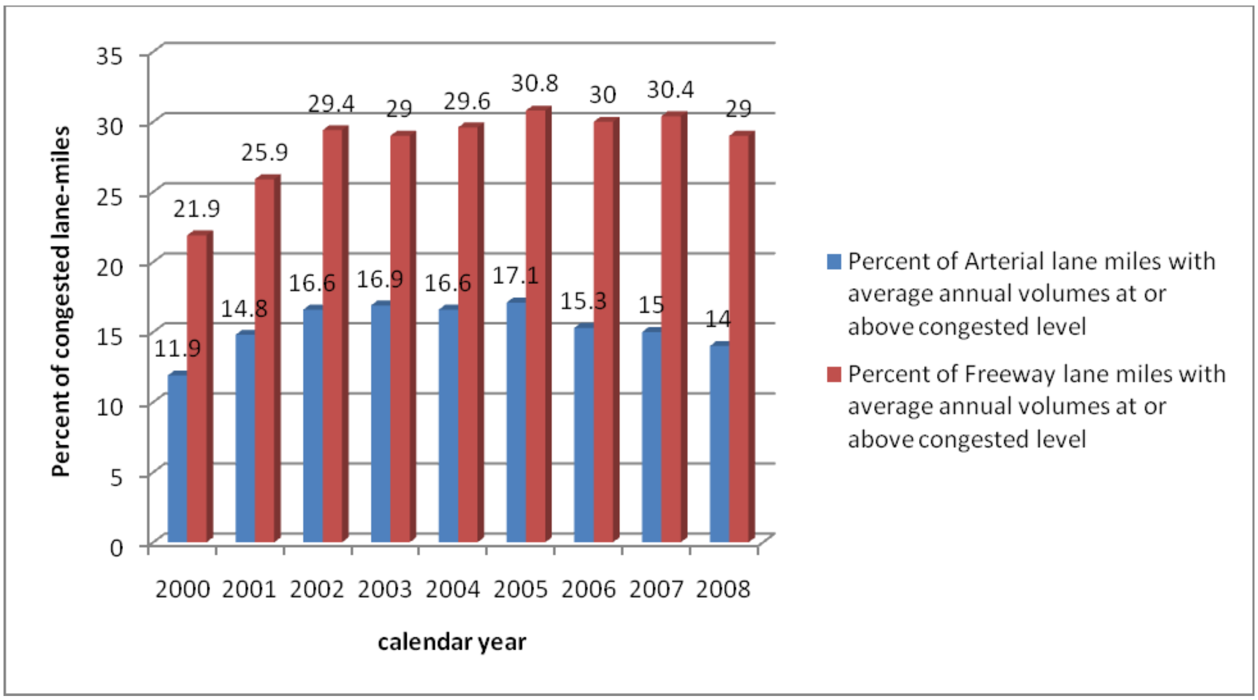


Figure 2. Percentage of freeway and arterial lanes at or above congestion levels (2000-2008)
(Source: *2010 Annual Attainment Report on Transportation System Performance*, Maryland Department of Transportation, 2010)

1.2.2 Performance Measures on State Highways

1.2.2.1 Mobility: Recurrent and Non-Recurrent Congestion

In the state of Maryland, the Washington DC Metropolitan Area is the largest metropolitan area and Baltimore is its largest city. The Washington metropolitan area[1] is one of the most congested regions in the country, consistently ranking in the top three U.S. cities in annual hours of delay per traveler. In the

[1] The Washington Metropolitan Area includes the District of Columbia and parts of the states of Maryland, Virginia, and West Virginia.

25 years from 1982 to 2007, travelers in the region experienced an increase of 46 hours of annual delay, the biggest increase among the nation (TTI, 2009). According to this report, in 2007 the Washington Metropolitan Area was ranked 2nd among 439 U.S. urban areas for annual delay per traveler and 7th for annual congestion cost. Baltimore is ranked 14th in terms of annual delay per traveler, and 16th for annual congestion cost. The detailed performance measures are shown in Table 1.

Table 1. Maryland mobility performance measures 2007

Performance measures	Washington Metropolitan Area	Baltimore	Unit
1. Roadway Congestion Index	1.34	1.21	-
2. Percent of Daily Travel in Congested Condition	49.1	46.8	Percent
3. Travel Speed on Freeway	41.5	43.9	Mph
4. Travel Speed on Arterial	25.1	27.7	Mph
5. Annual delay per traveler	62 (2)	44 (14)	Hour
6. Annual travel Delay	133,862 (7)[2]	56,964 (18)	1,000 hours
7. Congestion Cost	2762 (7)	1276 (16)	$ million
8. Wasted Fuel per Traveler	42 (2)	32 (13)	Gallon
9. Freeway traffic speed estimates	41.5	43.9	Mph
10. Arterial street traffic speed estimates	25.1	27.7	Mph
11. Urban Area Demand and Roadway Growth Trends	more than 35	more than 35	Percent
12. Travel Time Index	1.39 (4)	1.31 (14)	-

(Source: *Urban Mobility Report*, Texas Transportation Institute, 2009)

Traffic incidents are another cause of travel delay. An incident causes non-recurring delays, which refers to congestion that occurs when incidents such as accidents, disabled vehicles, special events, or weather related occurrences result in temporary traffic demand that exceeds roadway capacity. It was reported that 60 percent of the congestion on United States' urban freeway are due to non-recurring congestion. Table 2 shows performance measures related to incidents along Maryland's major highway corridors.

Table 2. Maryland incident performance measure in 2008

Performance measures		Unit
1. Number of total incidents on freeway	56,200	incident
2. Average incident duration on freeway during peak period[3]	73.03	minute
3. Average incident duration on freeway during off peak period	93.68	minute
4. Average incident response time during peak period	5.86	minute
5. Average incident response time during off peak period	7.19	minute
6. Average incident clearance time during peak period	67.17	minute
7. Average incident clearance time during off peak period	86.49	minute

(Source: Maryland Department of Transportation, 2008)

[2] Parenthesis indicates rank among 439 urban areas in the nation.

[3] Peak period=weekday 7:00-9:30 am and 4:00-6:30 pm

1.2.2.2 Safety

According to Maryland Strategic Highway Safety Action Plan (SHSAP) 2006-2010, Maryland established the goal to eliminate motor vehicle fatalities and serious injuries on Maryland roads and highways. To track progress, the State's SHSP set the following measurable objectives: (1) To reduce the annual motor vehicle fatalities to fewer than 550 by 2010, and (2) To reduce the annual motor vehicle injuries to fewer than 50,000 by 2010 (SHSAP, 2006). Some of the safety performance measures that could be used are:

1. Fatalities per 100 million vehicle miles traveled;
2. Accidents per 100 million vehicle miles traveled;
3. Annual number of highway-related fatalities;
4. Annual number of highway-related injuries;
5. Annual number of incidents occurred on each corridor;
6. Average duration of incident, response time, and clearance time;

1.2.2.3 Sustainability and Environmental impact

The Smart, Green & Growing initiative is a long-range, statewide initiative aiming to achieve a more sustainable Maryland future by linking community revitalization, transportation improvements, economic development, Smart Growth, and environmental restoration efforts. In response to this initiative, the Maryland Transportation Plan of 2009 has set forth a long-term vision for Maryland's transportation system and a framework for the most efficient investment of resources to ensure sustainability. This initiates the attention for sustainability performance measures. The household transportation cost is indicated as the performance measure for sustainability (NCHRP, 2003). Some of the transportation cost measures (TTI, 2009) that could be used to evaluate sustainability are:

1. Wasted fuel per gallon: Extra fuel consumed during congested travel.
2. Wasted fuel per traveler: Extra fuel consumed per traveler during congested travel.
3. Excess fuel consumed: increased fuel consumption due to travel in congested conditions rather than free flow conditions.

1.2.2.4 Green House Gas Emission

In Maryland, the transportation sector ranks second in greenhouse gas emissions accounting for 30% in 2005. In 2005, on-road gasoline vehicles accounted for 74 percent of transportation greenhouse gas emissions in Maryland while on-road diesel vehicles contributed to 18 percent. The Maryland Transportation Plan 2009 (MDOT, 2009a) has set goal for reducing greenhouse gas emission in all sectors as shown in Figure 3.

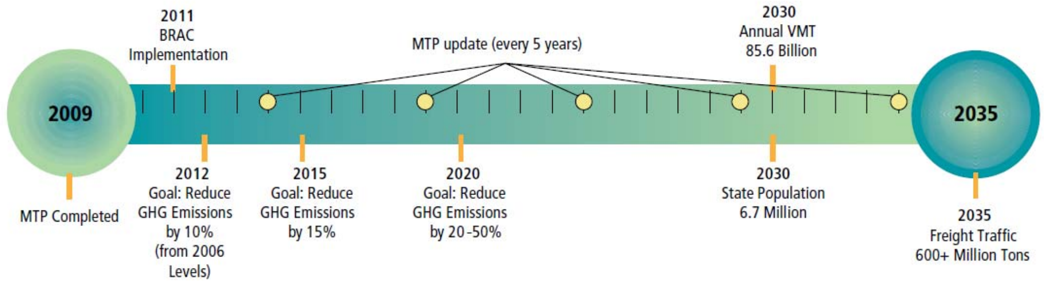


Figure 3. Maryland's greenhouse gas emission future goal
(Source: *2009 Maryland Transportation Plan*, Maryland Department of Transportation)

According to the 2008 Maryland Climate Change Commission, transportation policies should focus on greenhouse gas reduction through efforts to reduce vehicle miles traveled and fuel carbon intensity. The linkage between the transportation policy and other kind of policies such as land uses, or transit system expansion should be implemented in coordination. A potential measure for greenhouse gas emissions is Metric Tons of carbon equivalent emissions from transportation sources.

1.2.2.5 Freight productivity

A comprehensive and consistent set of performance measures of the freight transportation system in Maryland is essential for ensuring the continued movement of goods through the state's highways, rails, waterways, and the air and port systems. Freight-specific performance measures help to identify needed transportation improvements and monitor their effectiveness. Some freight performance measures that are applicable in Maryland are:

1. Cost of highway freight per ton-mile;
2. Hours of delay at border crossings;
3. Travel Time in Freight Significant Corridors;
4. Expenses per Mile for the Motor Carrier Industry;
5. Improvements in the Movement of Highway and Intermodal Freight;

1.2.3 Summary and the Role of MSTM

As transportation decision-making shifts to a more performance-based paradigm, it is critical for SHA to be able to track the transportation system performance over time, and anticipate system performance changes under alternative transportation planning and policy scenarios. Information provided by the MSTM, such as traffic flow and speed on highway facilities and ridership on transit facilities, is essential for computing performance measures regarding mobility, energy, pollution emissions, climate change, and freight transportation. With safety considerations increasingly integrated into the transportation planning process, the MSTM can also provide inputs for safety performance analysis, such as expected accident counts and severity on different transportation facilities under various operating conditions. The MSTM is especially valuable for performance measurement at the statewide level, in rural areas, and for corridors that are either not in a metropolitan area or in cross metropolitan planning area boundaries.

1.3 CORRIDOR FORECASTS AND CONGESTION MANAGEMENT

1.3.1 Background and Corridor Traffic Forecasts

Approximately 70% of all traffic in Maryland travels on the State Highway system even though this system is comprised of less than 20% of the total road system in the state. While we focus on the status of corridor traffic congestion in the Washington DC and Baltimore metropolitan areas in this subsection, it should also be noted that traffic congestion and other transportation issues also impact rural areas in Maryland along major highway corridors.

Figure 4 shows a list of the top ten most congested facilities in the Washington DC Transportation Planning Board planning area (TPB, 2008a).

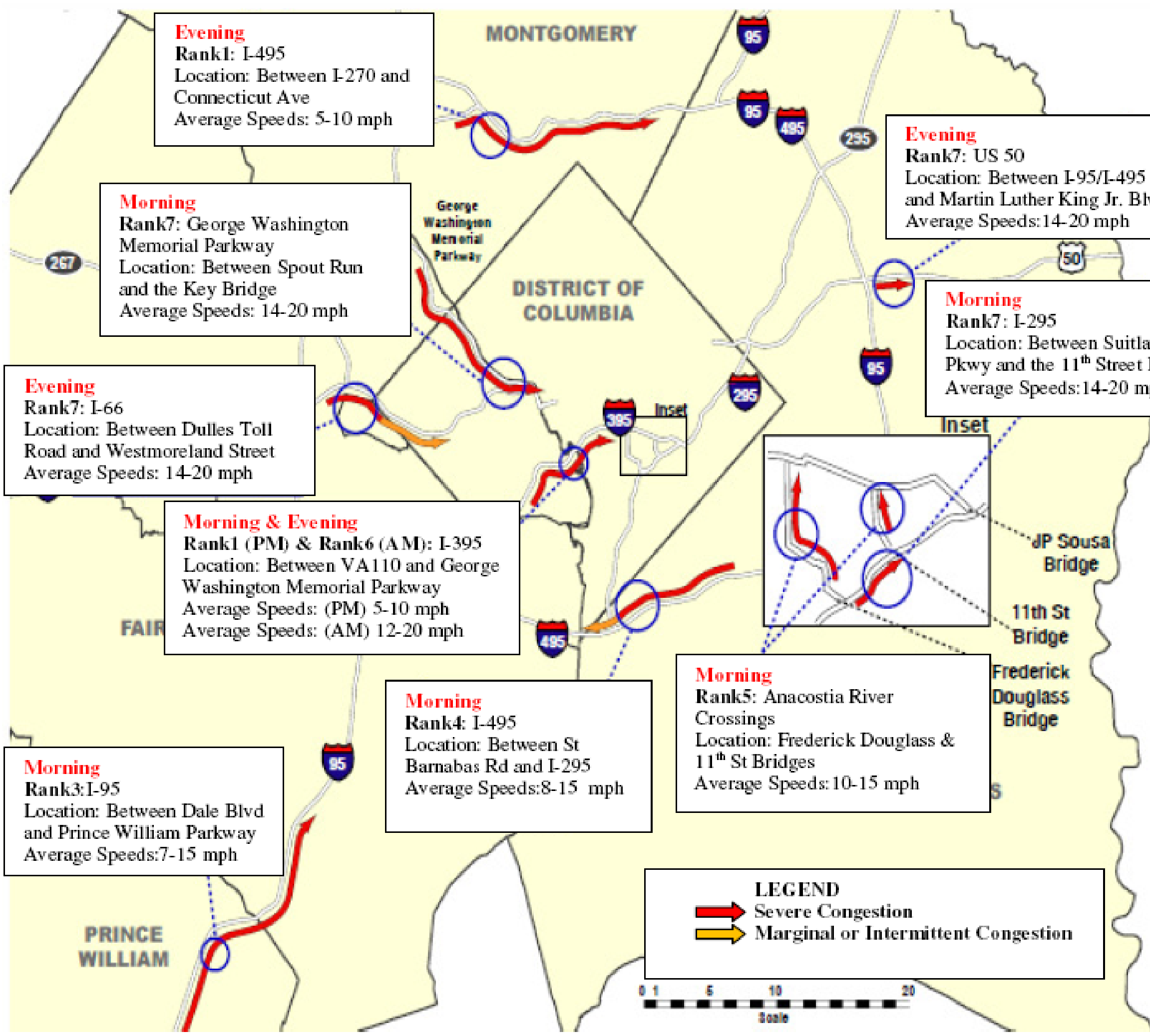


Figure 4. Top Ten Congested Segments on the Regional Freeway System
(Source: National Capital Region Transportation Planning Board, 2008)

Figure 5 and Figure 6 show 2005 and 2030 projected traffic conditions in the Washington DC metropolitan area. In 2005, the most congested corridors during the afternoon peak period are the northwestern half of the Capital Beltway, I-270 from the Beltway to north of Gaithersburg, I-395 from the District's Southeast-Southwest Freeway to Dumfries, Virginia, and I-66 from the Beltway through the City of Fairfax, Virginia. The projection of the 2030 condition incorporates existing facilities plus those listed in the National Capital Region's Financially Constrained Long-Range Transportation Plan (CLRP, 2006). It should be noted that the 2006 CLRP as pictured in this congestion map includes both the Inter-County Connector (ICC) and Beltway HOT Lane project as described above, but does not contain the Shirley Highway (I-95/395) HOT Lane project, as it was not included in the 2006 CLRP.

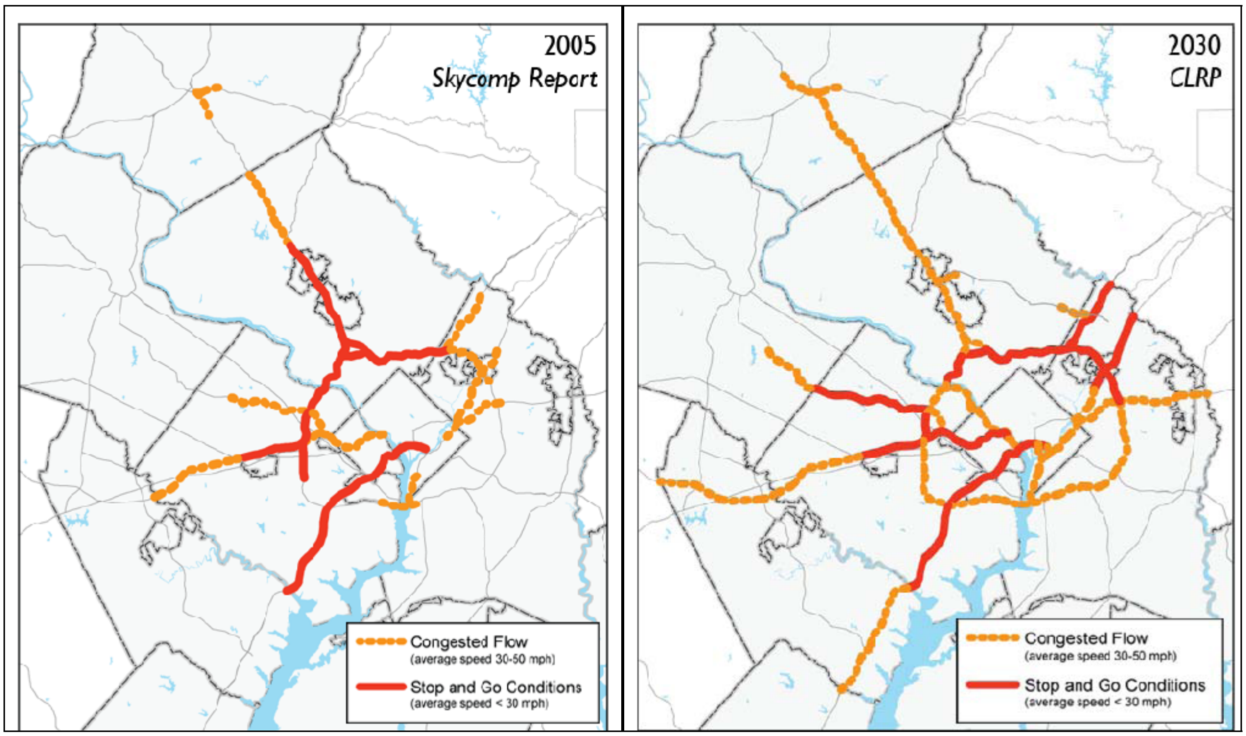


Figure 5. Recurring afternoon peak congestion (left)
Figure 6. 2030 projection for the 2006 CLRP (right)
(Source: National Capital Region Transportation Planning Board, 2008)

From Figure 6, the 2030 map shows that the majority of the corridor will experience an increase in congestion from 2005. The corridors that are expected to worsen in congestion include the Dulles Toll Road from the Loudoun County line to the Capital Beltway, I-66 from the Beltway to the Roosevelt Bridge, I-95 in Maryland and the Baltimore-Washington Parkway. However, there are some areas where congestion is expected to decline. One such area is the Virginia portion of the Capital Beltway between Shirley Highway (I-95/395) and the American Legion Bridge.

According to the Inter County Connector study (ICC purpose and need report), the east-west traffic demand is projected to increase dramatically from 2000 to 2030. The screen line in that study was defined as the hypothetical north-south lines parallel to major north-south routes in the study area. Table 3 lists the east-west traffic volumes by type of facility across each screen line as well as the percent change from 2000 to 2030. The 2030 projection is based on the scenario for which the facilities listed in the Transportation Planning Board's 2006 CLRP will be carried out.

Table 3. East-West Traffic Volumes (Average Daily Traffic) by facility (1,000's)

Screen line	Facility	2000	2030	Percent Increase
A	I-370	66	96	45
(I-270)	Other Arterials	510	664	30
	Beltway	130	154	18
	TOTAL	706	914	29
B	Other Arterials	228	261	14
(MD97/MD185)	Beltway	244	251	3
	TOTAL	472	512	8
C	Other Arterials	191	243	27
(MD182/MD97)	Beltway	249	257	3
	TOTAL	440	500	14
D	Other Arterials	155	209	35
(US29)	Beltway	249	257	3
	TOTAL	404	466	15
E	Other Arterials	143	198	38
(I-95)	Beltway	232	273	18
	TOTAL	375	471	26
F	Other Arterials	106	121	14
(US1)	Beltway	236	276	17
	TOTAL	342	397	16

(Source: Inter County Connector, Purpose and Need Report)

In Table 3, the traffic volumes on every road that cross the screen line are added to yield the total traffic volume crossing it. For example, the sum of the 2000 average daily traffic annual daily traffic (ADT) on the roads crossing the screen line just east of I-270 is 706,000 vehicles. Future ADT is projected to increase 29 percent to 914,000 vehicles by 2030. The travel time from Rockville to BWI Thurgood Marshall Airport is expected to increase by almost 50 percent in 2030 resulting in 100 minutes travel time.

In Baltimore, the congestion indicator is available from the photographic surveys of approximately 575 miles of highways conducted during the morning and evening peak periods of commuter travel (BMC, 2004). Figures 7 and 8 depict analysis conducted in the spring of 2002. The increasing levels of congestion and longer durations of the peak periods (peak spreading) show the need for improvements in the transportation system.

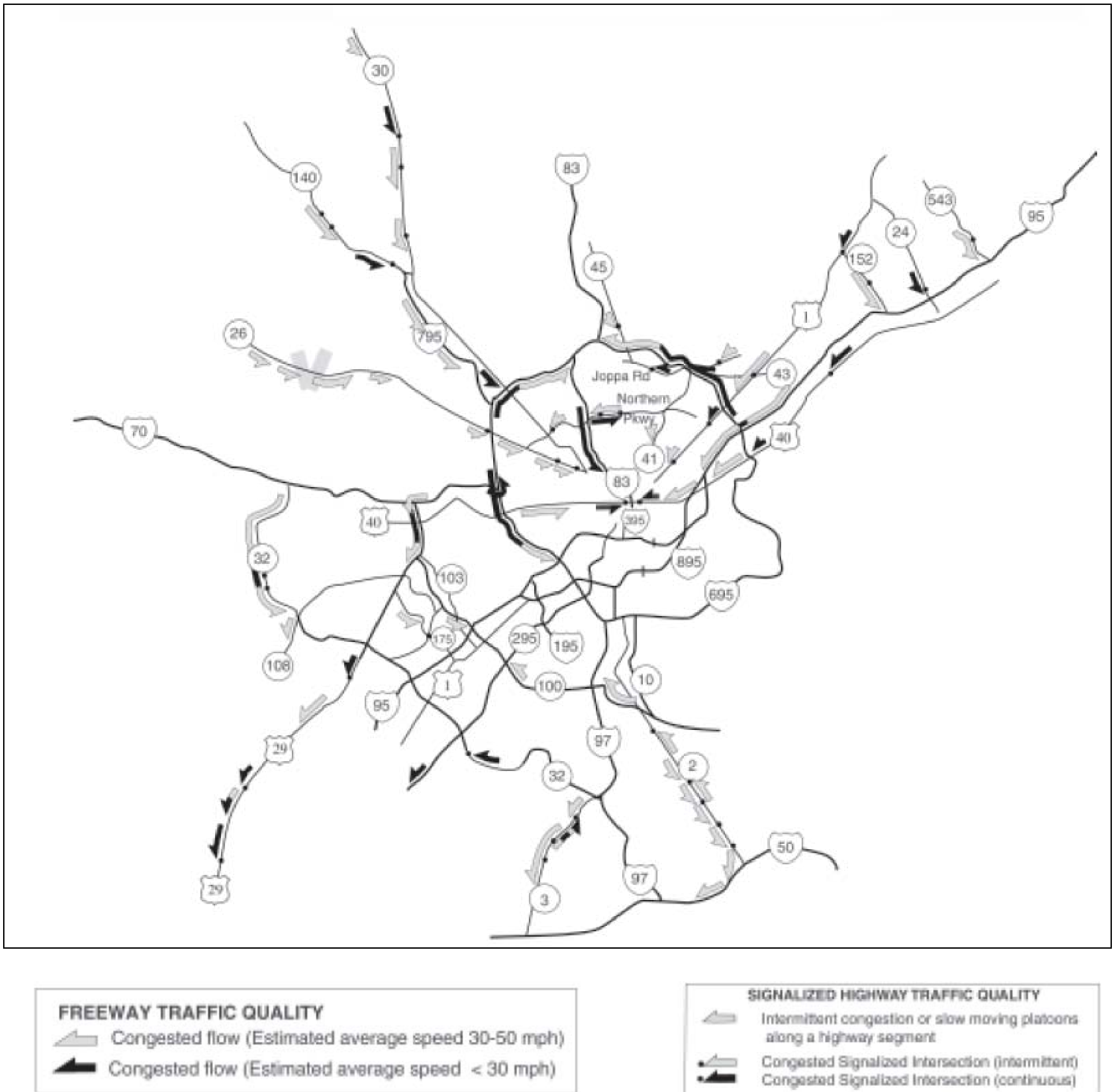


Figure 7. Congestion during morning peak, 2002

(Source: Baltimore Metropolitan Council, Baltimore Regional Transportation Plan, 2004)

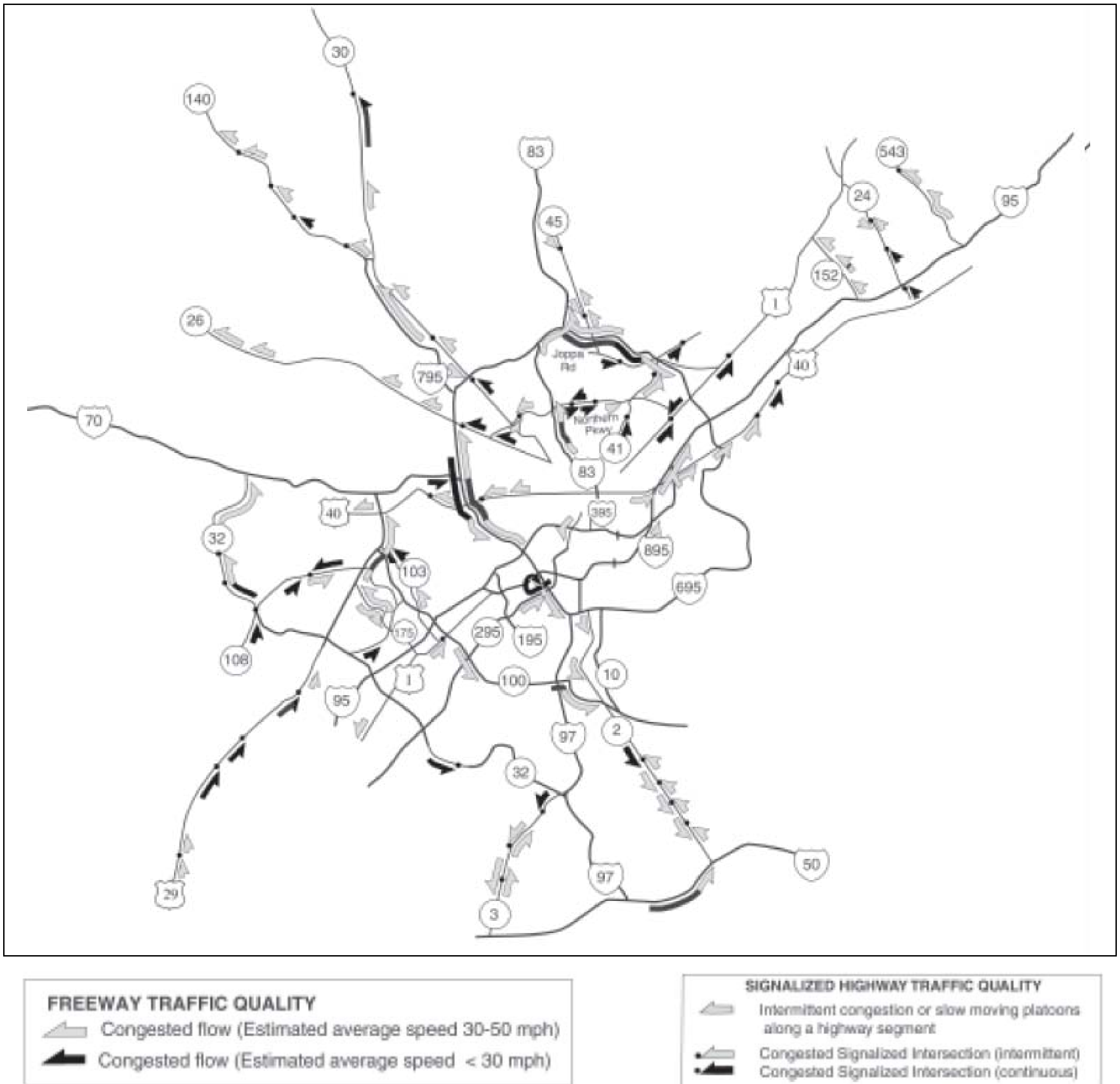


Figure 8. Congestion during evening peak, 2002
(Source: Baltimore Metropolitan Council, Baltimore Regional Transportation Plan, 2004)

The study conducted by the Baltimore Metropolitan Council (BMC, 2004) estimated the performance measures by comparing the base year scenario 2000 and the scenario 2030. The existing and committed (E&C) highway network for the Baltimore region includes all existing roadways and any new roads, additional lanes and transit projects scheduled for construction by the year 2008. According to this study, the most problematic areas continue to be the major connectors linking the region's perimeter with the central business district of Baltimore City. The corridors, which are expected to be severely congested, are I-95, I-695, I-83, and MD 295 (Baltimore-Washington Parkway). Figure 9 and 10 show congested roadways in the year 2000 and 2030 respectively where the red segment indicates roadway conditions under level of service E and F. Table 4 displays corresponding performance measures for the A.M. peak period (6 A.M. – 10 A.M.) and a 24-hour period of the projected congestion scenario in 2030.

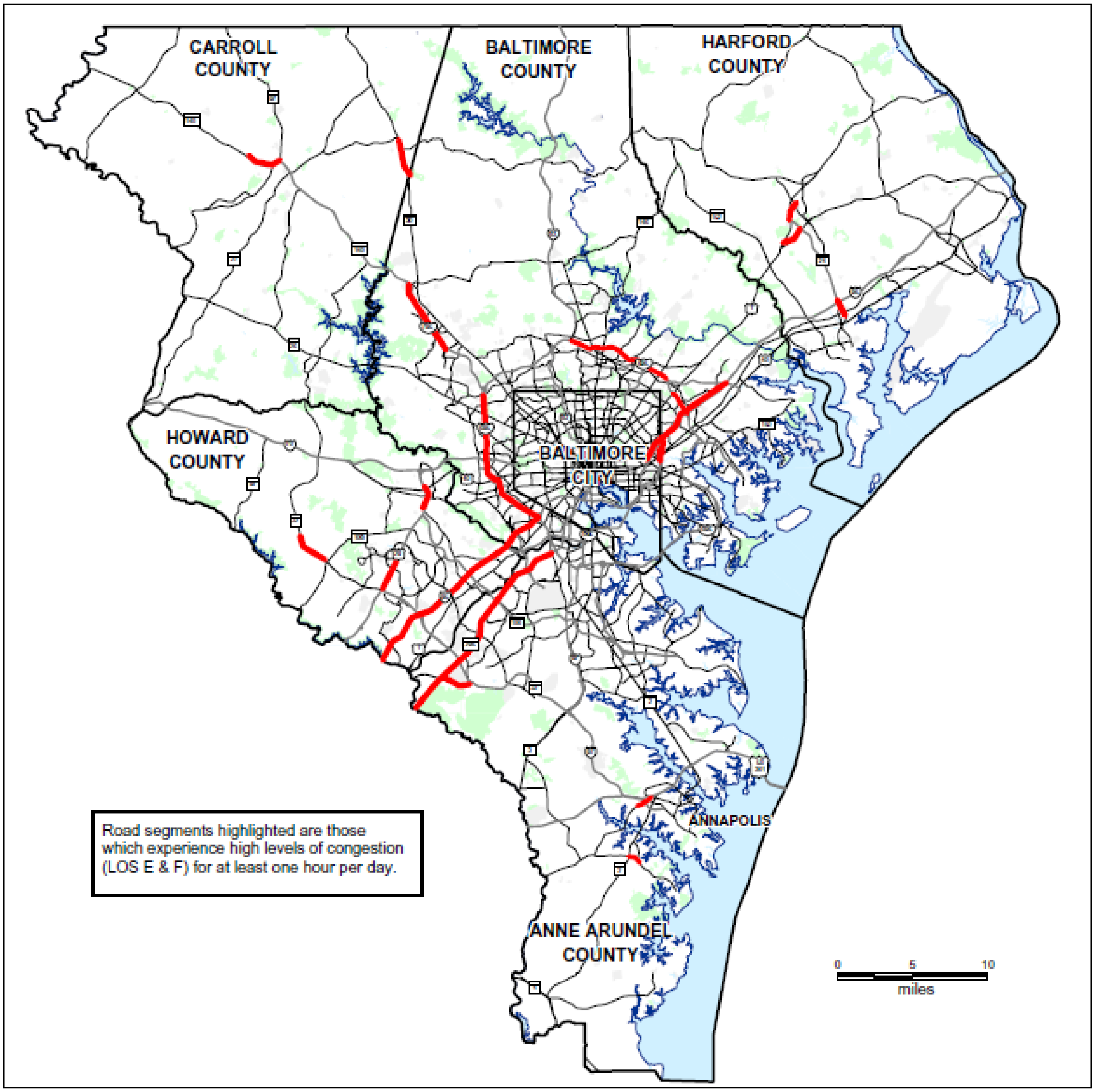


Figure 9. Congested Roadways: Year 2000
(Source: Baltimore Metropolitan Council, Baltimore Regional Transportation Plan, 2004)

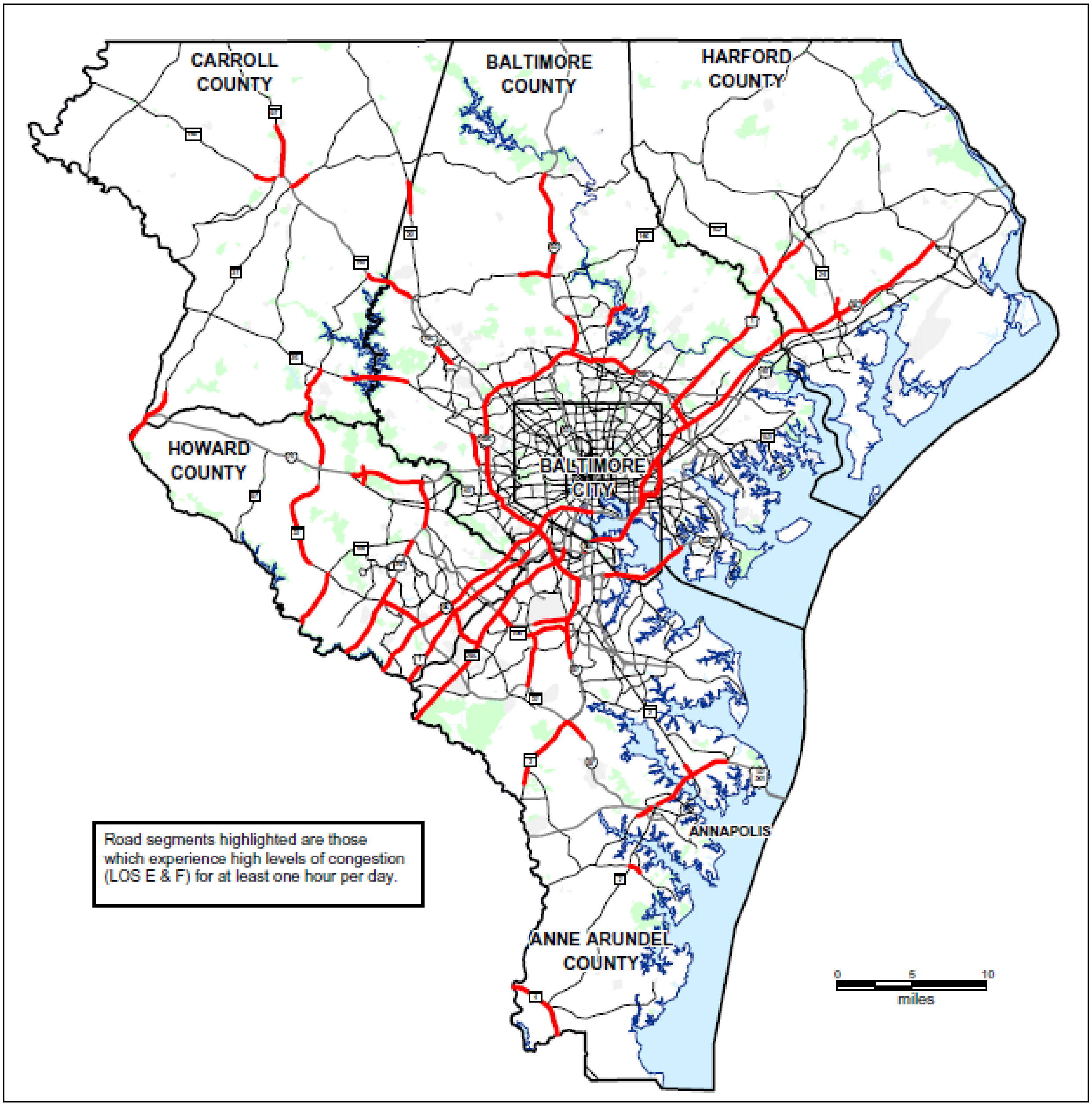


Figure 10. Congested Roadways 2030 E&C
(Source: Baltimore Metropolitan Council, Baltimore Regional Transportation Plan, 2004)

Based on the analysis, the average weekday vehicle miles traveled in the Baltimore region is projected to increase by 37 percent. The congested vehicle miles traveled is expected to increase by nearly 280 percent. The vehicle hours of delay is expected to increase by more than 400 percent because of the increased traffic congestion.

Table 4. Regional AM Peak and 24-hour measures: 2000 and 2030 E&C

Performance Measures	AM Peak Period		Average Weekday ADT	
	2000	2030	2000	2030
Vehicle Miles Traveled (VMT)				
Freeways	7,292,000	8,895,000	29,461,000	40,670,000
Arterials	5,822,000	7,920,000	21,541,000	28,536,000
Collector and Local Roads	2,084,000	3,266,000	7,244,000	10,644,000
All Roads	15,198,000	20,080,000	58,427,000	79,849,000
Congested VMT (LOS E&F)				
Freeways	2,126,000	5,312,000	3,663,000	13,119,000
Arterials	581,000	2,276,000	865,000	3,881,000
Collector and Local Roads	53,000	425,000	83,000	645,000
All Roads	2,760,000	8,013,000	4,611,000	17,644,000
Percentage of Congested VMT				
Freeways	29.1%	59.7%	12.4%	32.3%
Arterials	10.0%	28.7%	4.0%	13.6%
Collector and Local Roads	2.5%	13.0%	1.1%	6.1%
All Roads	18.2%	39.9%	7.9%	22.1%
Vehicle Hours of Delay	12,472	54,702	20,297	104,898

(Source: Baltimore Metropolitan Council, 2004)

1.3.2 Congestion Management Strategies

Measures to alleviate congestion generally rely on capacity expansion, system operational improvements, and other congestion management strategies. In the consolidated transportation program year 2008 to 2013, 43 percent of the Maryland Department of Transportation's funding will be spent on transportation system preservation (MDOT, 2009a). Therefore, the policy that solely relies on capacity expansion may not be effective. Rather, capacity expansion should be complimented with congestion management strategies such as pricing/tolling, managed lanes, incident management, peak spreading incentives, and transit improvements to achieve better system performance. Congestion management strategies related to land use (e.g. smart growth, transit oriented develop) will be discussed in Section 1.5 of this report.

1.3.2.1 Pricing, Toll Lanes, and Managed Lanes

On May 4, 2004 the Maryland Secretary of Transportation announced an Express Toll Lanes (ETL) initiative. Under this initiative, the Secretary has directed the Maryland Department of Transportation and Maryland Transportation Authority to consider implementing ETL on several existing facilities in Maryland. According to this initiative, Express Toll Lanes are actively under consideration in the Baltimore and Washington regions, for I-95, I-270, I-495/I-95, and MD 5. The map for the Statewide Express Toll Lanes is shown in Figure 11. Figure 12 indicates the index of the roadway in the corridor.

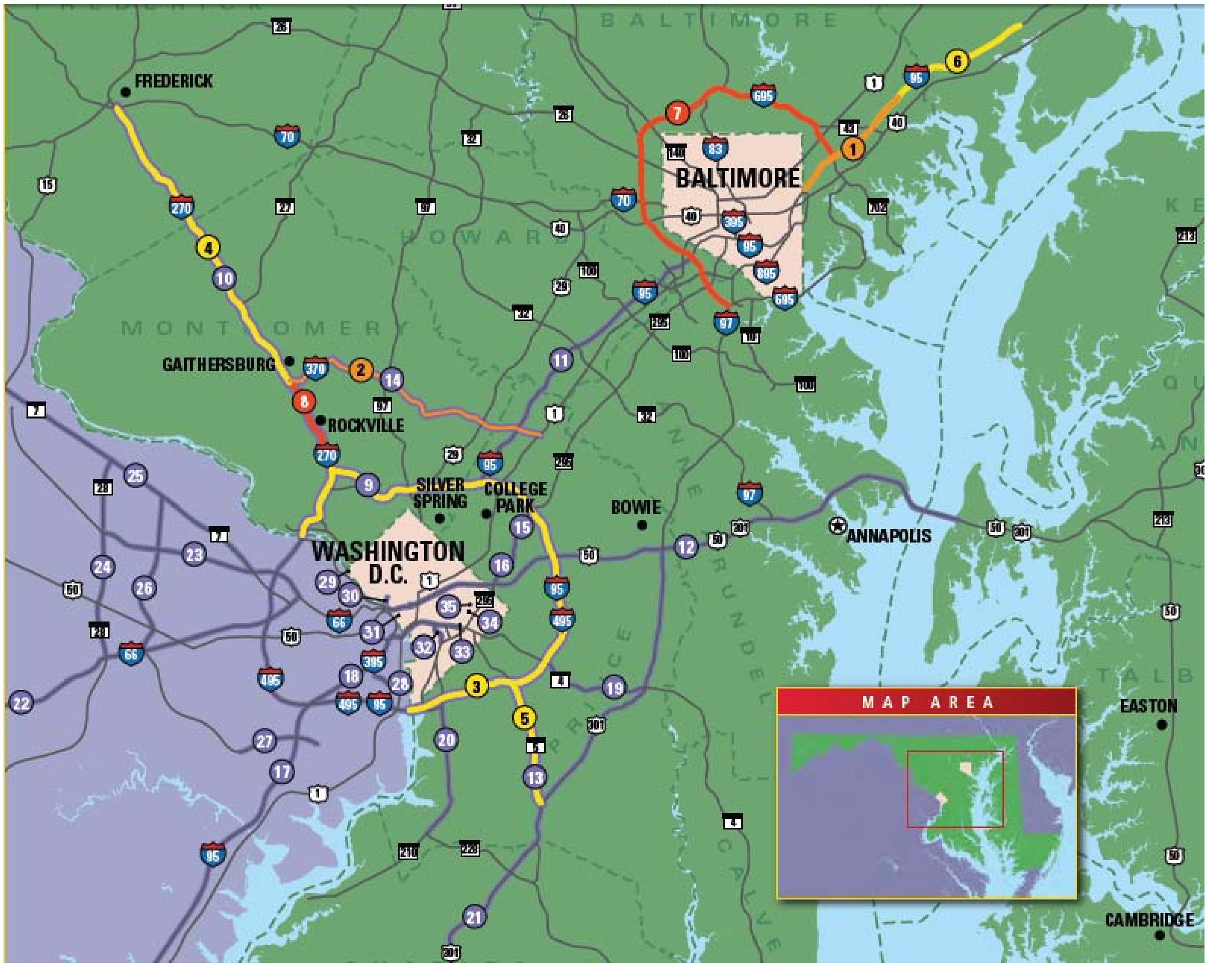


Figure 11. Statewide Express Toll Lanes network
(Source: Maryland Department of Transportation, 2010a, Maryland Statewide ETL Network Initiative)

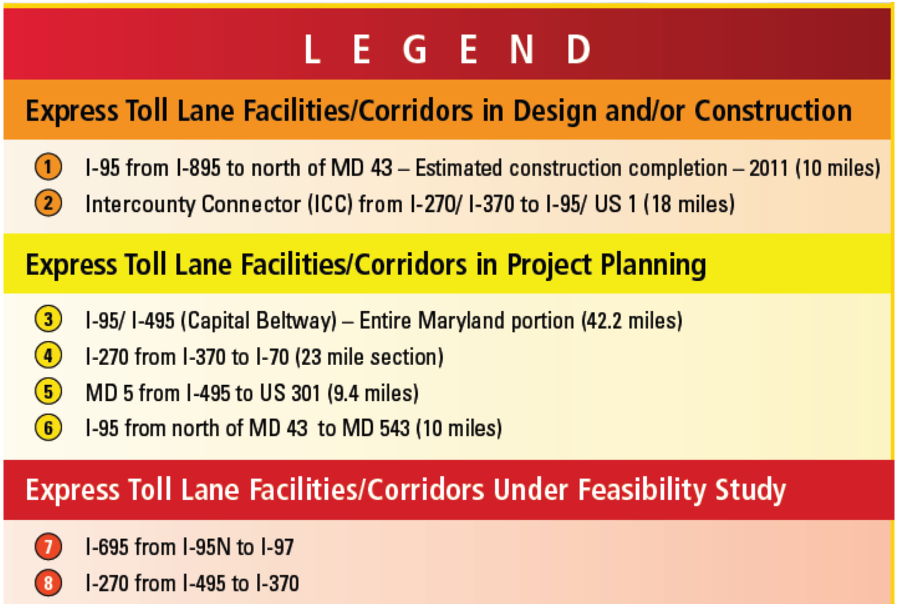


Figure 12. Legend for the Statewide ETL map under study and construction plan
(Source: Maryland Department of Transportation, 2010a, Maryland Statewide ETL Network Initiative)

Currently, the I-95/395 high occupancy toll (HOT) lanes project is under study for possible inclusion into the region's financially Constrained Long Range Transportation Plan (CLRP). The Inter-County Connector in suburban Maryland and the Northern Virginia Capital Beltway high occupancy toll (HOT) lanes project are already in construction and will open to traffic in the near future. A brief description of some major congestion pricing projects under the Statewide Express Toll Lanes is given below:

1) I-95 High Occupancy Toll (HOT) lanes from I-895 to north of MD 43 (section 100)

In July 2005, the Maryland Transportation Authority (MDTA) received federal approval to construct Express Toll Lanes (ETL) on the most congested portion of I-95 north of Baltimore City. This 8-mile segment stretches from the I-895 (N) split in east Baltimore City, to north of MD 43 in White Marsh, Baltimore County. Once completed, there will be two ETL and four general-purpose lanes in each direction. The tolls will be managed to maintain relatively congestion-free traffic flow. The toll for using the ETL will vary depending on the time of day and amount of traffic on the road.

2) The Inter-County Connector (ICC) Express Toll Lanes (ETL)

The Inter-County Connector is an 18-mile east-west highway in Montgomery and Prince George's counties in Maryland that will run between I-270 and I-95/US 1. The need for the ICC is primarily due to the lack of a high capacity transportation facility in the developed portions of Montgomery and northwestern Prince George's Counties (now connected mainly by the Capital Beltway). The project will include six variably-priced lanes with express bus service connecting to Metrorail stations. This project was included in the CLRP, 2004. The project is currently under construction and is expected to be completed in 2012. The ICC will rely on ETL facilities where the toll price will be mileage-based with prices that vary depending on the time of day (peak, non peak).

3) The Capital Beltway Express Toll Lanes (ETL) entire Maryland portion

Currently, the Capital Beltway study is being conducted to consider different alternatives for managed lane policies including high occupancy vehicle lanes (HOV), high occupancy toll lanes (HOT), and Express Toll Lanes (ETL). In addition to the Full Capital Beltway Study, Maryland and Virginia are conducting two joint mobility studies (South Side and West Side Mobility Studies) along the I-95/I-495 corridor.

The South Side Mobility Study examines the lane configuration and connectivity of the various projects along the 14-mile south side segment of I-95/I-495 as shown in the Figure 13. The Southside Mobility Study led by the Virginia Department of Transportation was completed in early 2009. The study shows that there is demand for both transit improvement and HOV in the future. The West Side Mobility Study led by SHA considers the 14-mile segment, which are separated into five segments: (1) Virginia portion of the Capital Beltway to the American Legion Bridge, (2) American Legion Bridge, (3) Maryland portion of the Capital Beltway, (4) I-270 West Spur, and (5) I-270 from the West Spur to the I-370 Interchange. The study completed in the fall of 2008 recommended that three alternatives should be considered and their evaluation over time studied. They are (1) the No-Build; (2) eight General Purpose & two Express Toll Lanes; and (3) six General Purpose & four Express Toll Lanes. The Transportation System Management/Transportation Demand Management (TSM/TDM) will be carried forward as part of the two build alternatives.

4) I-270 (from I-370 to I-70)

This is an important corridor that serves technology and other businesses operating in the area and provides access to growing residential communities. The primary needs of this project are to relieve existing congestion and provide capacity for projected development in Montgomery County and Frederick County. Express Toll Lanes could potentially be used in place of, or in conjunction with, current High Occupancy Vehicle (HOV) lanes.

5) MD 5 (I-495 to US 301)

Project planning studies are underway for MD 5 between I-495 (Capital Beltway) and US 301. Express Toll Lanes are one of the alternatives being considered.

6) I-95 from north of MD 43 to MD 543

The I-95 Master Plan conducted in 2003 recommended that at the project planning phase three concepts should be considered for additional study. These concepts included the No-Build Alternative, the General Purpose Lanes (GPL) Alternative, and the Managed Lanes (ML) Alternative. The Authority developed preliminary alternatives based on these concepts. This corridor has similar characteristics as the Section 100 Corridor. Therefore, similar operational efficiency, safety, congestion management and revenue production are anticipated in this corridor with an ETL strategy.

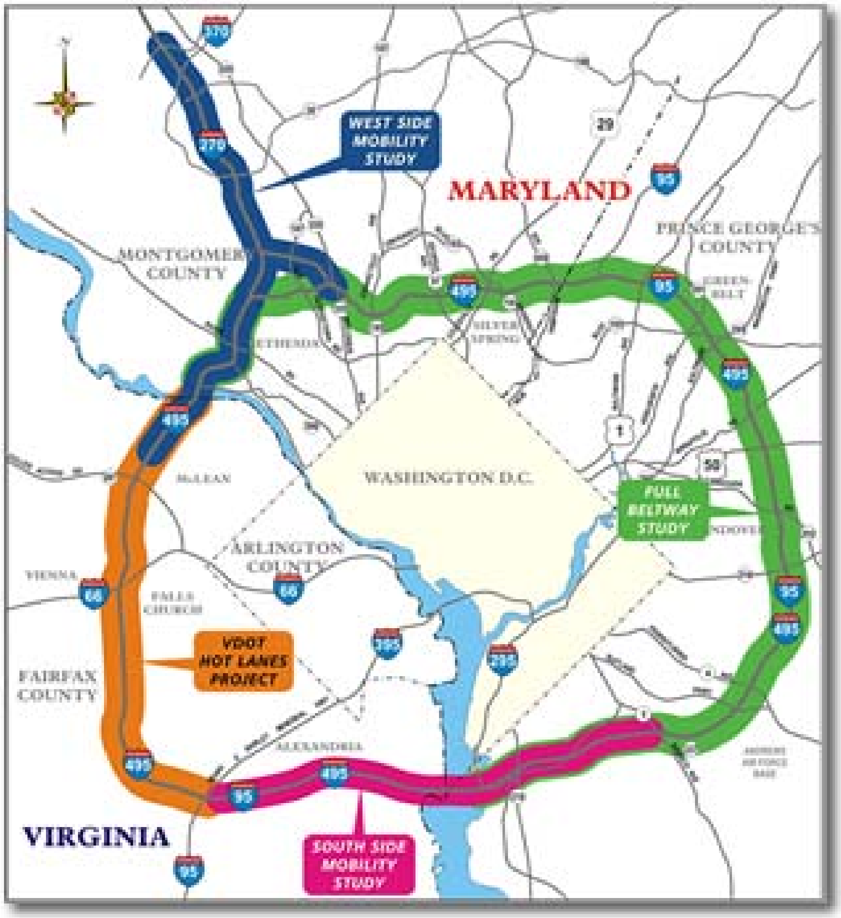


Figure 13. The Capital Beltway study area
(Source: Maryland Department of Transportation 2010b, Capital Beltway Study)

1.3.2.2 Incident Management

In terms of incident management, the Coordinated Highways Action Response Team (CHART) operations have became part of a regional advanced traffic management system for the Baltimore-Washington region. A better understanding of drivers' demand responses (e.g. route change, peak spreading, modal shifts) to non-recurrent congestion at the corridor and system levels is important for the success of SHA's incident management effort.

The frequency distribution of incident/disabled vehicles by roadway is shown in Figure 14 and the distribution of average incident duration is shown in Figure 15.

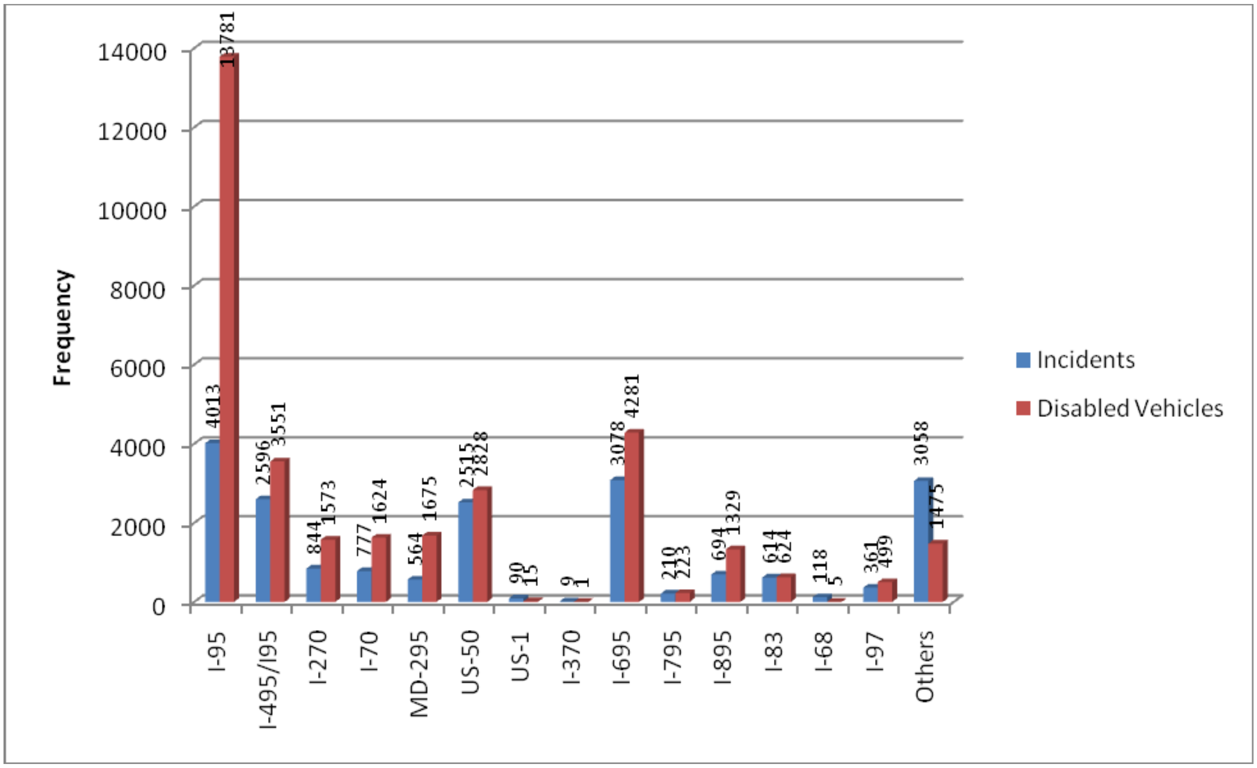


Figure 14. Distribution of Incidents and Disabled Vehicles on major Maryland corridors in 2008
(Source: Maryland Department of Transportation, Coordinated Highway Action Response Team, 2008, Available online at http://chartinput.umd.edu/)

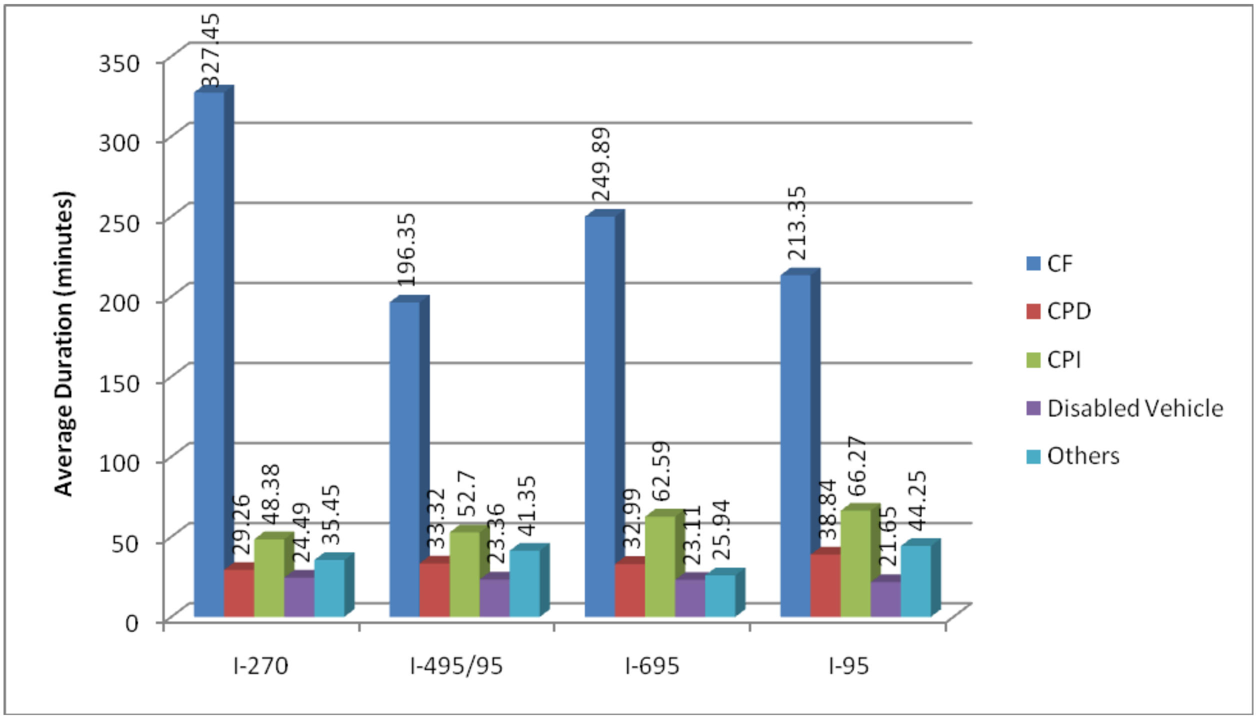


Figure 15. Distribution of Average Incident Duration on major Maryland corridors in 2008
(Source: Maryland Department of Transportation, Coordinated Highway Action Response Team, 2008, Available online at http://chartinput.umd.edu/)[4]

Based on the statistics shown in Figures 14 and 15, it is clear that the six major commuting freeways, I-495/95 (Capital Beltway), I-695 (Baltimore Beltway), I-95 (from the Delaware border to the Capital Beltway), US 50, MD 295, and I-270, had a very large number of incidents/disabled vehicles in the year 2008. It is noted that since I-95, US 50 and I-270 are connected to I-495/95, any incident on I-495/95 is likely to have vehicles queued back to I-95, US 50 and I-270 and causes serious congestion on those three freeways as well.

1.3.2.3 Peak Spreading

Peak spreading is a phenomenon wherein motorists shift their departure times in response to congestion, incidents, tolls, and/or traveler information services. Peak spreading should be an important consideration in evaluating congestion management strategies and traditional congestion pricing policies. In addition, other travel demand management strategies may also induce peak spreading patterns that are beneficial to the society and users. Examples include incentives toward flexible work schedules, peak-period parking management, dynamic tolling, other peak period travel restrictions, and advanced traveler information systems.

[4] CF, CPD, and CPI stands for Collision with Fatalities, Collision with Property Damage, and Collision with Personal Injuries, respectively.

1.3.2.4 Transit and Multimodal Transportation Improvements

The I-270/US 15 Corridor is currently being considered as a transit way alternative. This vital corridor provides an essential connection between the Washington DC metropolitan area and both central and western Maryland. Facility improvements in conjunction with the proposed transit options include: Light Rail Transit (LRT), Bus Rapid Transit (BRT), and Premium Bus Service along a dedicated corridor known as the Corridor Cities Transitway. Traffic conditions on this corridor especially from the Shady Grove road to the I-70 section are expected to worsen dramatically by 2025. This is mainly due to projected increases in population and employment as the result of planned development along this Montgomery County portion of the Corridor, and the projected expansion of suburban residential development in the Frederick area. In addition, there are a limited number of alternate north-south routes available to meet the current transportation needs of the Corridor.

Other major transit improvement projects include the Purple Line and the Red Line LRT projects. The Purple Line is a proposed east-west high-capacity LRT line that connects communities between Bethesda in Montgomery County and New Carrolton in Prince George’s County in Maryland. It is expected to provide additional transit capacity in this congested corridor, improve travel reliability, provide connections among existing Metro (red, green, and orange lines), Marc, and Amtrak stations, and support economic development in Maryland. The Red Line is a 14-mile east-west LRT line proposed for Baltimore, MD. It connects the areas of Woodlawn, Edmondson Village, West Baltimore, downtown Baltimore, Harbor East, Fells Points, Canton and the Johns Hopkins Bayview Medical Center Campus.

1.3.3 Summary and the Role of MSTM

In order to improve transportation, environmental, and livability conditions for Maryland residents and visitors, SHA has initiated major planning efforts to improve critical highway corridors in urban and rural areas. The SHA is also committed to integrating safety, mobility, environmental stewardship, and socio-economic objectives in its transportation planning process and Comprehensive Highway Corridors (CHC) program. The CHC program identifies the critical highway corridors in Maryland, and develops multimodal transportation plans and improvement programs to mitigate congestion, improve safety, and promote environmental stewardship along these corridors. The CHC program will provide vital support to the economic growth in Maryland with an efficient, safe, and sustainable transportation system. The MSTM should be an integral part of the CHC program and the long-range transportation planning at the SHA because it provides essential information on highway corridor traffic forecasts, transit ridership analysis, and other system performance measures for corridor improvements and congestion management.

With the high cost of highway capacity expansion, various congestion management strategies provide attractive and effective solutions to congestion and transportation sustainability problems. Their success depends on a good understanding of behavior and demand responses from system users and non-users. For instance, the congestion mitigation effects of toll lanes and other managed lanes are determined by route choice (how many drivers will use the toll lanes, and how many will shift to other alternative routes), departure time choice (how many will change departure time to off-peak and peak shoulder hours), mode choice (how many will switch to transit), destination choice (how many will change destinations to either avoid toll or take advantage of the improved level of service on toll lanes), vehicle occupancy choice (how many will carpool), trip frequency choice (how many will cancel their trips or add new trips), and other demand responses. The current version of the MSTM is capable of modeling most of these demand responses, and therefore a valuable modeling asset for the SHA. It needs to be improved to better consider departure time choices, dynamic routing behavior, and multimodal mode choices. For corridor-level traffic operations and planning studies, there are also opportunities to integrate the MSTM with microscopic traffic simulation models for an improved analysis of corridor-level congestion management strategies, their operational effectiveness at the corridor level, and their broader system-level performance impact.

1.4 FREIGHT TRANSPORTATION

The multimodal freight system of Maryland is an interconnected network of highways, railroads, waterways and marine terminals, and cargo airports. The movement of multimodal freight in Maryland is critical to the state, regional, and national economies. In order to identify freight planning and policy analysis needs, we have reviewed a number of national and regional-level freight studies, the statewide freight transportation plan, and other freight studies in Maryland. We present several critical freight analysis issues in the following sections, and discuss the importance of a statewide transportation model that systematically considers multiple freight modes for statewide freight transportation planning.

1.4.1 Growing Freight Transportation Demand

Economic and population growths will lead to a significant increase in freight transportation demand in Maryland. About 692 million tons of goods were transported inbound, outbound, intrastate, and through Maryland in 2006, which accounted for approximately $2.3 trillion in combined value. The overall tonnage is estimated to increase more than 100% by 2035, comprising about 1.4 billion total tons and $5.0 trillion of combined value. Table 5 and 6 show 2006 and 2035 tonnage and value by freight mode and flow type.

Table 5. Summary of Statewide Freight Flows by Weight and Value, 2006

Flow Type	Weight (Million Tons) / Value (Billion Dollars)				
	Total	Truck	Rail	Water	Air
Inbound	138.6 / 362.3	106.4 / 299.3	22.2 / 37.8	9.92 / 24.9	0.0856 / 0.378
Outbound	105.7 / 353.4	91.8 / 287.0	6.82 / 32.7	7.03 / 33.3	0.0705 / 0.361
Intrastate	64.3 / 142.3	57.8 / 129.7	2.35 / 4.87	4.17 / 7.73	0.001 / 0.004
Through	383.6 / 1,430.6	328.2 / 1,256.5	37.7 / 112.5	17.7 / 61.4	-
Total	**692.3 / 2,288.5**	**584.3 / 1,972.5**	**69.1 / 187.7**	**38.8 / 127.3**	**0.157 / 0.743**

(Source: Maryland Statewide Freight Plan, 2009)

Table 6. Summary of Statewide Freight Flows by Weight and Value, 2035

Flow Type	Weight (Million Tons) / Value (Billion Dollars)				
	Total	Truck	Rail	Water	Air
Inbound	292.3 / 790.5	233.1 / 677.5	43.7 / 71.2	15.3 / 40.3	0.231 / 1.54
Outbound	235.2 / 935.7	197.5 / 755.7	15.7 / 71.4	21.7 / 107.0	0.211 / 1.62
Intrastate	151.2 / 346.6	137.1 / 310.8	4.97 / 14.1	9.16 / 21.7	0.002 / 0.009
Through	743.2 / 2,909.1	647.5 / 2,604.2	67.7 / 188.2	28.0 / 116.7	-
Total	**1,421.9 / 4,981.8**	**1,215.2 / 4,348.1**	**132.1 / 344.9**	**74.2 / 285.7**	**0.444 / 3.17**

(Source: Maryland Statewide Freight Plan, 2009)

1.4.2 Freight Congestion on Major Highway Corridors

Congestion has major impacts on freight operations and service reliability. The SHA maintains a traffic monitoring system to collect traffic volume data and to calculate Average Annual Daily Traffic (AADT) and Average Annual Daily Truck Traffic (AADTT) counts on the state's highways. Table 7 identifies the highway AADTT for major segments in 2007. The most heavily utilized highway segments, in terms of total AADTT, have truck traffic volumes in excess of 15,000 trucks per day. Most of these congested segments are located along the I-95 and I-81 corridors.

Table 7. Top Maryland Highway Segments by Total AADTT, 2007

Rank	Location	AADTT Range	Notes
1	I-95 DE state line to Havre de Grace except for the Tydings Bridge	16,300 to 17,700	Lower truck counts on Tydings Bridge (over Susquehanna)
2	I-81 Washington County	15,200 to 16,000	Except a short section between MD 58 and Maugansville Road near Mack Truck plant
3	I-95 between the Baltimore and Washington Beltways	15,800 to 15,900	Drops to 10,200 between MD 32 and MD 175 (Jessup)
4	I-95 in Baltimore and Harford Counties	13,800 to 15,200	From I-695 to Aberdeen area
5	I-95/I-495 in Prince George's County	12,400 to 13,600	
6	I-95 Baltimore County/Baltimore City	11,100 to 13,000	Inside I-695 Beltway

(Source: Maryland Statewide Freight Plan, 2009)

Maryland is primarily a "through" state for freight transportation, with more than half of the freight tonnage passing through the state. "Through" truck traffic has greatly worsened congestion on the I-95 and I-81 corridors, which both have a north-south orientation and connect large population centers. "Through" trips account for approximately 97 percent of total truck tonnage on I-81, and 57 percent of total truck tonnage on I-95. Figure 16 and 17 show the estimated truck freight tonnage on Maryland highways based on the TRANSEARCH database in 2006 and 2035 respectively. Again, we can see I-95 and I-81 accommodated the heaviest truck tonnage in 2006. These Interstate highways will continue to carry a large share of the truck tonnage in 2035. The level of congestion on these highway corridors is expected to get much worse under the business-as-usual scenario. Currently, the Maryland Department of Transportation (MDOT) is involved with the I-95 Corridor Coalition to evaluate truck and rail capacity bottlenecks and to try to shift freight from these congested corridors to other corridors, and shift highway truck freight traffic to other freight modes.

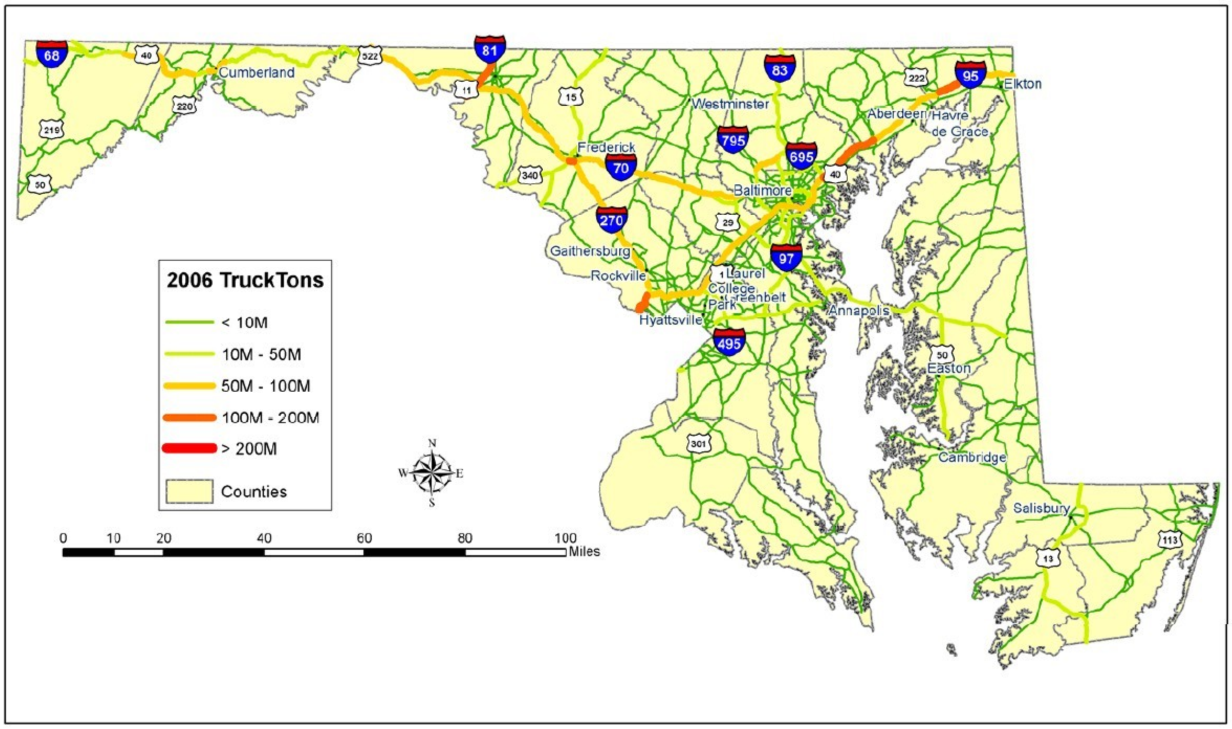


Figure 16. Total Truck Tonnage 2006
(Source: 2003 TRANSEARCH Insight, forecast update to 2006 by Cambridge Systematics, Inc.)

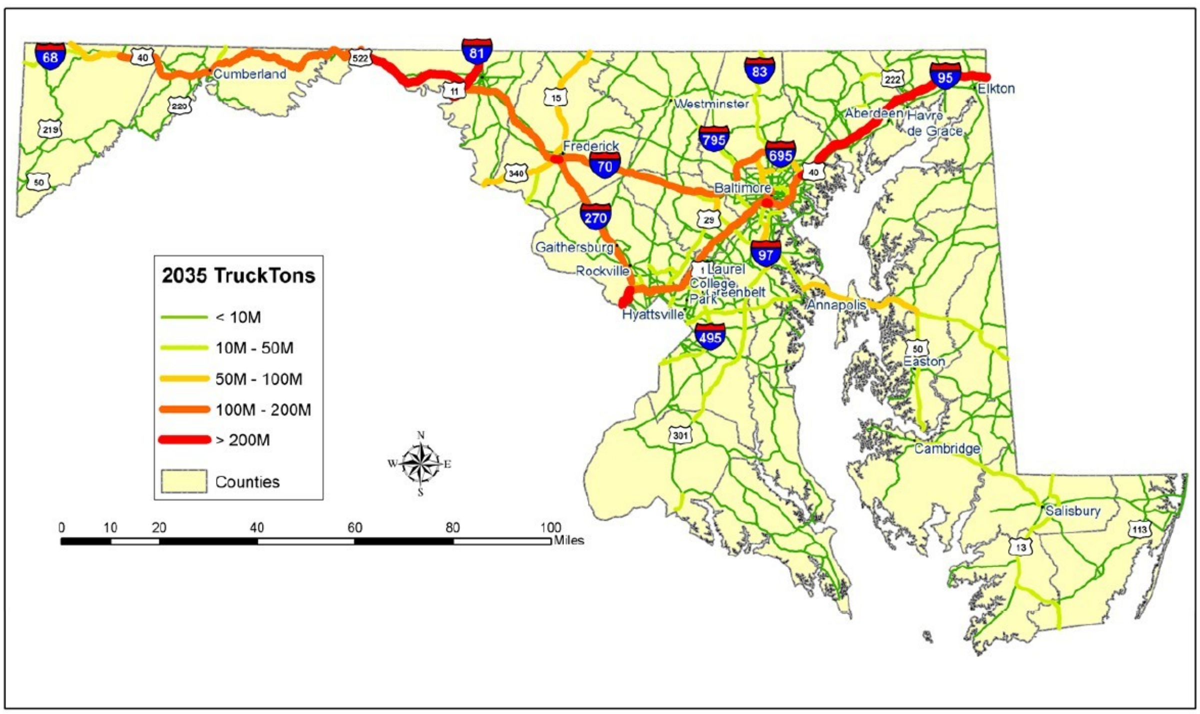


Figure 17. Total Truck Tonnages 2035
(Source: 2003 TRANSEARCH Insight, forecast update to 2006 by Cambridge Systematics, Inc.)

1.4.3 Freight Demand Growths on Non-Highway Modes

Tables 5 and 6 in the previous subsection show that aside from the trucking mode, other freight modes are also experiencing rapid demand growths in Maryland. Shippers and carriers have increasingly shifted from trucking to rail for the long-haul portion of freight trips. This trend has also increased service demand at intermodal freight transfer (truck-rail) facilities. The air cargo freight mode serves a growing market of relatively more valuable and time-sensitive goods. The Port of Baltimore plans to significantly expand the capacity of its freight facilities by 2025.

1.4.3.1 Rail

Figures 18 and 19 illustrate the 2006 total rail tonnage and the estimated 2035 total rail tonnage in Maryland respectively. The bulk of the rail freight flows use the east-west CSX rail corridor, and the north-south Northeast rail corridor. Compared to 2006 flows, the 2035 flow forecasts show significant demand growths on both corridors.

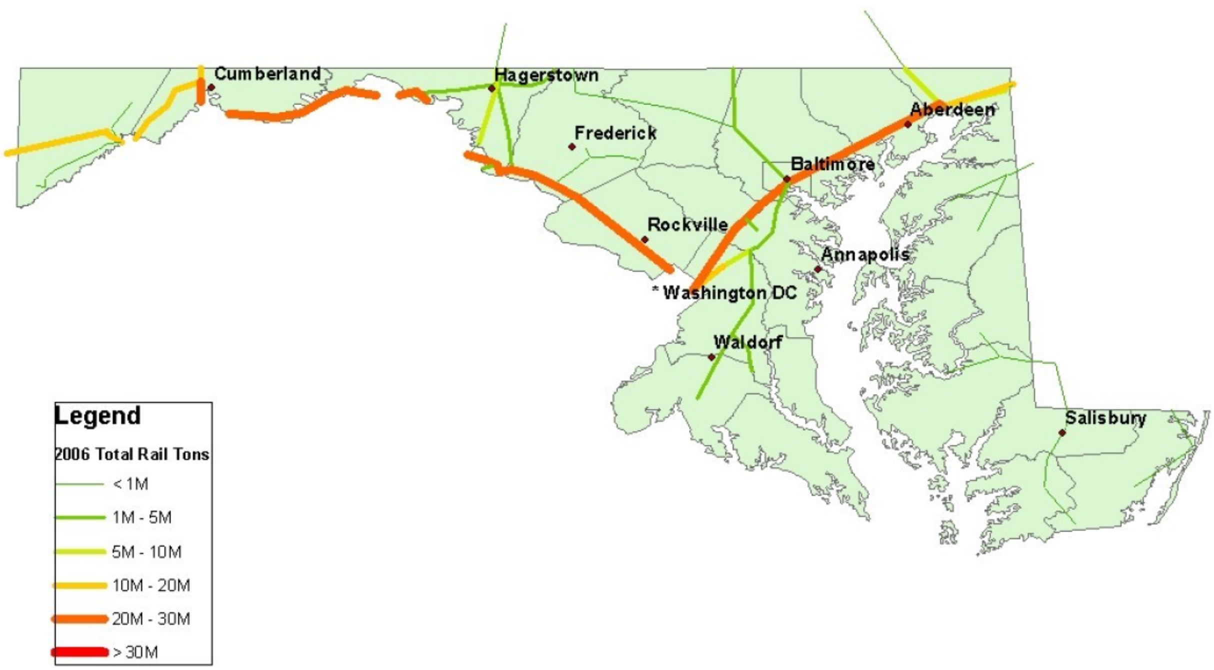


Figure 18. Total Rail Tonnage 2006
(Source: 2003 TRANSEARCH Insight, forecast update to 2006 by Cambridge Systematics, Inc.)

Figure 19. Total Rail Tonnages 2035
(Source: 2003 TRANSEARCH Insight, forecast update to 2006 by Cambridge Systematics, Inc.)

There are also plans for rail system improvements in or near Maryland. Funds from the Transportation Investment Generating Economic Recovery (TIGER) grant has initiated a project, titled "The National Gateway Freight Rail Corridor," which is a package of rail infrastructure and intermodal terminal projects. This project will enhance transportation service options along three major freight rail corridors owned and operated by CSX through the Midwest and Atlantic coast (TPB, 2008). A total investment of $284 million is proposed in Maryland, the District of Columbia, and Virginia. The funding will improve the rail-connected ports and provide resources to upgrade the railway lines of several corridors including the Atlantic Coast Corridor (I-95 corridor) and the Eastern Gateway Corridor (I-70/I-76 corridor), which are identified by the project as "The National Rail Gateway Corridors." Rail transportation capacity along these corridors will be expanded with new equipments that enable double-stacked containers.

With increased rail shipping capacity, these rail corridors in Maryland will also become more marketable to major East Coast ports and shippers, implying that there will be additional rail freight demand and additional truck traffic on highways that serve intermodal freight transfer facilities. On the positive side, the implementation of this and other rail freight capacity enhancement projects can further promote rail as a more cost-effective alternative to long-haul trucking. In Maryland, the highway congestion-mitigation impacts of this rail project will be significant. It is estimated that a total of 1,084,000 trucks trips will be removed from the I-95, I-70, and I-68 highway corridors between 2012 and 2021, which is equivalent to $379 million of benefits in reduced congestion, fuel consumption, pollution emissions, and green house gas emissions. The amount of removed truck trips in Virginia and D.C. is 1,325,000, with the benefits valued at $573 million.

1.4.3.2 Air Cargo

Although air cargo accounts for the smallest share among all freight modes, shipments transported via air are usually high-value and time-sensitive items, which makes them the fastest growing transportation demand worldwide in recent years. According to the MWCOG's Washington-Baltimore Regional Air Cargo Study (2008), the air cargo industry worldwide is expected to increase approximately five percent annually between 2008 and 2025, fueled by long-term increases in worldwide gross domestic product (GDP) and by rapid market expansion. In the United States, the estimated growth in air cargo is commensurate with growth in GDP (FAA, 2008), while the fastest growth is expected in international air freight.

The Baltimore-Washington International Thurgood Marshall Airport (BWI) and other major air cargo airports serving this region (e.g. Washington Dulles International Airport, IAD) will be influenced by these global and national air freight growths. Between 2010 and 2020, BWI's total freight shipment will increase by nearly 15 percent to 132,000 metric tons, and by another 14 percent to a total of 150,000 metric tons in the following decade. By 2030, the share of domestic air cargo as a percent of total air cargo at BWI will increase and account for 97 percent of air cargo handled by BWI. In contrast, most of the growth between 2010 and 2030 at IAD will be attributed to increased international air cargo activities.

With the rapidly growing highway traffic and air freight demand, highway accessibility to and from BWI will deteriorate under the do-nothing scenario. The area accessible between 30 and 60 minutes from BWI is estimated to shrink (MWCOG, 2008). BWI is accessible to I-95 and I-70, which are the major highway corridors for the ground transportation of air cargo. Increased air cargo demand can further exacerbate the congestion problem on these highway corridors. Furthermore, the thriving air cargo market will also generate induced demand on truck-air and other air-related intermodal transfer services. All of these issues deserve attention and further analysis.

1.4.3.3 Waterway

In 2006, the Port of Baltimore handled 42 million tons of freight shipments, and was ranked 18th among all U.S. ports for total trade measured by total tonnage (MDOT, 2009b). Two thirds of the freight shipments were imports and exports. The Maryland Port Administration (MPA) has released its Strategic Plan (MPA, 2008), which defines specific goals for its long-range 2025 Vision (MPA, 2007) and methods for achieving these goals. According to the Strategic Plan, MPA will devote its effort to the expansion of the Port of Baltimore, and to the development of new cargo handling and supporting facilities. A land acquisition policy will be implemented, ensuring an adequate real estate portfolio that meets anticipated cargo needs in 2025. The accessibility of the Port of Baltimore and related intermodal facilities are also identified as important issues for the Port of Baltimore. With the expectation that new rail projects will allow double-stacked containers, there is also a plan in place to provide double-stacked rail car access to at least one MPA container terminal.

1.4.3.4 Intermodal Freight Facilities

Figure 20 shows the current locations of major intermodal freight facilities in Maryland. The rail-truck and truck-port-rail intermodal facilities are primarily located within the Baltimore region, while the air-truck facilities are mainly located around the BWI airport. It should be pointed out that intermodal freight facilities in other states (e.g. along the I-95 corridor) may also have a major impact on freight transportation in Maryland.

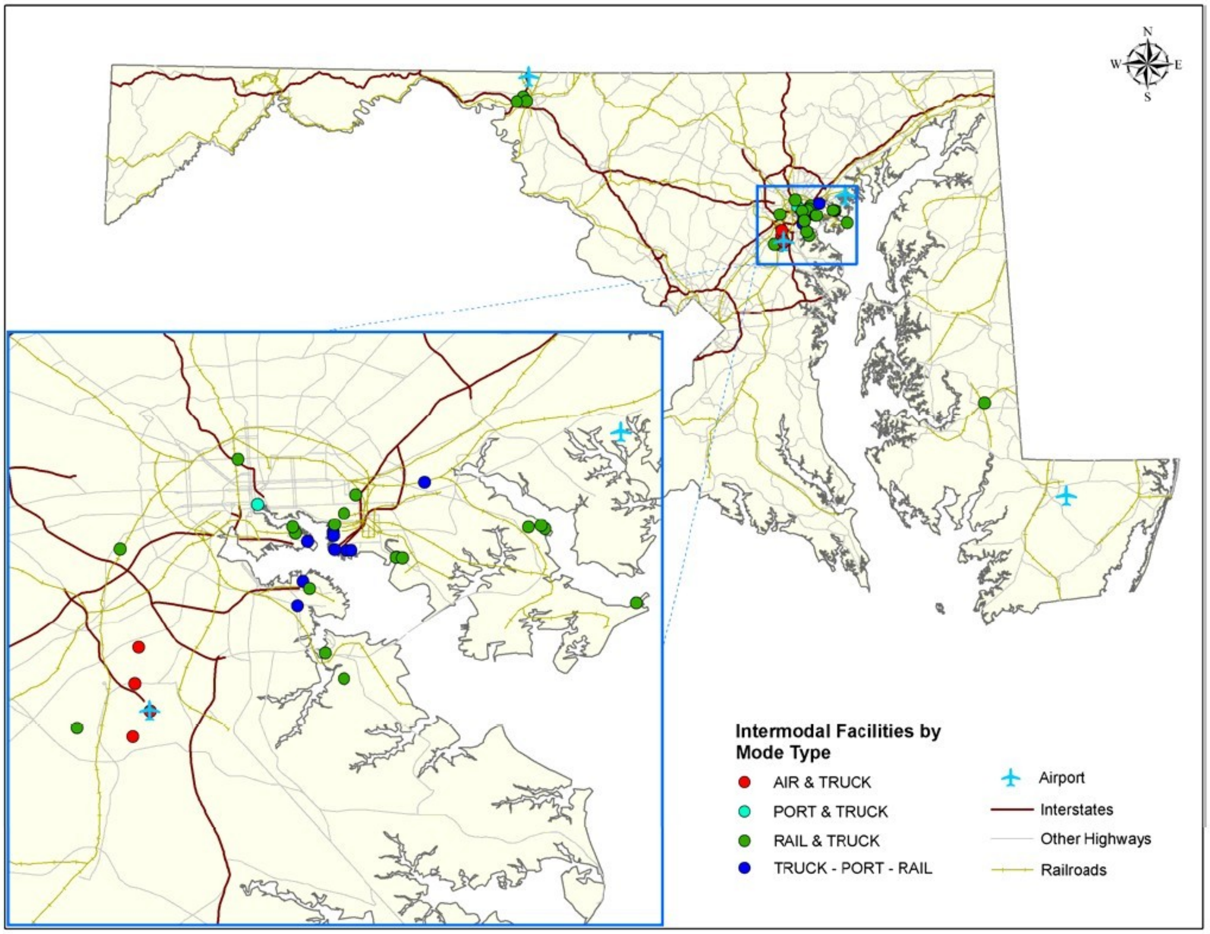


Figure 20. Intermodal Facilities by Mode
(Source: 2008 National Transportation Atlas Database)

The intermodal freight traffic has been playing a crucial role in goods movement in Maryland, and will become even more important with increasing freight transportation demands in all freight modes and increasing freight intermodalism. A study based on the TRANSEARCH data for the period of 2006 to 2035 indicates that the secondary traffic (including intermodal traffic) will "experience the highest tonnage growth of any commodity class in the State of Maryland, with volumes expected to grow by more than two and a half times than the current volume (267 percent) through 2035" (MDOT, 2009b). For instance, intermodal container shipment is the fastest-growing segment of international shipping because of its relatively low shipping cost.

1.4.4 Summary and the Role of MSTM

Freight is becoming an increasingly important issue for SHA. Not only does freight contribute to congestion but freight also contributes to the state's economic vitality by supporting the timely delivery of goods throughout the state. Planning for freight movement is critical both to future congestion relief and economic development. Comprehensive planning for surface freight movements would involve both highway (truck) and rail modes.

Highway congestion continues to have a major negative impact on the operations and reliability of freight delivery in Maryland, with increasing delays on the Interstate system (e.g. I-95, I-81, and the Beltways in Baltimore and Washington, DC). These major highways are already operating at capacity during rush hours and near capacity during many of the off-peak hours. With truck traffic growth estimated at more than 100% in the next 30 years (Source: Maryland Freight Transportation Plan) and similar increasing trends in passenger travel demand, highway congestion is expected to get worse.

The MSTM has greatly improved SHA's ability to model and analyze freight travel in Maryland. It includes a statewide truck module for analyzing in-state truck flows, and utilizes the FHWA Freight Analysis Framework for analyzing cross-border truck flows. With MSTM, future truck traffic flows on specific highway corridors can be estimated and studied under various policy and growth scenarios.

In the current version of the MSTM, freight modes other than trucking are not considered. In order to jointly analyze highway, rail and other freight movements, SHA needs to improve the MSTM with considerations for multiple freight modes. A statewide transportation model that considers multimodal freight transportation has many benefits. It can be used to identify highway-rail transfer points where freight can shift from one mode to another. It will also enable SHA to examine congestion relief options such as shifting freight movements from highway to rail, or from congested corridors to uncongested/less congested corridors. It can also consider the impact of truck-to-rail freight diversions on local traffic near intermodal transfer facilities and major ports.

An improved MSTM with a multimodal freight analysis capability will greatly enhance SHA's capability in freight analysis for multimodal inter-regional corridors. It will also help SHA to improve freight planning decision-making and to support economic growth in Maryland.

1.5 ECONOMIC GROWTH, LAND USE CHANGE, AND TRANSPORTATION INVESTMENT SCENARIO ANALYSIS

1.5.1 Background

In 1992, the Economic Growth, Resource Protection and Planning Act was proposed, which established eight visions for development of Maryland to guide the policy-making and to propose how future development should occur. These visions are centered on development in suitable areas, protection of sensitive areas, and the establishment of proper funding mechanisms. This Growth Act provided a foundation for a bigger and broader land use reform.

In 1997, the Maryland General Assembly adopted the Smart Growth and Neighborhood Conservation Initiative, aimed at mitigating the increasingly severe sprawl development in Maryland and concentrating urban development in certain preferred areas. The primary vehicle for this approach was embodied in the Smart Growth Areas Act, which states that all the "growth-related" funding should be allocated to locally-designated "Priority Funding Areas" (PFAs) that meet certain state criteria. The places, such as Baltimore City, the already heavily-developed areas inside the Baltimore and

Washington Beltways, and the neighborhoods designated by the Department of Housing and Community Development, have been designated as PFAs.

In 2006, the Office of Smart Growth was reestablished by Governor O'Malley. Facing the escalating pressure from population growth which may lead to another 580,000 households and 810,000 new jobs locating in the state by 2030 (MDP, 2009), the state increasingly confronts issues and decisions of statewide significance: traffic congestion in the Baltimore-Washington corridor, rapid development in southern Maryland and the Eastern Shore, economic revitalization in Western Maryland, etc. As a result, it is an appropriate time to re-embrace the concept of Smart Growth and promote sustainable growth in Maryland.

The Smart, Green, and Growing (SGG) legislation was signed in May 2009 by Governor O'Malley, who affirmed that "This legislation represents Maryland's position as a national leader in environmental initiatives, and a sustainable approach to development throughout our state."

Economic growth, population growth, land use policies, and transportation investment all have a profound impact on the transportation system in Maryland. Related policies and scenarios should be carefully analyzed to support decision-making at the state and local levels. These policy and scenario analysis needs are discussed in this section, and then the role of MSTM is identified.

1.5.2 Economic and Population Growth

Future travel demand in Maryland is influenced by demographic and economic growth patterns such as population growth, geographical distribution of households, income changes, and employment growth.

The state of Maryland has an average population density of 575 people per square mile (the average U.S. density is only 85 people per square mile). Based on the 2009 Maryland Transportation Plan (MDOT, 2009a), the state's population is estimated to increase from more than 5.6 million in 2007 to 6.7 million by 2030. Significant differences in population growth patterns exist between Maryland's urban and rural areas. Figure 21 shows the population growth trends by region. The two densest regions are the Baltimore Region and the Washington Suburban Region, with the density of 1,163 and 1,210 people per square mile, respectively. In 2005, the population from these two regions totaled nearly 4.6 million, accounting for almost 83 percent of the state total. By 2030, the population of these two regions is expected to grow to 5.3 million. Meanwhile, the population of the other four regions (i.e. Southern Maryland, Western Maryland, Upper Eastern Maryland, and Lower Eastern Maryland) is growing steadily as well. The demographical growth brings both opportunities and challenges to the state's passenger and freight transportation system. Like many other areas in the U.S., Maryland also expects an older and more diversified population structure in the future, which has many transportation implications (e.g. providing affordable transportation to all groups of population, accommodating different travel needs).

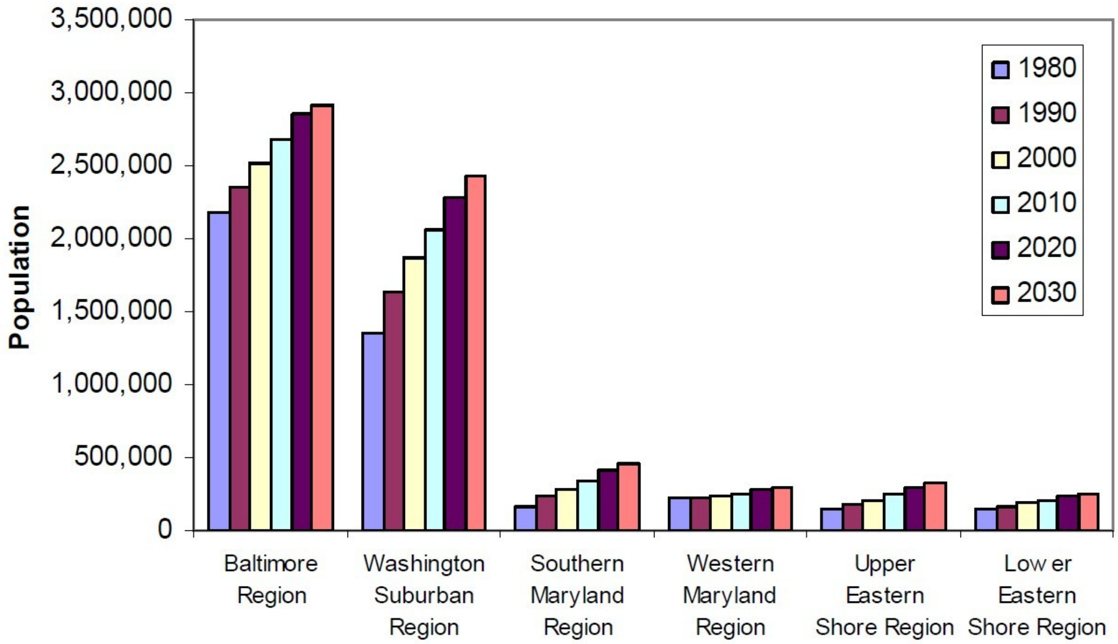


Figure 21. Population Trends by Region
(Source: Maryland Department of Planning, Planning Data Service, December 2008)

Per-capita income in Maryland, which reflects the relative economic well-being of the people in the state and is positively correlated to travel demand, currently ranks sixth in the nation at $46,460 (MDOT, 2009b) and is estimated to increase steadily in the next two decades, as shown in Figure 22. Income growth is expected to generate increased total and per-capita demand for goods and services. Again, the Baltimore and Washington Suburban Regions continually outpace the rest of the state in per capita income growth. The two regions ranked 26th and 6th respectively among all U.S. metropolitan areas in 2007 (Canan, 2008).

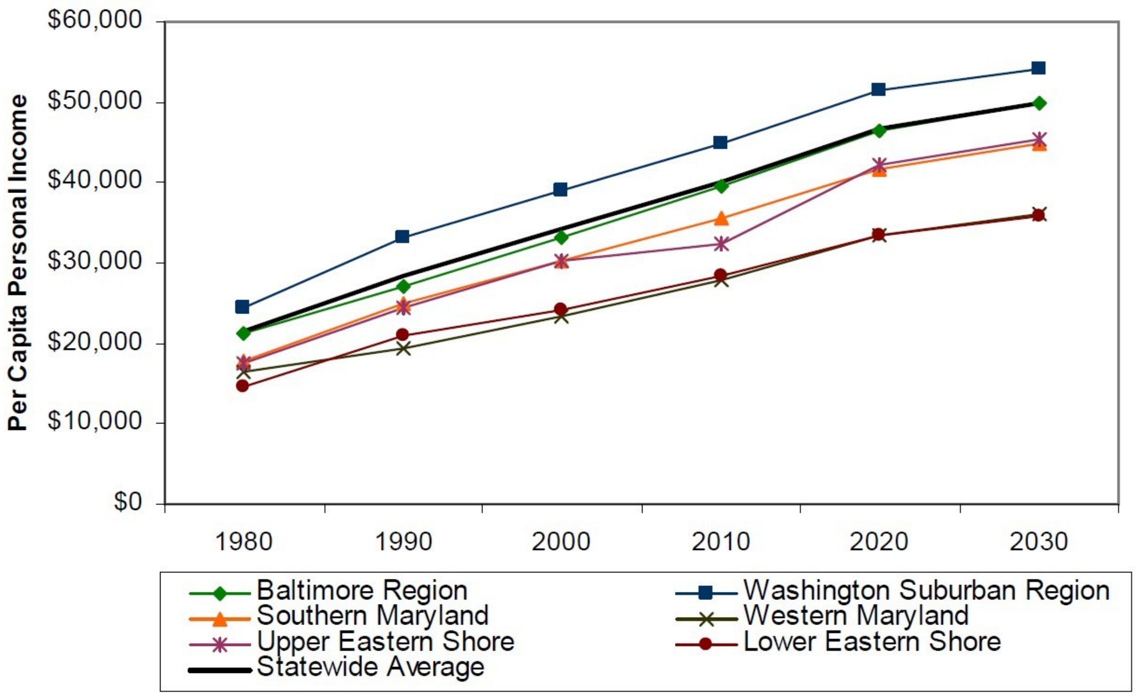


Figure 22. Maryland per Capita Income by Region (Constant 2000 Dollars)
(Source: Historical data, 1970-2005, from the U.S. Bureau of Economic Analysis, Projections by the Maryland Department of Planning, Planning Data Services, February 2009)

Employment growth is a good indicator of economic growth. The total employment in Maryland grew by nearly 19 percent between 1997 and 2007 to 3.4 million. The projected number of jobs will increase to more than 4 million by 2030, as predicted by the Maryland Department of Planning (2009). The Baltimore Region and the Washington Suburban Region account for the largest share of employment (Figure 23.). The Southern Maryland Region has also been enjoying fast job-growth rates in recent years. The imbalance between labor force and job growths in the state and in certain regions of the state (e.g. Baltimore and DC Suburban regions) could become an issue between 2000 and 2030 (MDP, 2008), which usually leads to longer commuting distances.

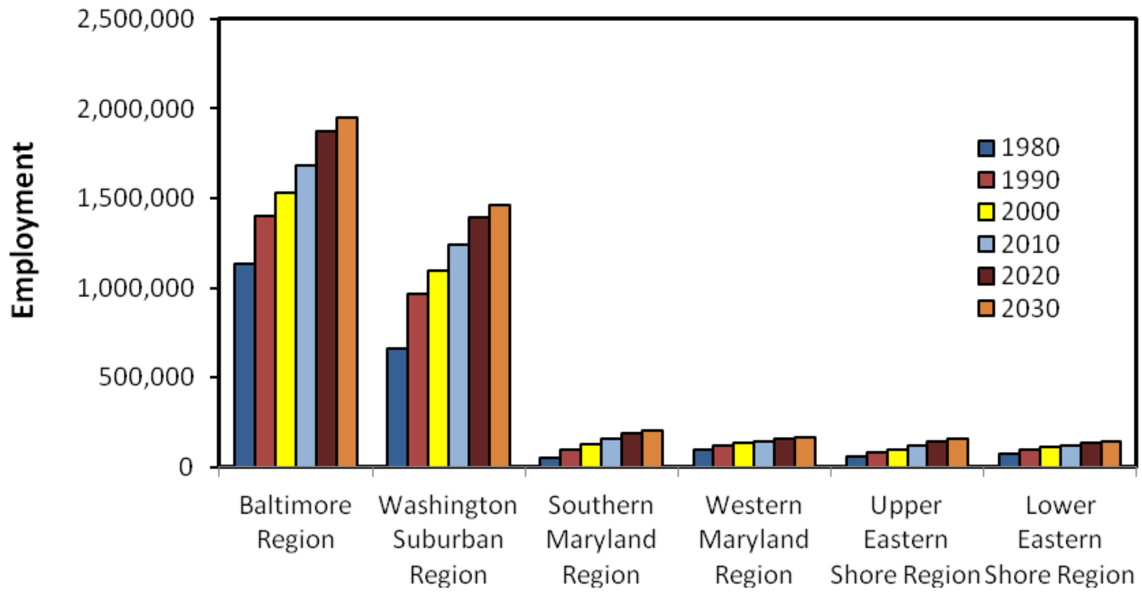
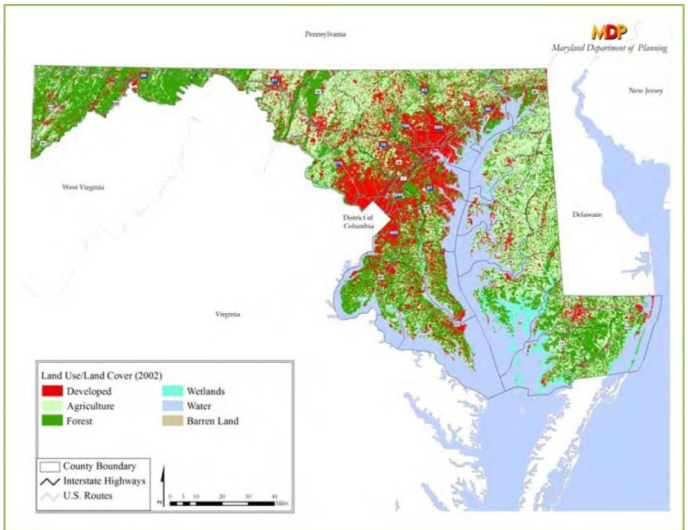


Figure 23. Employment Trend by Region
(Source: Maryland Department of Planning, Planning Data Service, October 2009)

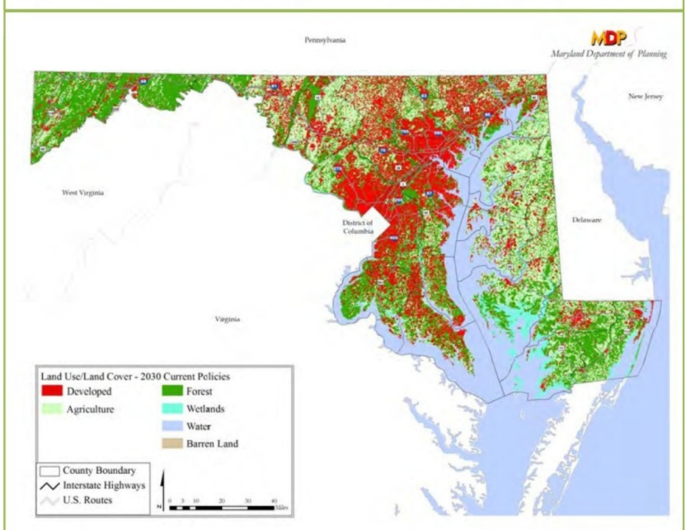
1.5.3 Land Use

Due to population growth and economic development over the past several decades, the amount of developed acres for residential, industrial or commercial use has doubled between 1973 and 2002, which represents a loss of more than 650,000 acres of agricultural and forest land in Maryland (MDP, 2008). The first picture in Figure 24 shows the land use pattern of developed areas in 2002. MDP projections indicate that in order to accommodate population and economic growth in the state, 650,000 additional acres of undeveloped land will be urbanized by 2030 without growth management, which is shown in the second picture of the Figure 24. The developed land cover (in red) will spread around the centers of the Baltimore and Washington DC metropolitan areas and to the Northern and Southern Maryland Regions.

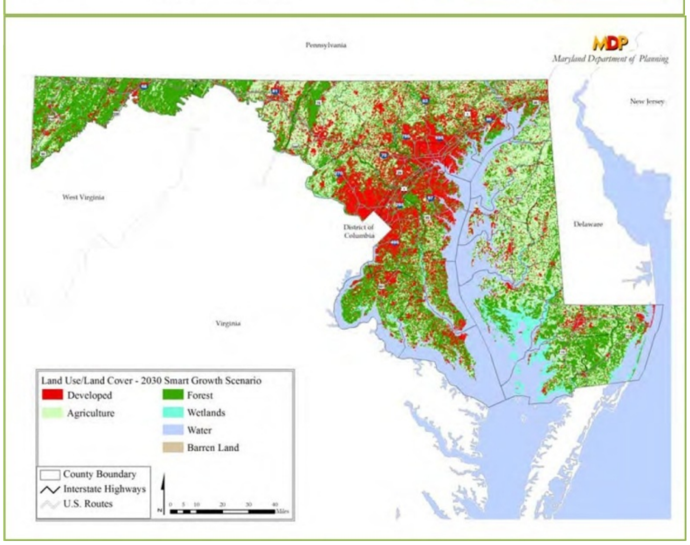
The Task Force on the Future for Growth and Development in Maryland has studied land use growth scenarios with MDP's Growth Simulation Model. In particular, the study has analyzed the possible effects of smart and sustainable growth scenarios. By assuming that most of the investments and 80% of population growth will be within the PFAs, the scenario study concludes that only 150,000 acres need to be developed, as displayed in the last graph of Figure 24. This smart growth scenario can preserve a considerable amount of land (500,000 acres). Under the Smart Growth land use policy, the state's development will be shaped in a more compact pattern. However, the Smart Growth and PFA policy is an incentive-based policy rather than a regulatory policy. The actual land use growth scenario is likely a compromise between the fully-realized smart growth scenario and the unlimited growth scenario. Other than the Smart Growth scenarios, several other land use scenarios are also of interest to decision-makers, and analyzed by the Maryland Scenario Project, which is led by the National Center for Smart Growth at the University of Maryland. That project assesses the statewide land use, transportation, and environmental implications of a broad range of economic variables and policy options.



2002 Land Use Pattern: 650,000 acres of lands have been occupied since 1973



2030 Unlimited Growth Scenario: 650,000 acres of lands would be occupied since 2002



2030 Smart Growth Scenario: 150,000 acres of lands would be occupied since 2002

Figure 24. Different Land Use Scenarios for Maryland
(Source: MDP, 2008)

1.5.4 Transit-Oriented Development (TOD)

Consistent with the goals of the Smart, Green, and Growing Initiatives, Maryland DOT promotes and facilitates transit-oriented development (TOD). The existing transit service is already extensive in Maryland and comprises over 75 rail, light rail and subway stations. Planned future transit investments will further enhance the transit system capacity and accessibility. Many more major transit facilities have been proposed and a number of Bus Rapid Transit lines are currently under study (e.g. along the I-270 corridor). TOD helps mitigate highway congestion and improves sustainability by effectively shifting passengers from private vehicles to public transit. With the TOD principles, neighborhoods around transit stations should become space where people can live, work, shop, and eat out all within a safe and sound walking distance to public transit. TOD has the potential to improve citizens' quality of life and their accessibility to jobs and activities. In the long run, TOD may stimulate community revitalization and lead to increased real estate values.

In the City of Baltimore, the TOD Task Force has been established since 2000. In 2004, TOD Pilot Projects in three chosen transit station areas were conducted to provide insights into constraints and possibilities of implementing the TOD planning approach in Baltimore. In 2005, TOD Development Guidelines were included in Baltimore City's Comprehensive Master Plan, "Live Earn Play Learn," to ensure a compact urban design and better pedestrian and transit-oriented transit facilities. The TOD concept is also examined in several ongoing transit-related studies, including the alignment of the new Red Line and the plans for future transit stations.

Compared to the traditional land development project, TOD has very different influences on vehicle ownership, trip generation, travel distance, mode choice, and other travel behavior. These differences create challenges for transportation planners and travel demand modeling tools.

1.5.5 Transportation Investment

Based on the Consolidated Transportation Program (CTP) 2009-2014, Maryland's six-year capital budget for transportation projects, a total of $8.4 billion dollars, will be invested to maintain and enhance the transportation system in Maryland (Department of Legislative Services, 2009). Figure 25 illustrates the MDOT proposed funding level for each transportation mode over the six-year period from 2009 to 2014. Funding for highways account for 48% of the total investment from MDOT, and represents the largest share. Transit funding, including those assigned to the Washington Metropolitan Area Transit Authority (WMATA) and MTA, accounts for 35% of the total budget.

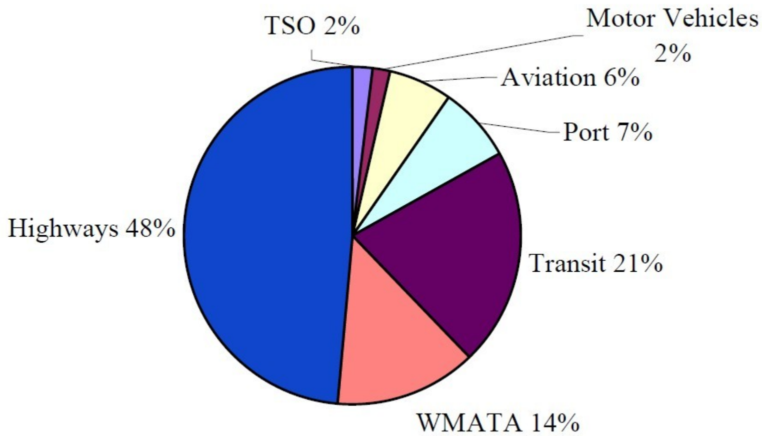


Figure 25. MDOT Proposed Capital Funding by Mode, 2009-2014 Consolidated Transportation Program (CTP)
(Source: Maryland Department of Transportation, January 2009 Consolidated Transportation Program)

In terms of the investment impact, from 1997 to 2006, the total investment from MDOT towards surface transportation (highway and transit) exceeded $20 billion (Cambridge Systematics, Inc. 2006), which was reported to generate a total of $44.9 billion in business output over the same period. An average of 32,703 jobs was supported each year, with a total of $16.1 billion in labor income flowing to Maryland employees. From the statewide economic model adopted in that study, each dollar of the transportation expenditure produced over $2.20 of return to the state's economy. Table 8 shows the detailed impacts of MDOT and SHA transportation investments.

Table 8. Summary of the Total Impacts from MDOT Program Outlay Over 10 Years (in Constant Year 2004 Dollars in Billions)

10-Year Total Impact	SHA	MTA	WMATA (Maryland Portion)	All Agencies
Direct Effect (Total Spending Budget)	$9.3	$5.9	$4.9	$20.1
Total Impact on Economic Output	$23.4	$11.7	$9.9	$44.9
Associated Impact on Jobs over 10 Years	170,068	81,672	75,288	327,028
(Average Jobs each Year)	(17,007)	(8,167)	(7,529)	(32,703)
Associated Impact on Labor Income	$7.8	$4.2	$4.1	$16.1

(Source: Cambridge Systematics, Inc., 2006)

Aside from developing PFAs' transportation infrastructures, MDOT will emphasize congestion mitigation. Various transportation investment policies are currently under study (MDOT, 2009a), including investments in technology and strategies that manage travel demand, system capacity enhancement, and system operational improvements. For instance, the Maryland Transportation Authority (MDTA) has invested a considerable amount of its budget in the construction of the I-95 Express Toll Lanes, the dedicated EZ-Pass lanes, and the Inter-County Connector (ICC). All of these projects are intended to improve travelers' travel time reliability and to manage congestion. The Coordinated Highways Action Response Team (CHART) operates a real-time traffic monitoring system that helps reduce highway congestion and that provides information to travelers. Multimodal transportation investments on the public transit system have also become an integral part of transportation improvement in Maryland.

1.5.6 Summary and the Role of MSTM

With expected economic and population growth, major land use policy initiatives, and competing transportation investment needs in Maryland, it is important for SHA to be able to conduct scenario analysis with tools such as the MSTM, and strategically allocate limited resources to support and accommodate these growths and changes in Maryland.

Statewide travel demand models have been widely employed by State Departments of Transportation and State Highway Agencies to:

(1) Analyze the transportation demand changes resulting from economic and population growth, and identify cost-effective transportation system improvements to support such growth;

(2) Assess the impact of land use policies and changes on the transportation system to either evaluate the effectiveness of these policies, or to ensure the impact on transportation system performance is considered in land development decision-making at the state and local levels; and

(3) Evaluate alternative transportation investment scenarios for optimal resource allocation and for funding/project prioritization.

The MSTM provides these analytical capabilities for SHA, and should be regularly applied for the aforementioned scenario analysis at the state or major-corridor levels. To analyze all transportation planning and policy issues with regard to economic/population growth, land use policies, and investment decision-making, SHA may consider the following improvements to the MSTM:

(1) Develop key parameters and modules that can enhance the MSTM's ability to consider smart growth policies, such as transit-oriented development;

(2) Develop key parameters and modules to better consider the transportation impact of future socio-demographic trends (e.g. aging); and

(3) Incorporate economy-land use-transportation feedback into the existing MSTM to better consider the economic impact of transportation system improvements, and land use-transportation integration.

1.6 SUMMARY AND IMPLICATIONS FOR SUBSEQUENT PROJECT TASKS

Many of the transportation planning and policy analysis needs identified and discussed in this Chapter are not unique to Maryland. More than twenty states have also developed statewide modeling tools, similar to the MSTM, to provide support to transportation decision-making at various levels. Issues such as performance-based decision-making, sustainable transportation, congestion management, freight analysis and planning, and system-level scenario analysis have also received a great deal of national attention. However, the planning and policy goals are usually different in different states, and the effective solutions to the seemingly similar transportation problems often depend on state-specific values, conditions, and resource availability. These differences impose different functional requirements on statewide transportation models.

The development of the MSTM is a great start towards SHA's goals of congestion mitigation, sustainable transportation, freight efficiency, and improved decision-making. The transportation planning and policy analysis needs documented in this report can be used to guide future improvements to the MSTM. An application-oriented and needs-driven approach for future MSTM enhancement can maximize the return on future SHA modeling investment.

The Task 1 findings herein served as a guide for the following project tasks:

Task 2 reviewed statewide transportation modeling practices in other states. The review covered data needs, model structures, and representative model applications. The focus was on the relative advantages and disadvantages of different statewide transportation modeling tools (e.g. advanced four-step, tour-based model, activity-based model) in addressing the transportation planning and policy needs in Maryland.

Task 3 identified available data sources in Maryland and adjacent states for future MSTM improvements. In particular, the research team assessed whether or not the available data sources provided sufficient information for SHA to enhance the MSTM and meet urgent planning and policy analysis needs.

Task 4 developed an improvement plan for the MSTM, which recommends the most cost-effective model enhancement options based on the transportation planning and policy analysis needs in Maryland.

Task 5 developed a prototype time-of-day choice (i.e. departure time choice, or peak spreading) model that may be further enhanced and integrated into the current version of MSTM. The needs for analyzing congestion management strategies at the corridor and statewide levels were considered as the research team specified and estimated this time-of-day choice model.

CHAPTER 2: REVIEW OF CURRENT STATEWIDE MODELING PRACTICES

2.1 INTRODUCTION

The Maryland State Highway Administration (SHA) recently invested in the development of the Maryland Statewide Transportation Model (MSTM), which provides a valuable tool for statewide transportation planning decision-making in Maryland. MSTM can help SHA meet a broad range of transportation planning and policy analysis needs (e.g. forecasting future levels of congestion, monitoring and forecasting system performance, analyzing inter-regional traffic flow patterns, evaluating tolling and pricing strategies, assessing highway corridor improvements, estimating green house gas emissions, analyzing freight transportation, among many others). Improved planning decisions and smarter transportation investment, resulting from applications of MSTM, lead to a more effective transportation system that supports continual economic development, enhances livability standards, and promotes sustainable growth in Maryland. A working version of MSTM has been developed based on the proven four-step method. The MSTM is currently being extensively tested and calibrated in a parallel project.

Different from traditional metropolitan transportation planning models that only focus on one specific urban area, statewide transportation models consider multimodal person and freight travel in all urban and rural areas within a state and any long-distance trips crossing state borders. More than 20 states in the US have developed operational statewide transportation models with varying degrees of sophistication, and 10 additional states are either in the process of developing or revising their statewide transportation models. Horowitz (2008) provides a graphical illustration of the status of statewide travel demand models in the U.S. (see Figure 26.).

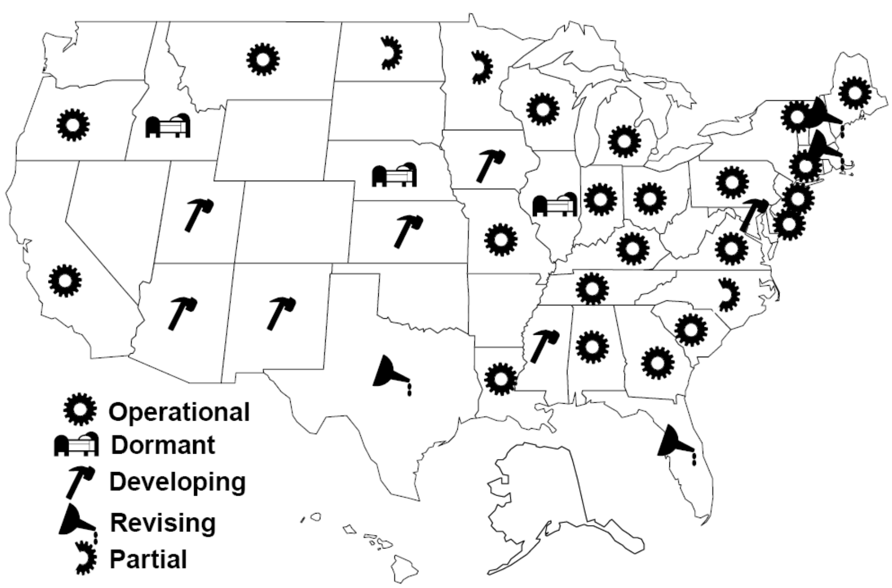


Figure 26. Status of Statewide Travel Demand Models
(Source: Horowitz 2008)

Most states, including Maryland, have adopted the four-step demand modeling approach for their statewide models (Souleyrette, *et al.* 1996, Giaimo and Schiffer 2005, Horowitz 2006, Cohen, *et al.* 2008, Horowitz 2008). Several states have started programs aimed at improving their statewide models from the basic four-step approach. A few statewide transportation models have incorporated advanced model features, such as advanced discrete choice methods, multimodal freight analysis modules, the tour-based microsimulation approach, and an activity-based model design.

Recent comprehensive reviews of statewide and metropolitan travel models can be found in:

- Guidebook on Statewide Travel Forecasting, Transportation Research Circular E-C011, 1999
- Statewide Travel Demand Modeling: Peer Exchange, Transportation Research Circular E-C075, September 2004
- Statewide Travel Forecasting Models, NCHRP Synthesis #358, 2006
- Forecasting Statewide Freight Toolkit, NCHRP Report #606, 2008
- Special Report 288 – Metropolitan Travel Forecasting, Current Practice and Future Direction, TRB Special Report #288, 2007.
- Statewide Travel Demand Forecasting White Paper. Requested by AASHTO and written by A.J. Horowitz, 2008.

The purpose of this chapter is not to conduct another comprehensive review of statewide travel modeling practices. Rather, this chapter supplements the aforementioned reviews in several ways based on the objectives of this SHA research project. First, the chapter focuses on three aspects of statewide travel models including methodology, data needs, and applications. Second, the discussion on statewide travel models in this chapter is organized into three sections (traditional four-step, advanced four-step, and activity-based/microsimulation) based on a modeling methodology. This will help the research team and SHA evaluate different options for improving the MSTM, which is currently based on the traditional four-step method. Third, while different from previous reviews that are comprehensive but offer little in-depth information on individual statewide models, this chapter describes selected representative statewide models in greater depth. Finally, this chapter includes various application examples of different statewide models that address issues similar to transportation planning and policy issues in Maryland.

After reviewing about twenty studies/projects in the U.S., the research team categorized statewide models into three groups: traditional four-step models, advanced four-step models, and activity-based/microsimulation models. Each of the following three sections (Sections 2.3, 2.4, and 2.5) discusses representative statewide models in these three groups respectively. Table 9 provides an overview of the statewide models that are selected for in-depth review in Task 2 of this SHA project. Section 2.6 summarizes statewide model validation. Section 2.7 summarizes various plans for improving statewide transportation models in other states. Section 2.8 summarizes the outreach activities in highlighted state DOT for their statewide model improvement. Finally, the implications of the review findings on developing an improvement plan for the Maryland Statewide Transportation Model are discussed in Section 2.9.

Table 9. An Overview of Selected Statewide Travel Demand Models

State (Model name)	Design period	Data sources	Modes considered	Purposes considered	Zone structure	Model description
California (HSR Interregional Model)	2006	The 2000-2001 Statewide Household Travel Survey, urban area travel surveys, onboard interview	Air, conventional rail, High-Speed Rail, and car	Business, commute, recreation, and other	4,667 zones, disaggregated from the previous Caltrans model's zone system.	Using complete discrete choice methods in all the sub-models. Using nested-logit models in the mode choice and access/egress mode choice sub-models. The model will be integrated with land use and economic model
Florida (FISHFM Freight Model)	Late 1990s to 2002	TRANSEARCH freight database	Truck, carload rail, intermodal rail, water, and air	14 commodity groups (agricultural products, minerals, coal, food, non-durable manufacturing, lumber, chemicals, paper, petroleum products, other durable manufacturing, clay/concrete/glass/stone, waste, miscellaneous freight, and warehousing)	Originally it has 508 internal zones and 32 external zones. It has been upgraded to 3974 zones by an on-going study	Commodity-based multimodal four-step freight model
Indiana	Mid 1990s, updated in 2004	Indiana statewide household travel survey	Auto, truck, and transit	Home-based work, home-based other, other business, non-home based, recreational	Previously 500 internal and 50-60 external, which was upgraded to 4,720 zones in 2004	Conventional four-step model.
Massachusetts	2000-2004	1995 National Personal Travel Survey (Massachusetts oversample), and ES-202 employment data	Multiple passenger modes	Business, private, and vacation	3,500 internal zones, 99 external stations, and 155 "park-n-ride" centroids	Conventional four-step model, with feedback loop between the first and the fourth steps.
Michigan	Mid 1990s	- Household-based travel surveys; - Border-crossing interviews; - Road traffic counts.	Auto only	Home-based work, home-based social recreation vacation, home-based other, non-home-based work, non-home-based other	2,307 internal TAZs and 85 external TAZs.	Conventional four-step model. Currently, MDOT is developing a more advanced tour-based model using a recently collected statewide survey data.
New Hampshire (NHSTMS)	1994-1995	- New Hampshire Activities and Travel Survey, transit on-board surveys, roadside intercept surveys	Non-auto, drive alone, carpool, auto access to transit, and truck	Work, school, shopping, recreation, chauffeuring, and other	About 500 zones, 1 zone per 5,000 population	Tour-based four-step model, with time-of-day sub-model.

State (Model name)	Design period	Data sources	Modes considered	Purposes considered	Zone structure	Model description
New Jersey	Late 1990s	Three MPO models and two additional urban models	Multiple passenger modes, Only truck mode in freight	Integrating purposes considered in those MPO models	2,762 internal zones and 51 external zones	Using model weaving technique to combine its three MPO models and two regional models.
Ohio	Since mid 1990s	Socioeconomic data (U.S. Census, County Business Patterns, ES-202, etc.), statewide household travel survey, long-distance travel survey, roadside interviews, traffic counts, land use/value data, etc. TRANSEARCH freight database.	Auto, air, walk to transit, drive to transit, multiple freight modes	Home, work (no work-based subtour), work (with work-based subtour), school, shop, recreation, and other. For long distance, the purposes include: household, work-related, and other.	Nested zone structure, with 700 activity model zones, 5,103 TAZs, and grid cells within each TAZ	Using activity-based approach, integrated with land use and economic modules. A simpler interim model is currently operational.
Oregon (TLUMIP Model)	Since 1996	Household activities and travel survey, Oregon travel behavior survey, recreation/tourism activity survey, longitudinal panel survey. For freight, commodity flow data, freight shipper and carrier survey data, and truck intercept survey data were collected.	Auto, transit, multiple freight modes,	Home-based work, work-related, recreation, home-based other, non-home-based other. For long distance, the purposes include: entire household, non-regular person work commute, and other. 42 commodity groups were clarified in the freight module of the second generation model.	125 zones in the 1st generation model, which was upgraded into a nested zone structure, with 2,950 alpha-zones and 519 more aggregated beta-zones.	Using activity-based approach, integrated with land use and economic modules. A simpler transitional model is currently operational.
Virginia		Census 2000, PUMS, 1995 American Travel Survey, 2000 Census Transportation Planning Package, 2001 National Household Travel Survey	Auto, rail, bus, and other	Home-based work, home-based other, and non-home based	Macro zone system (522 zones) and micro zone system (1,059 zones)	Conventional four-step model. Recently, VDOT has evaluated the feasibility of activity-based approach in Virginia, and decided to maintain the basic methodology.

2.2 THE CURRENT MSTM MODEL

Before getting into a more detailed methodological discussion and suggesting suitable improvement strategies, the current version (as of 2010) of the Maryland Statewide Transportation Model (MSTM) is summarized here. A more complete presentation of the MSTM can be found in the MSTM Users Guide, which is available from SHA upon request.

Geographically, the Statewide Model incorporates the entire states of Maryland and Delaware, District of Columbia, and portions of New Jersey, Pennsylvania, Virginia, and West Virginia. These areas comprise a total of 1607 zones. Zones outside Maryland are included in the model based on the work commutes going in and out of Maryland and are extracted from the 2000 Census Transportation Planning Package (CTPP). A Regional Model including the entire United States, Canada, and Mexico is divided into 189 zones, and includes information on long distance passenger travel.

Socioeconomic and demographic data from the 2000 Census survey and the 2003 Quarterly Census of Employment and Wages (ES-202) are used to create travel demand data. Data from the Census include population, occupation status, household incomes divided into quintiles, household sizes and the number of workers within those households, average household income, median household income, and the total number of workers.

The number of trips produced is estimated based on household information and trip generation patterns from recent household travel surveys conducted within the two MPOs (i.e. Washington D.C. and Baltimore). Long distance trips are micro-simulated based on the National Household Travel Survey in 2001. Several trip-purpose categories are considered in the MSTM and separately modeled: Home Based Work (HBW), Journey to Work (JTW), Journey at Work (JAW), School (SCH), Home Based Shop (HBS), and Home Based Other (HBO). Trip attractions are derived from regression analyses based on a household travel survey and socioeconomic data. For freight travel analysis, the statewide truck model is an adaptation of the Baltimore and Washington DC MPO truck and commercial vehicle models. The regional truck model generates long-distance truck trips based on given commodity flow data and the Freight Analysis Framework Version 2 (FAF2) developed by the Federal Highway Administration (FHWA).

The MSTM employs a sequential four-step demand modeling framework as illustrated in Figure 27.

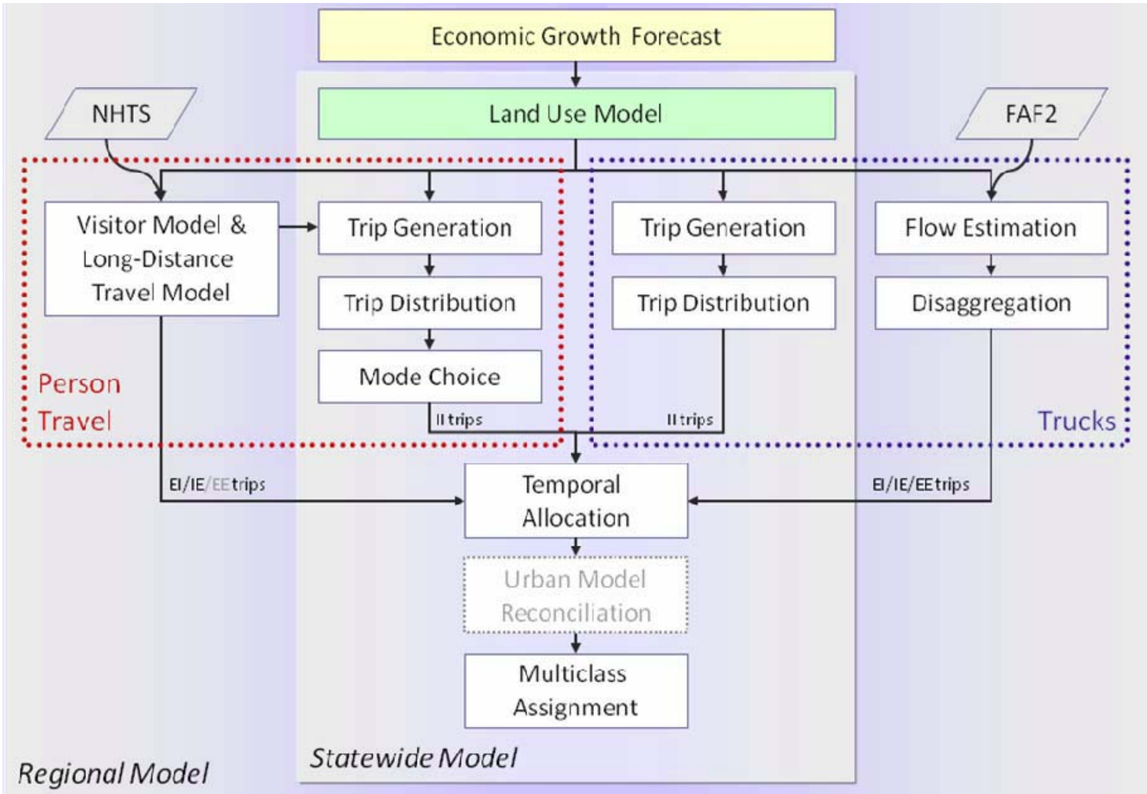


Figure 27. Flowchart of the Maryland Statewide Transportation Model

(Source: MSTM User Guide)

The first step of the MSTM's sequential modeling modules, i.e. the person trip generation, generally follows a similar approach as the Baltimore Metropolitan Council (BMC) model, in terms of methodology and trip purpose identification. Trip production rates by household category have been taken directly from the BMC model and adjusted to the statewide income quintiles. Trip attractions are calculated based on regression-type equations in the BMC model. Adjustments to BMC model coefficients have been made to yield statewide trip production and attraction results. ES202, CTPP, and other socioeconomic data are used to customize trip attraction rates with alternative measures of area type.

Gravity model techniques are used for trip distribution. Trips with home base are organized in order of income categories. An exponential form is used for the impedance function in the gravity model. The impedance function is based on generalized travel time that considers various travel disutilities (time, cost, etc.) and composite travel time that considers travel costs on multiple modes.

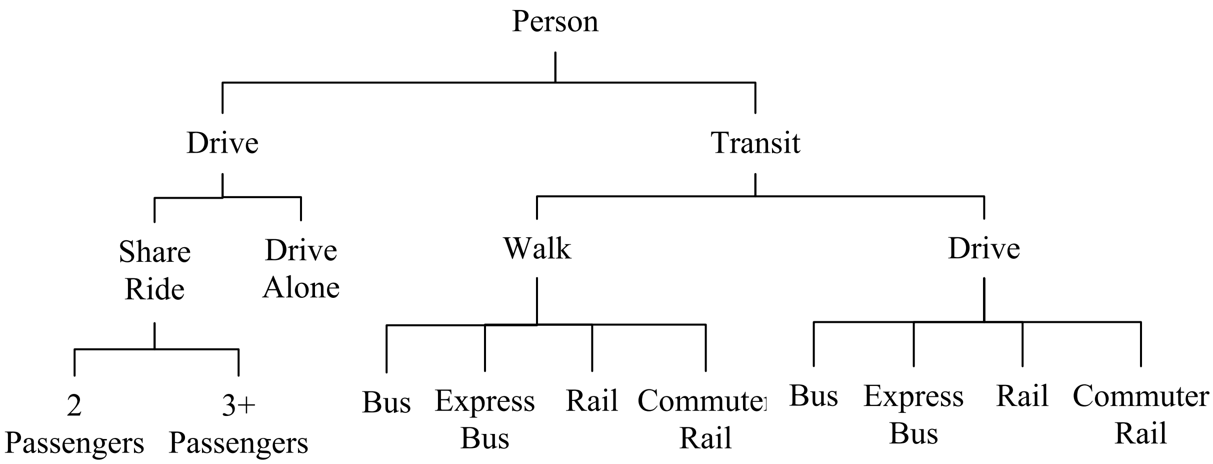


Figure 28. Structure of the MSTM Mode Choice Model

The mode choice step employs a nested logit model, as shown in Figure 28. In the driving nest, 2 passengers and 3+ passengers are specified separately in the ride sharing sub-nest. In the transit nest, transit riders with walking and driving access modes are considered separately. Transit options include regular bus, express bus, rail, and commuter rail.

Variables specified in the mode choice model include in-vehicle time, terminal time (time at the production and attraction zones), auto operating cost (the cost of driving per mile based on fuel prices and maintenance costs), auto toll cost, auto parking cost, transit walk time (the time to transfer by walking to or from a transit station), waiting time for mass transit to arrive or depart, transit fare, area type bias (suburban vs. central business district), and the drive-access time (the time it takes to drive to a transit or park-and-ride station).

The MSTM considers time-of-day with fixed trip percentage in each of the four time periods (AM peak, PM peak, mid-day and other off-peak) for each trip purpose. The temporal distributions of trips with different purposes were taken directly from the BMC model.

The aforementioned demand modeling steps deal with passenger trips with both ends in Maryland. Internal-external trips and external-internal trips are analyzed by the Person Long Distance Module (PeLoDiT) and the Visitor Travel Module (ViMo) respectively in MSTM. Each individual long-distance trip crossing the state boundary is micro-simulated with the trip origin-destination information derived from the 2001 National Household Travel Survey Long Distance Trip Sample. The flowchart in Figure 29 explains the procedure of the PeLoDiT simulation (ViMo has a similar structure.)

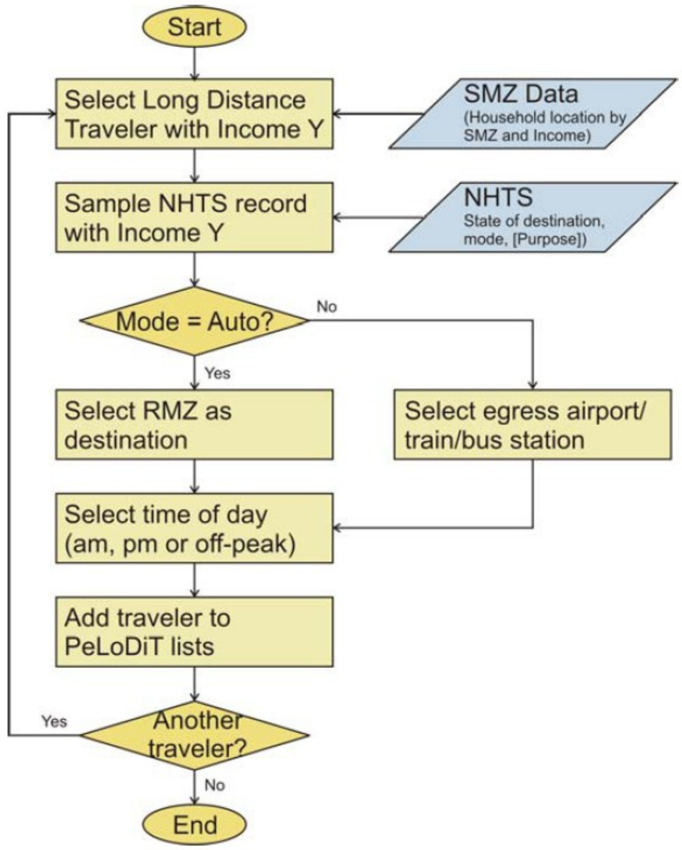


Figure 29. The Flowchart of the PeLoDiT Simulation
(Source: MSTM User Guide)

MSTM employs Multi-Class Assignment (MCA) to assign auto/truck and transit trips. This MCA is integrated in the CUBE Voyager package. In the first iteration, the shortest path is loaded with all trips between each OD pair (i.e. all-or-nothing assignment). During iterations, trips with the same OD are then averaged out between the current- and previous-iteration shortest paths until certain stopping criteria have been satisfied. During the assignment step, travelers are segmented into five different income groups and assigned onto the highway network system together with other four user classes (i.e. Commercial Vehicles, Regional Autos, Regional Trucks, and Medium/Heavy Statewide Trucks). The transit assignment adopts an "All-or-Nothing" approach, which assigns transit trips on the shortest paths between all OD pairs.

In its present form, MSTM can be employed for a number of transportation planning and policy applications. Model outputs can be utilized to supplement MPO travel analysis, conduct sub-area planning studies, forecast future-year auto/truck traffic volumes and transit ridership, and develop statewide and regional transportation plans.

2.3 TRADITIONAL FOUR-STEP MODELS

The traditional four-step demand modeling approach seen in many metropolitan travel demand models is also the most dominant methodology for statewide demand analysis. Most statewide models that have adopted the traditional four-step method have the following characteristics in their passenger and freight analysis modules. Their passenger travel models usually are constructed from existing metropolitan planning organization (MPO) models and national personal/household travel surveys (e.g. Massachusetts and Missouri). In some cases (e.g. New Jersey), the statewide model is entirely built from the MPO models (three MPO models in New Jersey). Methods for the freight analysis modules range from simple growth factor methods (e.g. Kentucky and Oklahoma, see CSI 2008), to non-commodity-based approaches using quick response techniques (e.g. Massachusetts and New Jersey, see FHWA 2007), and to commodity-based approaches based on national and commercial freight databases (e.g. Freight Analysis Framework, TRANSSEARCH).

2.3.1 Model Structure

A basic four-step model is defined by its four sequential stages: trip generation, trip distribution, modal split, and traffic assignment, as shown in Figure 30. The demand modeling process is aggregate and trip-based with limited analysis of individual travel behavior. Trip generation is usually analyzed with household-level cross-classification methods based on large-scale surveys that forecast trip production totals for all Traffic Analysis Zones (TAZ) by trip purpose. Zonal-level multiple regression models are often formulated to predict trip attractions. Trip distribution is estimated with gravity and multinomial logit models. For the modal split stage, the basic four-step models either adopt fixed modal shares from observed datasets or employ multinomial logit mode choice analysis. Traffic assignment is typically based on a single-class static user equilibrium assignment algorithm. Time-of-day choices and peak spreading are not considered in basic four step models. Instead, the 24-hour demand matrix is converted to several time-of-day matrices (e.g. AM peak, PM peak, mid-day, and other off-peak) based on observed demand shares in different time periods. Statewide models that fall into the category of traditional four step models include Indiana, Maryland, Massachusetts, Michigan, New Jersey, Tennessee, Virginia, Wisconsin, and others.

The New Jersey Statewide Model is an interesting case. Three MPO models in the State of New Jersey and two cross-border regional travel demand models have been directly combined into a cohesive statewide model. The three MPO models include the North Jersey Regional Transportation Model, Delaware Valley Regional Planning Commission Model, and the South Jersey Transportation Planning Organization Model. The cross-border models are the Port Authority of NY/NJ Interstate Network Model and the Delaware New Castle County Model. All of them are basic four-step models. If most of the areas/population in a state are within metropolitan planning boundaries (e.g. New Jersey, Maryland), this approach of developing statewide models based on existing MPO models can be quite effective and save model development cost and time.

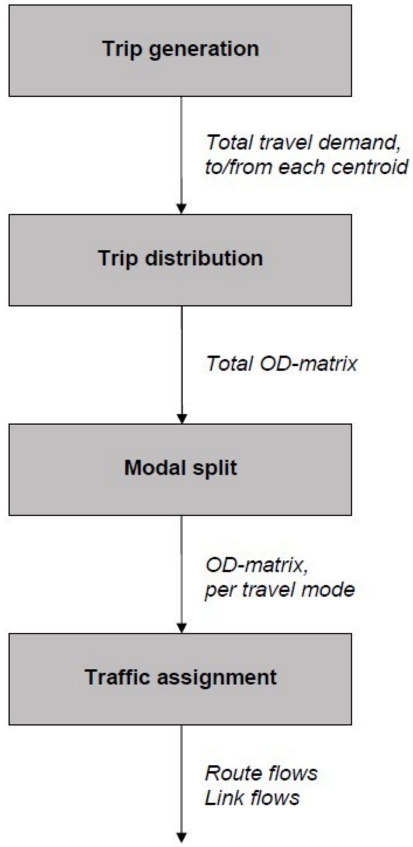


Figure 30. The Basic Four-Step Model Structure without Feedbacks

One challenge in developing statewide models from several existing MPO models is to ensure consistency among all component MPO models, especially along MPO model boundaries. In the development of the New Jersey Statewide Model, a technique known as "trip table weaving" has been used extensively to address this issue. For trips in each MPO model with at least one end in external zones (i.e. external-external, external-internal, internal-external) with their origin-destination tables at different time scales (daily, peak periods, and time-of-day) are "woven" between relevant MPO models. After trips crossing MPO model boundaries are distributed from one model to its connecting model, the total number of external trips is then balanced to ensure consistency. For freight trips, a gravity model representing inter-county commodity flows is used to construct truck trip tables.

In statewide models based on the traditional four-step methods, the freight modules usually employ relatively simple methodologies that rely on available freight demand data sources. For instance, Louisiana, Oklahoma, and Kentucky all employ the Origin-Destination Factoring Method wherein growth factors based on economic, employment, and other growth indicators are applied to existing freight OD data, such as the TRANSEARCH database. Other states with more closely spaced or contiguous urban areas such as New Jersey and Massachusetts (Cambridge Systematics, Inc. 2008) have employed four-step truck models without considering the modal split step (i.e. only truck freight trips are considered). All truck trips are usually classified into light, medium, and heavy truck trips, and then assigned to highway networks simultaneously with passenger trips.

2.3.2 Data

In general, the development of statewide models based on traditional four-step techniques does not require dedicated data collection efforts. Since it is usually very costly to collect comprehensive travel behavior data at the statewide level, national data sources are commonly used with oversampling at the state level (e.g. Massachusetts). The available national datasets include the decennial Census Transportation Planning Package (CTPP), the American Travel Survey (ATS) in 1995, the Nationwide Personal Transportation Survey (NPTS) in 1995, and the National Household Travel Survey (NHTS) in 2001. Indiana is an exception, which conducted its own household travel survey in 1995 and used this dedicated survey data together with the CTPP and the NHTS 2001 data.

Aside from the national level data sources, sub-state level datasets initially collected for regional and metropolitan demand modeling have also been used in statewide model development. For instance, the New Jersey model also relies on the sub-state Regional Travel Household Interview Survey (RT-HIS) and the Comprehensive Total Travel Survey (CTTS) conducted by the Metropolitan Transportation Authority (MTA) in 1989. The RT-HIS data, collected during 1997 and 1998, include 4,541 households with weekday travel information and an additional 275 households with weekend travel information in 14 counties in northern New Jersey. Traffic count data previously collected on various transportation facilities have been routinely used for statewide model calibration and validation. In the development of the trucking freight module for the Virginia statewide model, traffic counts classified by vehicle types were used to develop truck travel demand information with OD matrix estimation methods.

2.3.3 Applications

Statewide transportation models based on the traditional four-step method can be applied to a variety of important transportation planning and policy analyses at the state and sub-state levels, including future travel volume and level-of-service forecasting on multimodal transportation facilities, performance measurement and monitoring, corridor-level transportation planning, congestion management, freight analysis, scenario testing and analysis and environmental impact studies, etc.. Selected application examples are presented below.

Corridor planning has been one of the major application areas of statewide models, and in some cases, the motivation for statewide model development in the first place. For instance, the New Jersey model has been employed to analyze and improve the I-78 corridor (connecting Pennsylvania and New York) traffic conditions. The Virginia model has proven valuable in analyzing trucking commodity flows along the I-81 corridor. The Indiana model was initially developed for the I-69 corridor study as mandated by Congress.

A key motivation for the development of the New Jersey model was to analyze truck freight movement within the state. The New Jersey statewide model has also played a crucial role in the New Jersey Congestion Management System, by evaluating various transportation improvement strategies such as High Occupancy Vehicle lanes, congestion pricing, arterial signal systems, and other intelligent transportation systems (Davis, 1998). These congestion management scenarios are an important component of New Jersey DOT’s five years transportation improvement plan (DeJohn *et al.* 2007).

The Virginia model is capable of tracking interstate travel through the state on significant highway corridors such as I-81. In the I-81 trucking study, the statewide model has been applied to estimate heavy truck percentages at various Interstate highway locations, to differentiate local and through-truck traffic, and to identify truck travel patterns inside Virginia. It has also been applied to estimate automobile traffic in rural areas and to analyze intercity passenger rail.

In Indiana, outputs from the statewide model were used to develop a sub-state demand model for the I-69 corridor (BLA, 2006). The corridor model was subsequently used to analyze the environmental and economic impact of the highway corridor. Figure 31 illustrates how the corridor travel demand model was developed from the statewide trip tables. The transportation network along the I-69 corridor in the corridor demand model is also more detailed than that in the statewide model. Results from the corridor demand model were used for alternative analysis in the I-69 Evansville to Indianapolis Tier 2 Environmental Impact Statement (EIS) study.

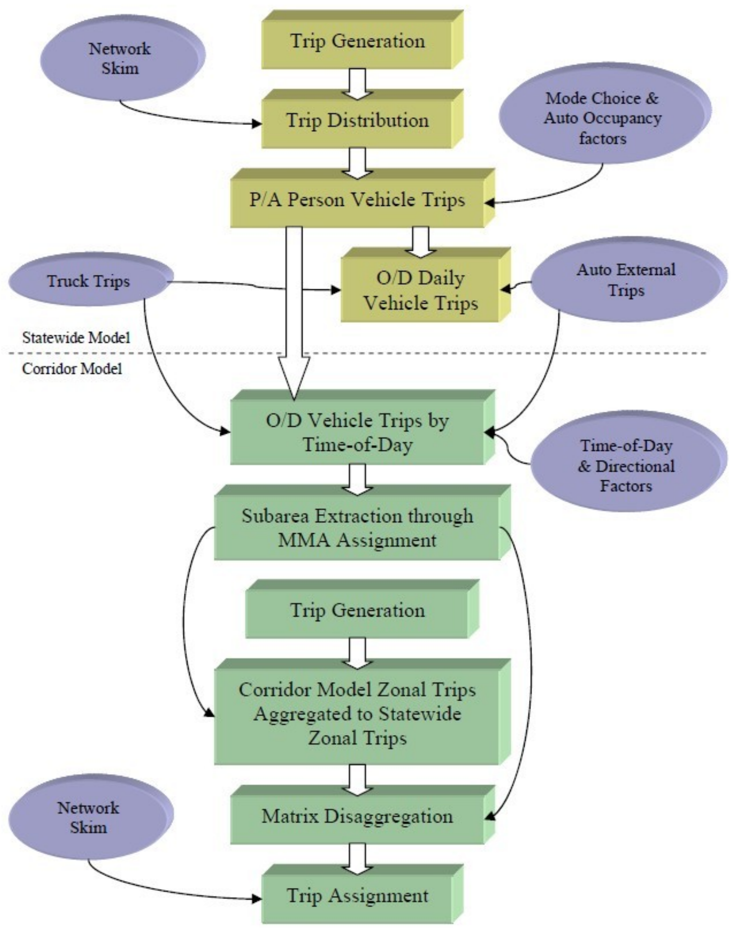


Figure 31. Developing Detailed Corridor Demand Model from the Indiana Statewide Model
(Source: BLA, 2006)

2.4 ADVANCED FOUR-STEP MODELS

Another group of statewide transportation models can be referred to as advanced four-step models. Compared to traditional four-step models, these models have incorporated advanced features that significantly improve the model capability and reliability for certain types of applications. But they still loosely follow the four-step modeling procedure, and do not represent a major shift in the behavioral modeling paradigm. Advanced four-step models discussed herein are usually developed independently from the MPO demand models in their respective States, except for Florida. The passenger demand module in the Florida model still uses data and components of previously-developed urban travel demand models.

2.4.1 Characteristics of Advanced Four-Step Models

The traditional four-step statewide model can be improved in several aspects. The aggregate trip generation and distribution steps could be improved with disaggregate individual choice models. Similarly, trip distribution and modal split can also be modeled jointly with discrete choice models such as nested logit. The trip-based structure in the traditional four-step models may be enhanced with tour-based methods that recognize trip chaining and choice interdependencies among individual trips in the same tour. Several states have also developed advanced statewide freight models that consider multiple modes of freight transportation (truck, rail, etc.) and multimodal commodity flow types. Other features in advanced four-step models include vehicle ownership modules, advanced traffic assignment (stochastic, multiclass, etc.), and time-of-day choices, which are not discussed in detail in this review because they are either considered in parallel SHA projects or will be considered in future tasks of this SHA project.

2.4.1.1 Advanced Discrete-Choice Models

Trip generation and distribution in traditional four-step models are considered at the aggregate traffic analysis zone (TAZ) level. Discrete choice models, especially advanced discrete choice models that allow flexible error-correlation structures among choice alternatives, can better represent choice alternatives available to individual travelers and decision factors important for them. In addition to applications at the modal split stage, discrete choice methods have been increasingly applied in advanced four-step models for the development of destination choice and trip frequency choice analysis (TRB, 2007).

An interesting example is the California Bay Area Interregional Model, which was developed for high-speed rail (HSR) analysis in California. It has adopted a model structure completely based on discrete choice methods for all modeling steps. The California model is comprised of four sub-models: trip frequency, destination choice, main mode choice, and access/egress mode choice, as illustrated in Figure 32.

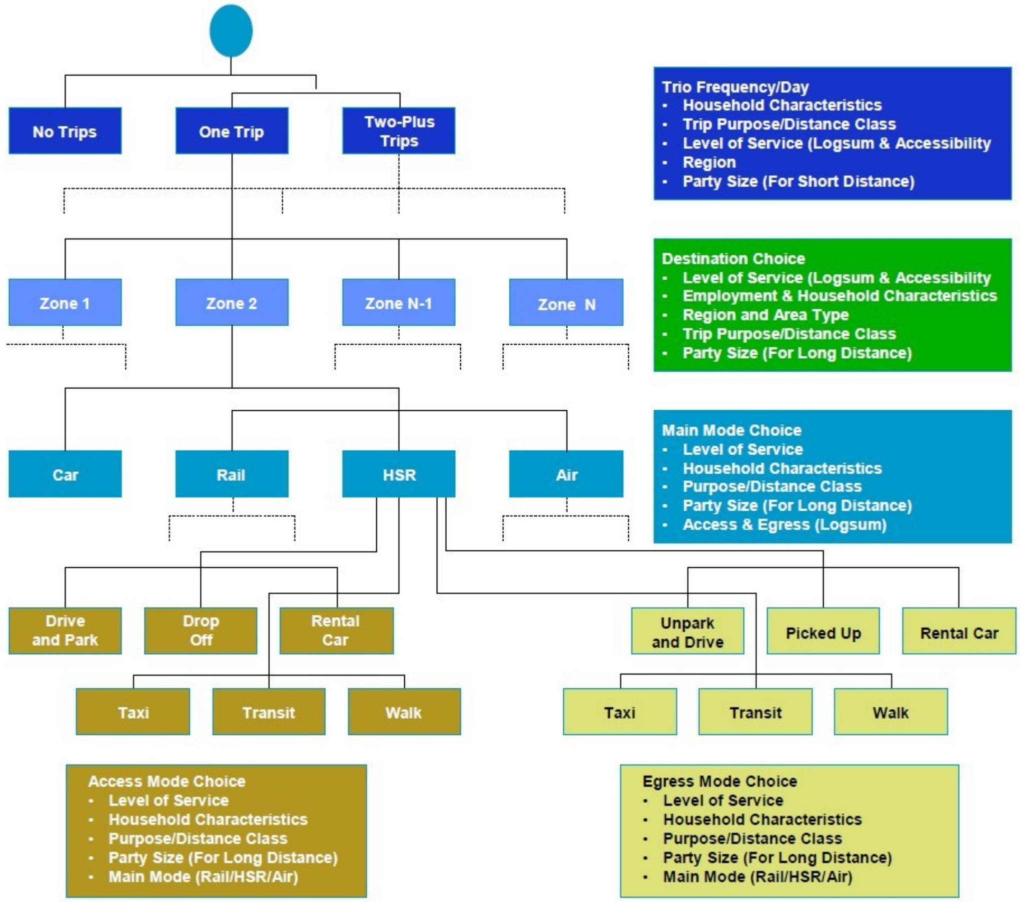


Figure 32. The Model Structure of California HSR Model
(Source: Cambridge Systematics, Inc. *et al.* 2007)

The trip frequency and destination choice modules employ multinomial logit models to estimate the number of trips by household and their destinations by four trip purposes: business, commute, recreation, and other. The main mode choice module is based on a nested logit model, which is shown to produce logical and statistically sound results. The mode choice set includes auto, air, conventional rail, and high-speed rail. The nested logit structure was also utilized in the access/egress mode choice modules wherein travelers select ground transportation modes for accessing and egressing air and rail transportation terminals.

2.4.1.2 Tour-Based Model

Compared to trip-based demand models, tour-based models recognize that multiple trips that form a complete tour (e.g. home to work to shopping and back to home) are interdependent due to scheduling, mode choice, travel companion and other constraints. The New Hampshire Statewide Travel Model System (NHSTMS) was one of the first statewide models that adopted tour-based components (e.g. tour-level generation, destination choice, and mode choice) within the four-step framework (Sharma *et al.* 2005).

The NHSTMS model flowchart is shown in Figure 33. Evidently, the tour-based model structure evolves from the four-step framework. The major difference is that OD trip tables are produced with tour-based analysis. Following a vehicle availability module, the tour generation stage predicts the number of tours for each household. Additional characteristics of the tours are then generated, such as the number and purposes of intermediate stops in each tour. The subsequent destination choice module is divided into two stages. The first stage uses a multinomial logit model to predict the primary destination for each tour. The second stage then determines destinations for secondary stops on the tour also with a discrete choice model. Similarly, the mode choice module also has a two-stage design. In Stage one, a tour-level binomial logit model determines whether or not the tour involves household vehicles. In Stage 2, trip-level multinomial logit models predict other modes used in the tour based on the trip-based stated-preference survey and transit onboard survey data.

The NHSTMS also incorporates a time-of-day module, which assumes a set of time-of-day factors for each trip purpose and converts daily trips to a.m. peak, midday, p.m. peak, and off-peak trips. This is similar to the traditional four-step model. But the NHSTMS's time-of-day component also supports trip time choice analysis and dynamic traffic assignment, modeling peak periods or peak hours to better simulate actual network conditions and associated travel delays. This capability is important for congestion management studies at the corridor or sub-network levels.

In 2005, the Michigan Department of Transportation decided to update its traditional four-step statewide model to a tour-based version with a three-phase model improvement program. (Faussett, 2005). The tour-based model structure at both urban and statewide levels was designed in the first phase, which also identified data needs. The second phase conducted a tour-based statewide household travel survey involving 14,300 households. They are currently in the third phase utilizing the survey data to develop and improve the statewide travel demand model.

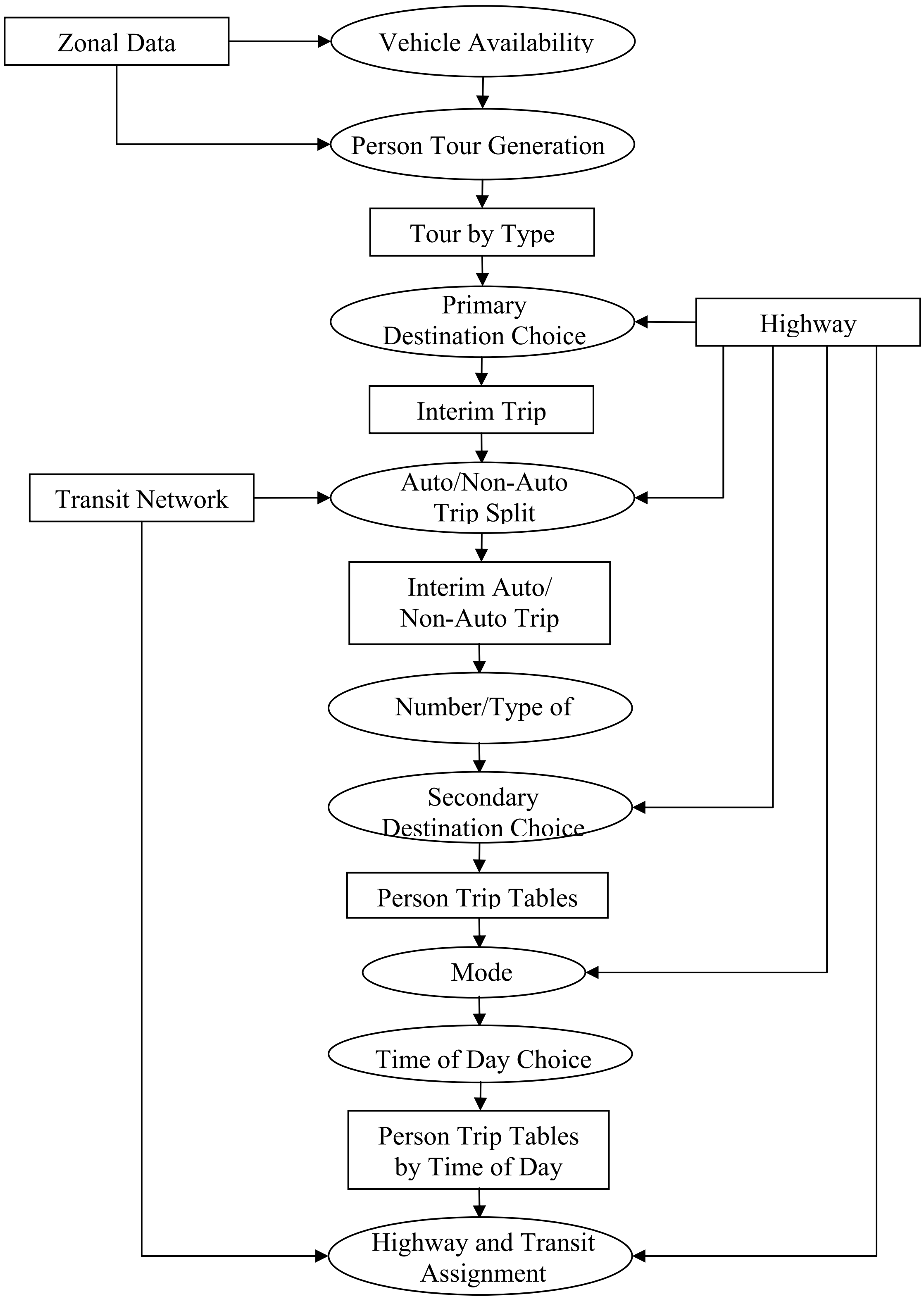


Figure 33. Flowchart of the New Hampshire NHSTMS Model

Source: (Cambridge Systematics 1998)

2.4.1.3 Commodity-based Multimodal Freight Analysis Model

Several states with multimodal freight planning needs have adopted more advanced freight analysis modules in their statewide models. Compared to the trucking-only method in traditional four-step models, these advanced freight analysis tools are more advanced for their capability in modeling multimodal freight mode choice by commodity type.

Resembling the four-step travel demand model for passenger travel, commodity-based freight models use commodity flow data and utility-maximization methods to determine freight mode share. Certain multimodal freight models simply apply existing mode shares (available from FAF, CFS, and TRANSEARCH databases) or adjust existing mode shares with market segmentation or other approaches (Cambridge Systematics, Inc. 2008). In more advanced cases, discrete mode choice models are developed to forecast freight mode share. These choice models are often based on incremental logit and similar pivot-point method that estimate future mode shares based on existing mode shares. The other three steps (trip generation, distribution, and assignment) in the multimodal freight models usually remain unchanged from trucking-only freight models. Several states have employed commodity-based freight modules in their statewide models, including Florida, Indiana, Vermont, and Wisconsin (Cambridge Systematics, Inc., 2005, Vermont DOT, 2001, Proussaloglou *et al.*, 2007).

The recent development of the Florida Intermodal Statewide Highway Freight Model (FISHFM) is a good example of improving a conventional four-step statewide model with an advanced freight analysis module. FISHFM has been integrated with the statewide four-step passenger travel model, the Florida Standard Urban Transportation Model Structure (FSUTMS). To support the implementation of the Florida DOT Statewide Intermodal Systems Plan, the main purpose of the FISHFM is to provide important freight travel forecasts and to help the Florida DOT serve the market of interregional freight and drayage movement to and from intermodal terminals (Washburn and Ko, 2007). The FISHFM is a multimodal commodity-based four-step model (Cambridge Systematics 2002), as shown in Figure 34.

All commodity flows in the FISHFM are segmented into a total of 14 commodity groups. A linear regression model and a standard gravity model are used for freight trip generation and distribution respectively. An incremental logit mode choice model forecast the modal share for each commodity type among five alternative freight modes including truck, carload rail, intermodal rail, water, and air. This incremental mode-choice model pivots the mode shares estimates from base mode shares in the most recent TRANSEARCH database. A highway assignment step is also included for assigning daily truck trip tables. Although the FISHFM-FSUTMS statewide model considers multimodal freight travel demand, it only assigns truck traffic on the highway network. This is common in most statewide transportation models because the network information for other freight modes is often lacking. No state has reported statewide models that are able to handle intermodal freight at the network level (Cambridge Systematics 2008).

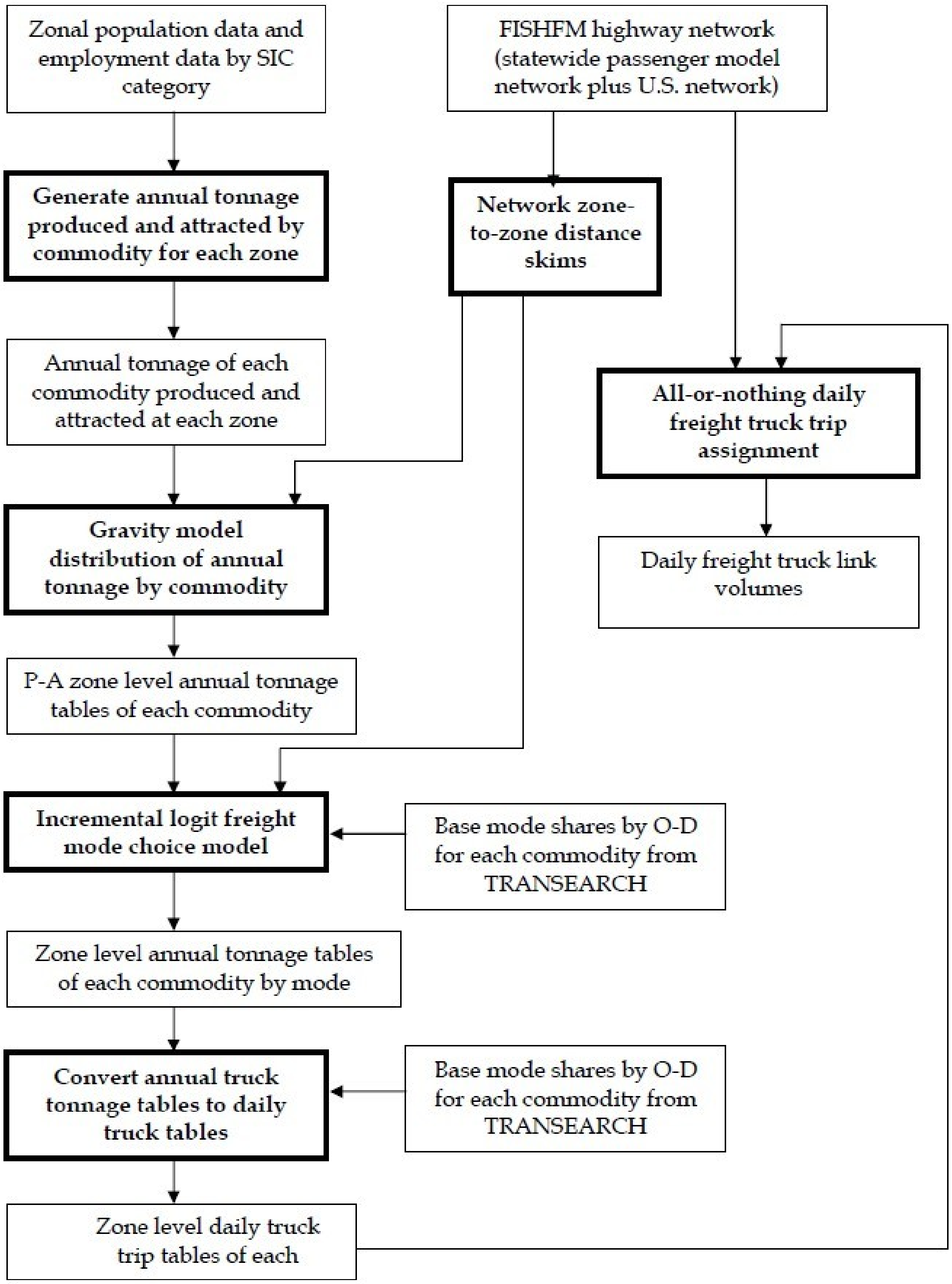


Figure 34. The Modeling Structure of Florida Intermodal Statewide Highway Freight Model
(Source: Cambridge Systematics, Inc., 2002)

2.4.2 Data

As expected, advanced four-step models demand more data than traditional four-step models. However, datasets that support the development of traditional four-step models may also be used for the development of advanced four-step models. Depending on the design and purpose of the advanced four-step models, it may be necessary to obtain additional supplemental data in some cases.

In the case of the California HSR model, the primary data source is the activity-based California Statewide Travel Survey, conducted in 2000-2001 for weekday travel (Caltrans, 2003) and a total of 17,040 households. To supplement the statewide travel survey data, three urban-area household travel surveys are also used, which cover Southern California, the San Francisco Bay Area, and the Sacramento Area respectively. In addition, a set of passenger intercept surveys with both revealed preference (RP) and stated preference (SP) components were conducted. The RP survey focused on the status of the latest modes for intercity travel used by survey respondents. The SP survey obtained the respondents' preference for the non-existing HSR mode. Air and some rail passenger surveys were conducted either at the airport/station or on board. The rest of the rail passenger surveys and auto passenger surveys were conducted through telephone interviews. The socioeconomic data in the statewide HSR model were obtained by combining data from urban models, previous versions of the Caltrans statewide models, and the U.S. Census Bureau.

For the development of tour-based models, household activity-travel surveys that collect both activity and travel information are often required. The NHSTMS was developed from the New Hampshire Activities and Travel Survey, conducted between August 1994 and June 1995. The survey covered a total of 2,844 households in New Hampshire, providing information on the activities and travel undertaken by all household members in a one-day period. A combined method of telephone interview and mail-in-mail-out travel diary was used to collect the activity and travel information. A series of transit on-board surveys and a cross-border vehicle intercept survey were also conducted to supplement the household survey and provide information on transit trips and external trips. In addition, for NHSTMS model applications, a stated-preference (SP) survey was conducted to test the potential statewide impact of upcoming transportation system and policy changes.

For multimodal commodity-based freight models, commodity-flow data by freight mode and commodity type are necessary. In general, a commodity flow survey (CFS), either from public-sector (e.g. Census Bureau's CFS) or commercially available private-sector sources (e.g. the TRANSEARCH data from Global Insight) can meet these data needs. Compared to free public-sector data, the commercial data usually have more detailed spatial zone structures (e.g. county-level) for freight analysis. The Oak Ridge National Laboratory completed the freight data integration work for Florida (Xiong, *et al.*, 2007). Florida purchased the TRANSEARCH database as the primary FISHFM data source that represents existing freight flow patterns at county-to-county level. In addition, socioeconomic data including population and employment information has been also employed as input to the trip generation step. The data sources include Regional Economic Information System (employment by Standard Industrial Classification, or SIC), Florida Population Studies, and County Business Patterns, etc.

As part of the FISHFM model development process, information regarding the location and activities (i.e. ton shipments from/to for both the base year and forecast year) of intermodal freight terminals was also gathered from the National Transportation Atlas Databases for the U.S. and Florida (Xiong *et al.*, 2007) and from intermodal terminal inventories managed by the various modal administrations in

Florida. In terms of freight model validation data, truck counts from the Florida AADT Report Series and Truck Weight Study Data for the U.S. were used to validate the estimated truck volumes.

2.4.3 Application Examples

One of the major applications of the California Statewide Model was to support the evaluation of proposed high-speed rail systems connecting major metropolitan areas between Southern and Northern California. The model has been used to evaluate HSR ridership and revenue for different planning years and under various scenarios including alternative alignments, service frequencies, station locations, operational plans, fare policies, and operating costs.

The NHSTMS was developed to address various transportation planning and policy needs (Giaimo and Schiffer 2005 and Cambridge Systematics 1998). Model applications include a highway project impact analysis, an air quality analysis, and studies of policy alternatives such as increasing tolls and transit fares. As stated in the New Hampshire DOT's final report on the statewide model, the NHSTMS would serve as an important tool that integrates congestion management, public transportation, and intermodal management system analysis. However, the lack of financial resources and well-trained staff has limited the applications of the NHSTMS. Consequently, the NHSTMS has been primarily used for corridor-level transportation studies, and its capabilities in other types of statewide and sub-state analysis have not been fully utilized. For instance, the model was used to estimate transit ridership and high occupancy vehicle (HOV) lane usage for the I-93 corridor. Another application was the impact analysis of adding additional transit services along the State Route 16 corridor, as part of the Corridor Preservation Program at New Hampshire DOT. More recently, the model was used for policy analysis in a tolling and capacity study along the I-93 corridor.

The integrated statewide passenger and freight model in Florida was applied in various statewide long-run and mid-run transportation planning studies and corridor analyses. Its commodity-based multimodal freight module provided inputs for Freight Movements Analysis and Freight Mode Shift Impact Analysis. One of the most important applications of the Florida statewide model is in the implementation of the Florida Strategic Intermodal System (SIS) Plan, which is a plan for a statewide multimodal transportation system consisting of high-priority transportation facilities including rail corridors, highways, waterways, and intermodal terminals (FDOT, 2010). This system plan aims at enhancing Florida's economic competitiveness by addressing various transportation and economy-related issues, such as meeting the growing freight travel demand, linking the economic regions, making planning and investment decisions, and balancing future growth and managing congestion with environmental stewardship. The statewide model has enabled an effective evaluation process for the SIS and each of its modal components (Hancock, 2008).

2.5 INTEGRATED TRANSPORTATION-LAND USE-ECONOMIC MICROSIMULATION MODELS

The most advanced statewide models depart from four-step models with integrated land use-economic-transport analysis and tour-based/activity-based microsimulation. They have been referred to as the "O-Models" by Giaimo *et al.* (2005) where "O" stands for omnipotence and also for Oregon and Ohio, the two states that have developed the most innovative statewide models of land use allocation, economic redistribution, and travel. These models attempt to account for all aspects of travel demand at a behavioral level using tour-based or activity-based microsimulation (Giaimo *et al.* 2005, Horowitz 2008). They are also characterized by the use of large amounts of purposely collected data, long development time, and high cost.

2.5.1 Model Structure

In terms of the model structure, the Ohio and Oregon models have many similarities since they were developed by the same group of developers. These two states have fully adopted the philosophy that travel is a consequence of diverse human and economic activities and therefore should be modeled from activity-based microsimulation. They have both integrated land use and economic components with their travel demand models. The details of these two statewide models are documented below.

2.5.1.1 Ohio

The Ohio model was designed as a combination of various economic, demographic, land use, and transportation components, with close interactions among them. The integrated model structure is shown in Figure 35. The prerequisites for the travel demand models are the land development and economic activity allocation models, which are built on the Production Exchange and Consumption Allocation System (PECAS), a land use model developed by Hunt *et al.* (2003). The PECAS model employs supply/demand equilibrium analysis throughout Ohio to locate economic activities and labor forces, which is based on a nested logit approach.

In the Ohio statewide travel demand model, the four-step approach has been replaced by a microsimulation of household activity-travel decisions. The household travel microsimulation has two main steps: household synthesis and personal travel tours. The disaggregate household synthesizer model uses a Monte Carlo simulation to create a list of synthesized households with various combinations of household characteristics by TAZ. The personal travel tour model consists of four components dealing with short-distance home-based, long-distance home-based, commercial work-based, and visitor tours separately (Costinett and Stryker, 2007). Figure 36 shows the flow chart of the short-distance home-based travel component, and the other three components have similar modeling frameworks. Microsimulation techniques are used in each of the component to determine household activity patterns, a list of tours made by the household, and the intermediate trips/stops within each tour. Destination, mode, scheduling (time and duration) choices are also modeled explicitly at the individual level with choice probabilities estimated by advanced logit models (Erhardt *et al.*, 2007). Finally, a stochastic user-optimal equilibrium is adopted for traffic assignment, which provides feedback loops of times and costs and personal travel tour models and activity allocation models. For post-processing and model applications, air pollution emissions and accident impact models have been established, as well as a traffic microsimulation model for small portions of the statewide network (e.g. for sub-area congestion management analysis).

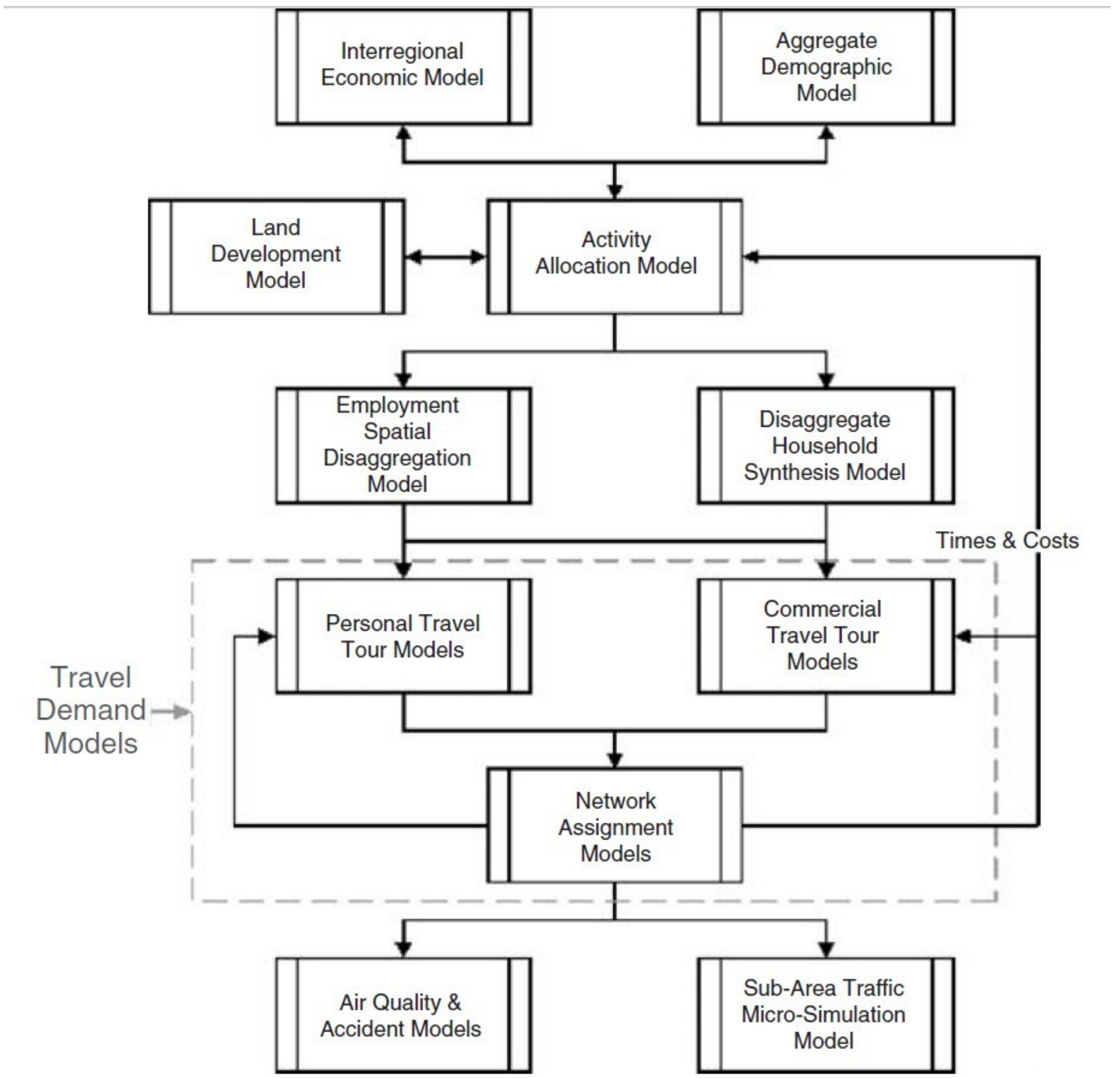


Figure 35. The Ohio Statewide Travel Forecasting Model
(Source: Horowitz, 2006)

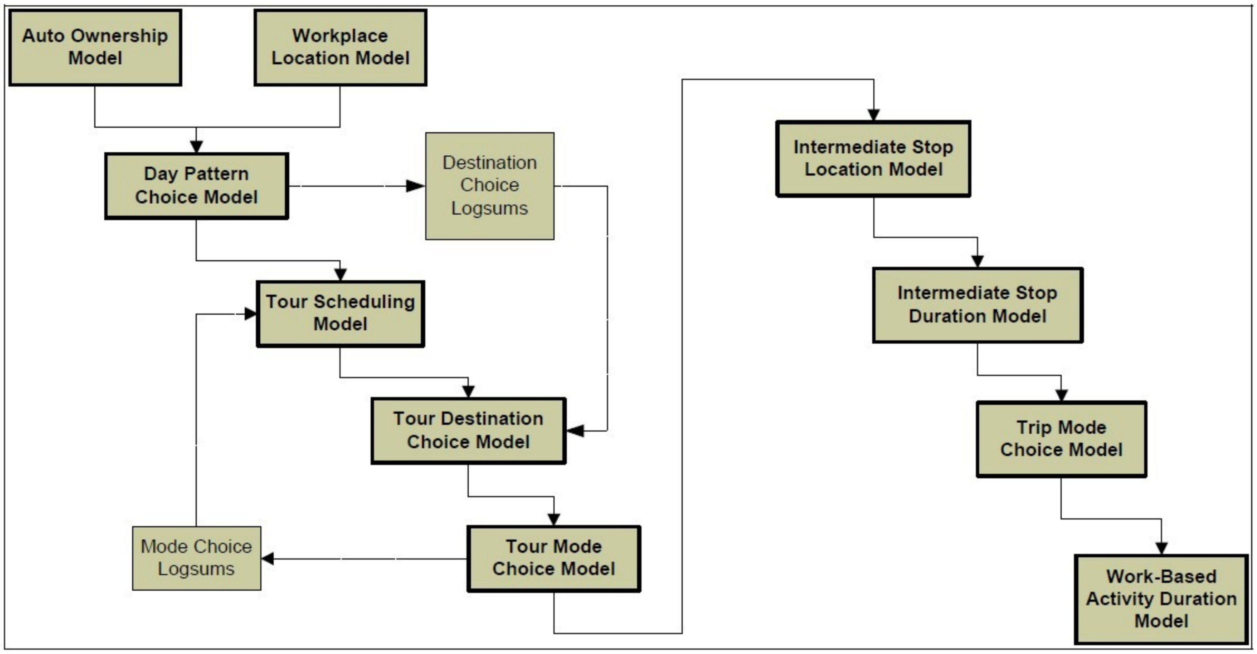


Figure 36. Flowchart of the Short-Distance Home-Based Travel Model
(Source: Picado, *et al*., 2007)

2.5.1.2 Oregon

The Oregon DOT embarked on its statewide modeling process in 1996 with the Transportation and Land Use Model Integration Project (TLUMIP) simulating economic, land use, and travel behavior. Currently, the Oregon statewide model is in a transitional phase from the first-generation model to the second-generation Oregon2 model.

The travel demand component of the Oregon2 model is an activity-based microsimulation model with one-year time increments, forecasting both passenger and freight movements. The Oregon2 modules include regional economics and demographics (ED), production allocations and interactions (PI), household allocations (HA), land development (LD), commercial transport (CT), person travel (PT), and transport supply (TS), as shown in Figure 37. The outputs from the seven modules provide the inputs to the data store of the Oregon2 model, which are then used for the next model iteration.

Figure 38 presents the model flowchart of the Oregon2 model, as well as that of a transitional model. The Oregon2 Transitional Model is the current operational statewide model in Oregon, which was built on the successful application of the first-generation model. It is not as ambitious as the full Oregon2 model, and adopts disaggregate microsimulation techniques only in the Personal Travel module and partially in the Commercial Transport module. Land development and population characteristics are modeled aggregately in the Transitional Model. The modular design of the Oregon2 model allows advanced components in the Transitional Model to be used in the full Oregon2 model.

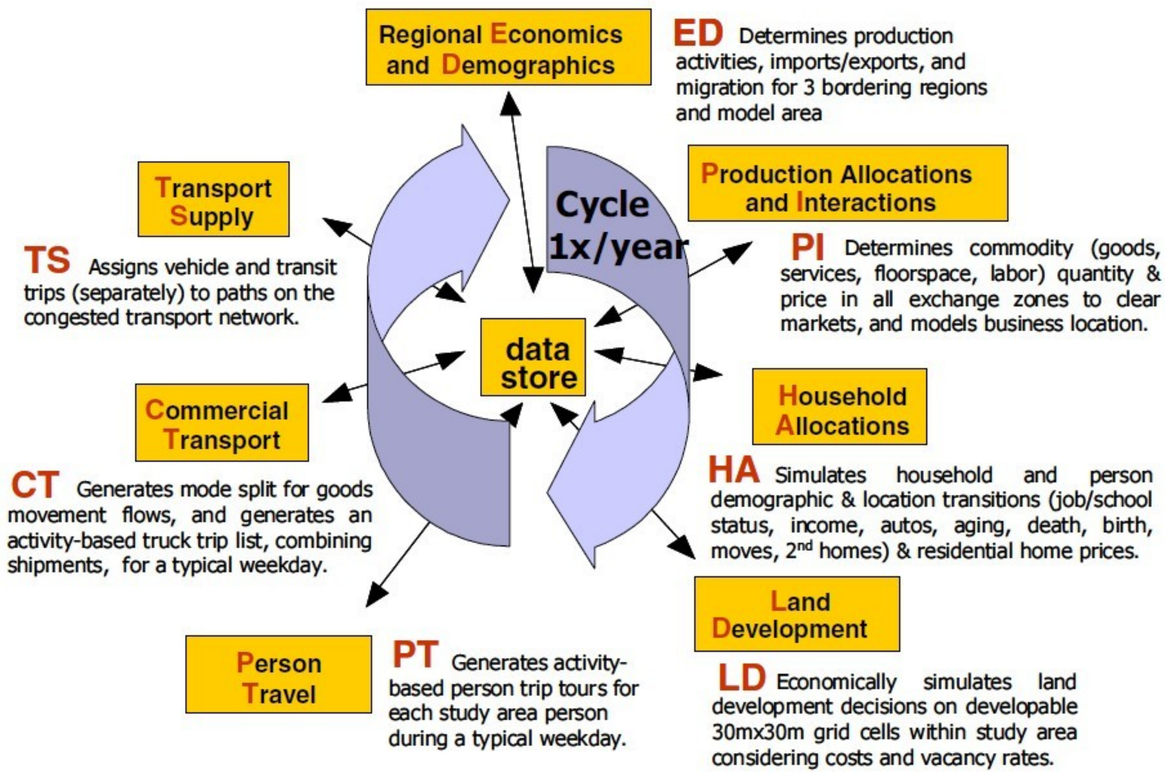


Figure 37. Modules in the Oregon2 Statewide Model
(Source: Hunt *et al*. 2004)

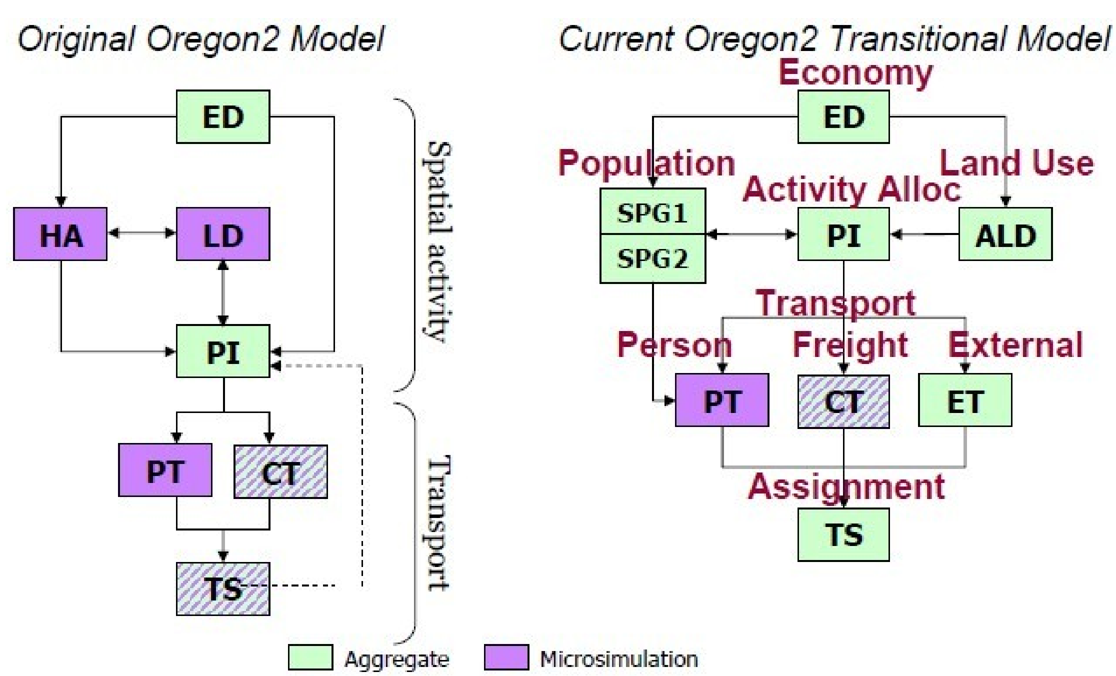


Figure 38. Difference between the Oregon2 Model and the Transitional Model

The Transitional Model treats travel demand and land use as consequences of economic activities. The seven modules can be categorized into two stages. In Figure 39, the top half of the model simulates the spatial activities, which starts with the ED module adopting an econometric model with simultaneous linear equations to estimate the total economic activities in the state and across state borders. All economic activities are then allocated to spatial analysis zones with land use development allocated in the ALD module and industrial activities allocated in the PI module. These spatial allocation modules are based on a spatial input-output analysis. The SPG module synthesizes a population that is consistent with the employment totals. Households and jobs are allocated to spatial zones, which is consistent with the PI labor flow results.

The lower half of the model simulates personal and commercial travel. The Transitional Model employs tour-based microsimulation of personal travel (PT) and commercial/goods transport (CT), and a simple truck model of external freight travel (ET). The PT module simulates daily travel for nearly six million people generated by the synthetic population module (SPG). The CT module translates daily merchandise flow generated in the PI module into truck trips. The resulting personal and freight travel demand is loaded onto the transportation network with the EMME/2 equilibrium approach in the TS module.

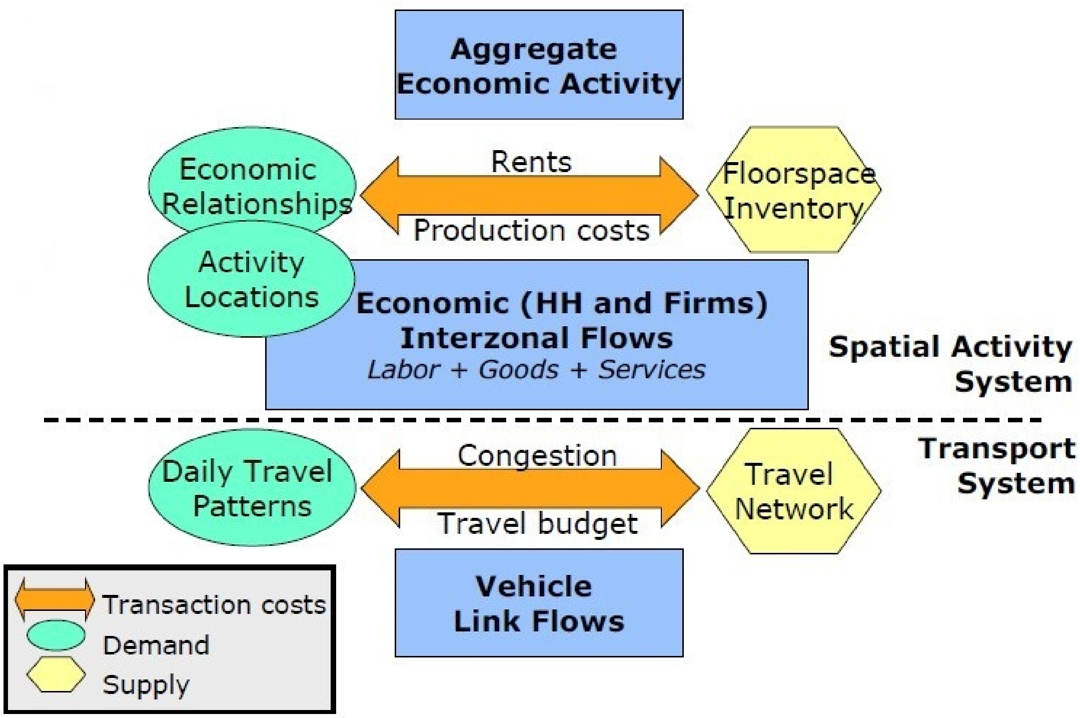


Figure 39. The Overall Economic-Land Use-Transport System
(Source: Weidner *et al.* 2007)

2.5.2 Data

The development of statewide tour-/activity-based land use, economic, and transportation microsimulation models requires significant data collection efforts. For instance, the Ohio model has an extensive list of demand-side data requirements:

- Socioeconomic data (U.S. Census, County Business Patterns, ES-202, and BEA Regional Economic Information System Program);
- Land use data from Department of Natural Resources and County Auditors;
- Land value data from county assessor;
- IMPLAN I/O data used for the aggregate demographic modeling;
- A traditional one-day household survey, a small subset of which were GPS-based, covering a total of 25,000 households;
- A two-week long distance (over 50 miles) travel survey, covering 2,000 households;
- TRANSEARCH data;
- A business establishment survey of about 800 establishments, supplementing the TRANSEARCH data;
- CTPP outside Ohio;
- Roadside surveys taken at approximately 700 locations; and
- Other data sources, including traffic counts, travel time studies, etc.

On the supply side, the network dataset is based on the Ohio DOT's Roadway Information Database. Ohio has adopted a more complex zoning system with three nested-zone structures: activity model zones, traffic analysis zones, and grid cells. The economic activity components have approximately 700 "activity model zones," each of which is made up of one or more traffic analysis zones. The number of TAZs is 5,103. For the purposes of maintaining land use and demographic data and for detailed microsimulation of personal and freight travel, each TAZ is further disaggregated into many grid cells. In order to properly account for cross-border traffic, relatively larger TAZs have been created to cover a halo of around 50 miles into the surrounding states. All other U.S. areas are represented by state-level zones in the Ohio model.

It should be noted that even traditional household travel surveys could be used for the development of advanced tour-based models, which is the case in the Ohio model. Oregon has recently invested in a new Household Activity Survey, which has a more activity-based focus and should provide superior data (compared to traditional household surveys) for statewide tour-/activity-based demand modeling.

2.5.3 Application Examples

The Ohio model was applied to analyze several tolling scenarios for the Turnpike Corridor, and determined to what extent parallel transportation facilities would be affected by various Turnpike tolling strategies. The Ohio model has also been applied extensively in the state's long-range transportation planning process. A "Macro Corridor" system analysis used the Ohio model to identify highway routes, which have high latent demand and therefore should receive priority funding from the government (Giaimo *et al*. 2005). The Ohio model also contributed to the design and evaluation of the state's Jobs and Progress Plan, which would invest new gas tax revenues to a series of transportation improvement strategies (Taft and Proctor, 2003). In this case, the statewide model was applied in conjunction with the

Ohio DOT's congestion management system to estimate the user benefits with the implementation of the statewide Jobs and Progress Plan.

The Oregon model was used in a series of studies to help decision makers address various high-priority planning and policy issues. The earliest statewide TLUMIP model was applied in several local case studies in Oregon. For example, the Eugene-Springfield Area Case Study and the Willamette Valley Livability Forum Study both tested the impact of various future land use, economic growth, vehicle mileage fees, highway investment, and transit investment scenarios on mobility, accessibility, equity, and livability. The TLUMIP model was also used in the Oregon DOT's Economic and Bridge Options Report (Oregon DOT, 2003) study. In order to ensure bridge safety, it is necessary to enforce vehicle weight limit for deteriorating bridges in Oregon. The statewide model then assessed the negative impact of such weight limit on state and regional economic production and jobs, transportation costs, and changes in travel and land use patterns. As the model-estimated negative impact of weight limit is significant in terms of potential reduction in production and jobs over the next 25 years, the Oregon legislature subsequently decided to invest an additional $4.5 billion in Oregon's transportation infrastructure.

Two application examples of the Oregon model are discussed in greater detail below to showcase the capability of the statewide model in addressing various land use planning and policy issues.

The Oregon statewide land use and transportation model was used in a case study of UrbanSim, a metropolitan-scale urban and land use simulation system for integration with transportation models (Waddell, 2002). UrbanSim was designed specifically to address the policy needs of metropolitan growth management and to compare alternate scenarios, particularly with emphasis on the interactions between land use and transportation. The model structure of UrbanSim is illustrated in Figure 40.

Compared to other land use models that are often aggregate in nature, UrbanSim was designed with a completely disaggregate approach (Waddell *et al*., 2003) with seven model components, modeling individual households, jobs, and real estate development and location choices with 150-meter grid cells. Following implementation in Honolulu and Salt Lake City, a case study of UrbanSim in the Eugene-Springfield urban area was conducted for integrated land use and transportation analysis in the mid 1990s. At that time, the Oregon statewide model simply provided transportation system costs and other information to UrbanSim. With its microsimulation and integrated modeling structure, the Oregon model compatibly served as an external transportation model to derive travel access indicators for UrbanSim, resulting in useful insights into the behavior of the UrbanSim model. This study also provided valuable information for future improvement to the land use component of the Oregon statewide model.

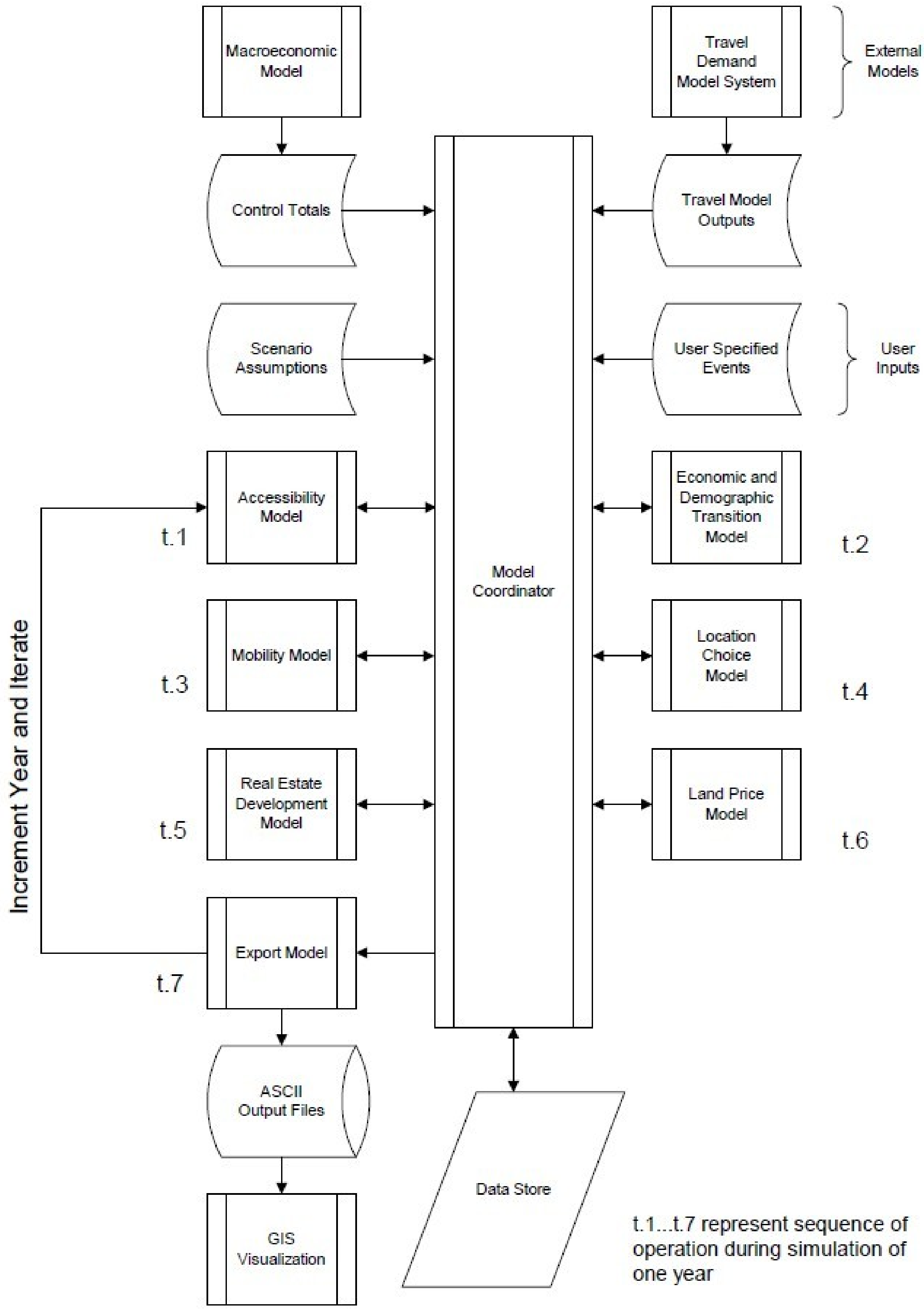


Figure 40. UrbanSim Model Structure
(Source: Waddell, 2002)

Another land use-related application of the Oregon statewide model was the Willamette Valley Livability Forum's Alternative Transportation Futures Project (ODOT 2001), which was also the first full application of the first-generation Oregon model. The statewide model was used to model eight transportation and land use scenarios:

- Reference Scenario
- Emphasis on Highway Investment
- Emphasis on Transit Investment
- Mileage Tax Emphasis (Travel Demand Management)
- Emphasis on Compact Land Use Development
- Hybrid 1 (a combination of the previous scenarios)
- Hybrid 2
- Hybrid 3

The Oregon model was applied in two rounds in the scenarios analysis, with the first round examining the first five scenarios and testing the responsiveness of land use and transportation patterns to various types of public policies. Results from the first round were used to develop effective hybrid scenarios. The second round then evaluated the proposed hybrid scenarios, which combined elements of the five previous scenarios. Final results show that any single policy instrument may not be very effective in addressing mobility, congestion, and sustainability issues and that any comprehensive policies incorporating land use and transportation investment measures should be pursued.

2.6 STATEWIDE MODEL VALIDATION

The difference between model estimation, calibration, validation, and sensitivity tests needs to be clarified before the validation of statewide transportation models is discussed. Model estimation is the process wherein model parameters and coefficients are estimated from empirical data with proper statistical or other well-established methods. During model calibration, these parameters and coefficients are further adjusted such that model outputs become sufficiently close to certain pre-determined target values. These target values are also usually based on observed data. Compared to more systematic methods for model estimation, the methods for model calibration are often ad-hoc and even arbitrary at times. Model validation is the step where outputs from a previously estimated and calibrated model are compared with observed data that have not been used in model estimation or calibration. In general, there are two types of sensitivity tests. The first type of sensitivity test focuses on how model outputs vary as the values of certain model coefficients change. It is often used to explore the impact of certain coefficients (especially those that the modelers do not have a lot of confidence in for various reasons) on model outcomes. The second type of sensitivity test may be referred to as "pressure test," which imposes arbitrary test scenarios on the model and examines if the model provides reasonable responses. It is also used to test when the model will breakdown (i.e. model outputs no longer make sense), which helps modelers understand the limitations of the model for various applications.

Model validation is a major component of the statewide modeling process since it determines whether or not a model is reasonably accurate and reliable. NCHRP Synthesis #358, published by the Transportation Research Board in 2006, reported that all states that have done validation used passenger vehicle volumes while most of them have also used truck counts. The current MSTM validates its results against passenger vehicle counts, truck counts, and CTPP commuting OD data. These three data sources are the most widely used data for validation in other states. Other frequently used data sources (i.e. data sources employed by at least three statewide models as reported in Horowitz 2006) include:

- Comparisons to national default trip generation values;
- Comparisons to average values (or other statistics) from own travel surveys;
- Comparisons to average values from similar states;
- Comparison to MPO models;
- Bus and rail passenger counts;
- Data from cordon surveys; and
- HPMS VMT estimates.

Most recently, the American Association of State Highway and Transportation Officials (AASHTO) and Cambridge Systematics, Inc. conducted a comprehensive study regarding validation and sensitivity considerations for statewide models (Cambridge Systematics, Inc. 2010). Based on their research findings, the aforementioned MSTM validation approach is a one-step validation focusing solely on the final outputs from the traffic assignment step. Commonly-accepted criteria for this type of validation are listed below:

- VMT by functional class absolute deviation;
- Link root mean-square error (RMSE) by volume strata;

- Screenline count absolute deviation;
- Link count absolute deviation;
- Cordon count absolute deviation;
- Correlation coefficient between link volume forecasts and counts; and
- Link-by-link comparisons.

Some states have improved the statewide transportation model validation process by moving towards a multi-step procedure that emphasizes the validation of multiple or in some cases all of the modules in statewide models. For instance, Florida and Texas have conducted comprehensive validation for each of the four steps in their statewide transportation models to ensure that each module performs at acceptable levels. Statistics reviewed in the multi-step model validation process include: number and percent of trips by purpose, aggregate trip rates, average trip lengths, auto occupancy rates, and estimated-over-observed ratios for VMT and vehicle hours traveled (VHT).

The Wisconsin Statewide Model (SWM) has been validated based on procedures outlined in the FHWA Model Validation and Reasonableness Checking Manual, including network and zone data checking, logic and sensitivity checking on parameters and input variables, and comparison of base-year and independent datasets. Validation of the trip generation model is based on trip production rates from NHTS add-on data. Validation of the trip distribution model relies on comparison of model estimated and observed average trip lengths, coincidence ratios, and percentage of intra-zonal trips. For mode choice validation, SWM focuses on comparing inter-city travel mode share against NHTS 2001 survey data and Amtrak ridership data obtained for the Wisconsin-Illinois-Minnesota corridor. Table 10 summarizes the validation alternatives for the modeling steps other than the assignment step.

Table 10. Validation for Trip Generation, Distribution, and Mode Choice Steps

Modules of Statewide Models	Validation Criteria(s)	Example States
Trip Generation	(1) Aggregate Trips (2) Trips by Purpose	FL, TX, and WI
Trip Distribution	(1) Travel Time (2) Average Trip Lengths	AZ, FL, TX, and WI
Mode Choice	(1) Auto Occupancy (2) Mode Share	CA, FL, LA, MS, and TX

The completed and ongoing calibration and validation steps for the MSTM are summarized in "Validation Strategy for the G1 Maryland Statewide Travel Model." Overall, the proposed calibration and validation plan for the MSTM is comprehensive, theoretically sound, methodologically feasible, and practical. Based on validation practices elsewhere and summarized in the NCHRP and FHWA reports, the research team has the following comments on the current MSTM validation plan.

Since SHA and other state agencies in Maryland may use outputs from various modules (not just the traffic assignment module) of the MSTM for travel forecasting and analysis, the multi-step validation procedure should be used. Trip generation rates, travel time/distance distributions, and mode share, as well as traffic assignment outputs, should all be included as part of the validation criteria. This has already been reflected in the current MSTM validation plan.

The current MSTM uses model specifications and coefficients from the BMC metropolitan travel demand model in several places. It is important that comprehensive sensitivity tests and model validation on the MSTM are conducted to further establish the validity of the MSTM. These actions should be planned based on expected MSTM applications. For instance, since the ability to assess the effects of pricing and tolling scenarios has been described as a main application area of the MSTM, sensitivity tests with hypothetical or real-world pricing/tolling scenarios should be designed and implemented (e.g. I-270 HOT lane or the Inter-County Connector toll road). Before the MSTM is applied to analyze multimodal transportation planning scenarios and policies, mode share estimates for both urban and intercity transit should be validated against observed data. Additional sensitivity tests on modal shifts may be conducted to assess the model performance and reasonableness under proposed multimodal transportation policies.

The use of screenlines/cordons has been shown to be a very effective calibration/validation technique. Since highway traffic and transit forecasts on major intercity corridors are important applications of the MSTM, it may be valuable to set up several highway, transit, and truck volume screenlines for model validation purposes. Possible screenlines include: (1) Baltimore-DC corridor, e.g. I-95, US 29, US 1, and MD 295; (2) DC-Frederick corridor, e.g. I-270, MD 355 and other parallel roads; (3) Transit screenlines for the above two corridors; and (4) Trucking screen line involving I-95 and I-81.

2.7 STATEWIDE MODEL IMPROVEMENT PLANS IN OTHER STATES

California is updating the interregional travel demand modeling system to a more advanced statewide integrated interregional transportation, land use, and economic model (Caltrans 2009). The new integrated model has the capability to better analyze the impact of policies, plans, programs, and major investments on transportation, on the economy, and on the environment at the statewide level. This new phase of modeling development is estimated to be completed in 2012.

In recent years, the New York Metropolitan Transportation Council (NYMTC) has pursued a tour-based model and planned to phase out the two original New Jersey models serving northern New Jersey (NJRTM and the New Jersey statewide model), though it is determined that the NYMTC model is not able to address some New Jersey statewide issues. In the end, New Jersey DOT has not immediately committed to replacing the current statewide model with the NYMTC tour-based model, because the new advanced model would take several years to complete. Instead, New Jersey DOT has focused on incrementally improving its existing statewide model.

In 2005, the Michigan Department of Transportation decided to update its traditional four-step statewide model to a tour-based version with a three-phase model improvement program (Faussett, 2005). The tour-based model structure at both urban and statewide levels was designed in the first phase, which also identifies data needs. The second phase conducted a tour-based statewide household travel survey involving 14,300 households. Currently, the project is in its third phase, where survey data is used to develop and improve the statewide travel demand model.

Virginia and Indiana have both considered developing a more advanced four-step model for statewide transportation analysis. When deciding to invest in more sophisticated four-step models a major concern is the lack of qualified staff members who would become acquainted with the more complex demand modeling procedures and applications. Other concerns are related to data requirements and costs. The potentially high cost associated with advanced models has been cited by Virginia DOT as a negative aspect of developing advanced models. A recent Virginia DOT study shows that developing and maintaining a statewide activity-based model is up to three times more expensive than an advanced four-step model over the course of five years ($4.2 to $5.6 million for an advanced four-step model versus $14.2 to $16.5 million for an activity-based model, see Virginia DOT, 2009), though these cost estimates may not be representative for other states because the actual design of advanced four-step and activity-based statewide models can significantly vary based on the transportation planning and policy needs that these models need to address.

In the same cost and feasibility analysis of statewide activity-based modeling in Virginia, it is also found that activity-based modeling techniques will be inevitably required for certain statewide transportation analysis. It is recommended that Virginia adopts a more incremental approach in improving the current statewide model toward a fully activity-based approach. Given the staffing and resource challenges, the incremental approach will allow the Virginia DOT modeling staff to gradually master the new modeling techniques.

Following the success of the first-generation statewide model in Oregon which employs traditional four-step methods for the travel demand modules, the Oregon DOT has developed an ambitious plan to improve the first-generation model and achieve a fully activity-based microsimulation structure for the second-generation statewide model. During the past decade, the Oregon DOT has invested significant resources in the development of the second-generation Oregon2 statewide model, and recently teamed with several MPOs in Oregon in conducting a new Household Activity Survey to support the calibration and validation of the Oregon2 model. During the development of the Oregon2 model, it was realized that delivering a production-version of a fully activity-based microsimulation model for person and freight travel, land use, and economic activities would take a long period of time and require more resources than currently available. Subsequently, a Transitional Statewide Model was developed and recently delivered to meet urgent transportation planning and policy analysis needs at the Oregon DOT. The Transitional Model has certain but not all the advanced features designed for Oregon2. Again, an incremental statewide model improvement approach was observed.

2.8 OUTREACH EFFORTS IN OTHER STATES RELATED TO STATEWIDE TRANSPORTATION MODELS

This section discusses the outreach efforts in other states related to their statewide transportation models. Several DOTs, e.g. Oregon DOT, Florida DOT, and Virginia DOT, have pursued interesting and effective model outreach activities, which are highlighted below. Examples of their outreach efforts include dedicated websites, newsletters, peer reviews, model steering/advisory committees, stakeholder meetings, and user groups.

2.8.1 Oregon DOT

The Oregon Modeling Steering Committee (OMSC) was formed in 1996 to provide direction and oversight to the Oregon Modeling Improvement Program (OMIP). The OMSC website can be found at http://www.oregon.gov/ODOT/TD/TPAU/OMSC.shtml. The main objective of the committee is to improve and promote land use and transportation modeling in the state of Oregon. The committee also serves as a consensus forum that coordinates the land use-transportation modeling efforts of federal, state, regional and local agencies. The main activities of OMSC are:

- Providing technical information and analyses to support informed decision-making. Support research, development and application of models at the local, regional and statewide level, improve and expand capabilities, support integration and the use of transportation models statewide.
- Providing a forum for the exchange of ideas and encourage the use and the diffusion of current and future technology.
- Proactively educating policy-makers on the use of transportation models as an analytical tool to support decision-making, through coursework, training, symposiums and case studies.
- Serving as a technical and professional support group to members, agencies, local governments, consultants and others to foster transportation modeling knowledge and expertise and to maximize resources.

The OMSC is divided into several subcommittees as shown in the organization chart (Figure 41).

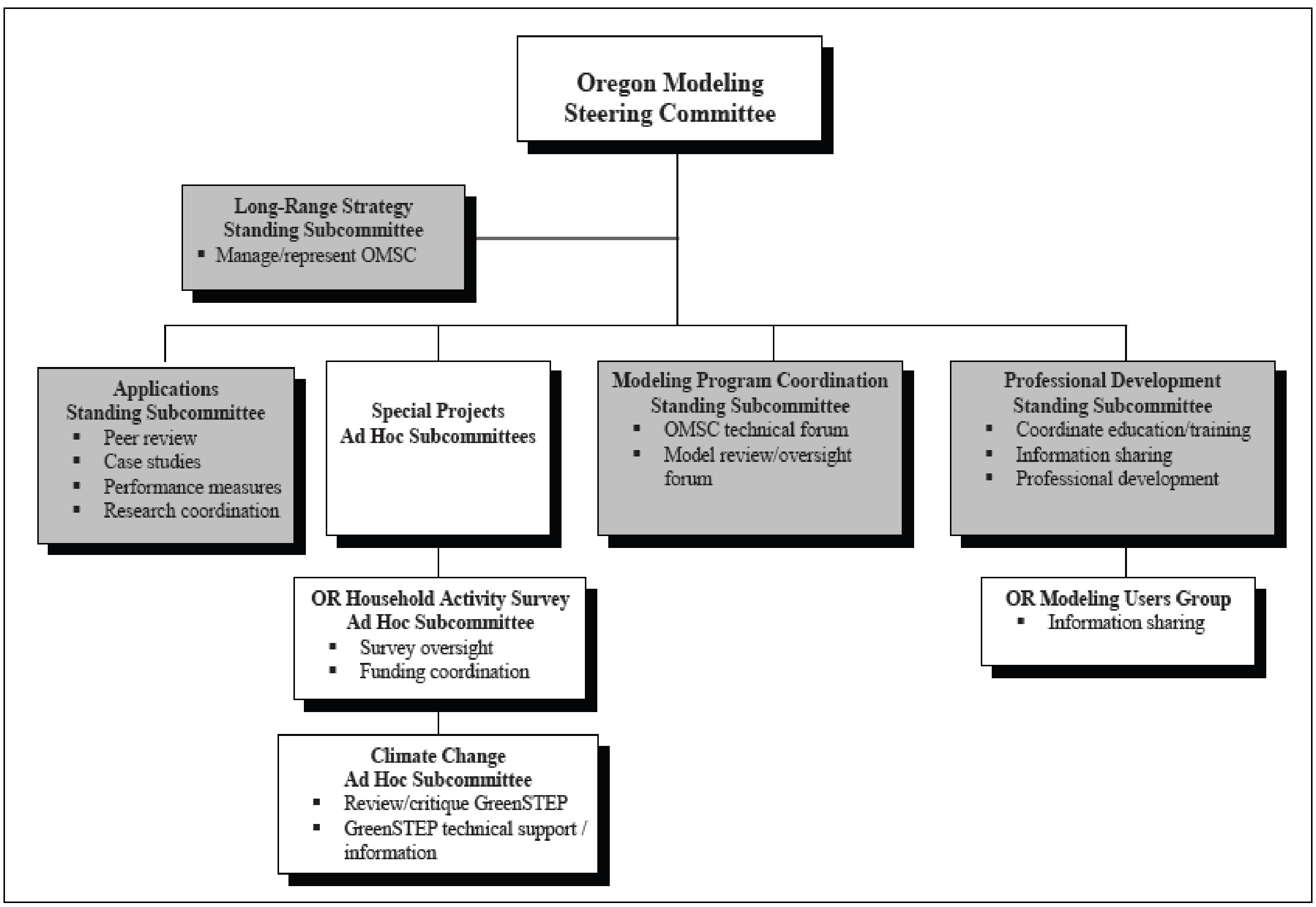


Figure 41. Organization Chart for the Oregon Modeling Steering Committee (FY2009-2010)
(Source: OMSC 2009-2010 Report)

The responsibility of each OMSC subcommittee is summarized below.

2.8.1.1 Long-Range Strategy

This subcommittee is responsible for developing an annual work plan, strategic activities and OMSC membership.

2.8.1.2 Applications

This subcommittee addresses the environment and the criteria under which models are applied, i.e., regulatory requirements and general applications. It focuses on peer review for local level model application and holds special meetings to identify possible research topics.

2.8.1.3 Oregon Household Activity Survey (OHAS) Ad Hoc Subcommittee

This subcommittee provides oversight for development and implementation of the Oregon statewide survey.

2.8.1.4 Climate Change Subcommittee (CCS) Ad Hoc Subcommittee

This subcommittee coordinates, provides technical guidance and oversights for model development and applications, and communicates results from analysis conducted on greenhouse gas emissions (GHG) and climate change.

2.8.1.5 Modeling Program Coordination Subcommittee

This subcommittee provides a technical and interactive forum for discussion of model development and application issues for MPOs and ODOT.

2.8.1.6 Professional Development

This subcommittee addresses technical model development, education, training and quality control.

2.8.1.7 Oregon Modeling Users Group (OMUG) Subcommittee

This subcommittee facilitates and encourages broad discussion and ideas on development and implementation of Oregon models throughout the Oregon modeling community.

2.8.2 Florida DOT

In Florida, a Model Task Force (MTF) establishes policy directions for transportation modeling and provides procedural guidelines for the development of the Florida Standard Model (FSUTMS). More information can be found at http://www.fsutmsonline.net/index.php. There are four technical committees serving the task force:

2.8.2.1 Data Committee

This committee provides guidance to the Florida Model Task Force and the Florida transportation modeling community regarding data needs, data collection, data analysis, archiving, and information management.

2.8.2.2 GIS Committee

The mission of the GIS Committee is to support the Florida Model Task Force in evaluating, coordinating, facilitating, and improving the use of GIS in transportation modeling.

2.8.2.3 Transit Committee

The transit committee leads the Florida Model Task Force in improving transit modeling within Florida, and in addressing federal and state planning requirements as they relate to transit planning.

2.8.2.4 Model Advancement Committee

This committee evaluates the Florida standard model and identifies opportunities for improvement. It reviews alternative modeling methodologies based on relative strengths and weaknesses, and recommends enhancements to the current FSUTMS process. The model advancement committee is divided into three subcommittees: (1) Toll Modeling, (2) Dynamic Traffic Assignment (DTA), and (3) Time of Day. The Toll Modeling committee aims to incorporate toll facility pricing scheme, such as Florida's Turnpike Enterprise, into FSUTMS-Cube, as well as study the possibility to use innovative toll methodologies. The DTA subcommittee is responsible for reviewing the existing DTA models and software, identifying requirement of Florida demand modeling, and implementing a dynamic traffic assignment process within the FSUTMS environment. The Time-of–Day (TOD) subcommittee’s objective is to develop procedures that integrate econometric models for passive and active peak spreading and implements TOD into FSUTMS framework.

2.8.3 Virginia DOT

The Virginia Transportation Modeling program (VTM) was created in 2005 and acts as a forum for the improvements of the state-of-practice in travel demand modeling in Virginia. The main activities include: (1) discussing modeling activities in Virginia, (2) assisting and enhancing modeling policies to promote consistent best-practice modeling in Virginia, (3) serving as a peer exchange to discuss modeling techniques and procedures, and (4) sponsoring training activities pertinent to modeling.

One of the major contributions of this program was the development of the first Virginia Travel Demand Modeling Policies and Procedures Manual in 2006. This manual is the cornerstone of the new VTM modeling system and created minimum guidelines and standards for Virginia's metropolitan area travel demand models. These guidelines and standards are intended to promote consistent best modeling practice throughout the state.

The Virginia DOT publishes a quarterly newsletter named VTM Connection. It keeps agency, employees, planning district commissions, metropolitan planning organizations and university transportation planning staff informed on the latest travel demand modeling activities in the commonwealth. For instance, VTM Connection provided updated information on the statewide household travel survey data availability and elaborated incentives for participation in the 2008 NHTS add-on program. The VTM Connection also regularly highlights upcoming research projects and real-world applications related to statewide models. The newsletter also collects recent news from the VDOT districts and MPO areas. The program and newsletter’s website can be found at: http://www.virginiadot.org/projects/vtm/newsletter.asp.

2.8.4 Summary

State DOTs conduct outreach activities to support, improve and promote statewide modeling. The Oregon Modeling Steering Committee (OMSC) supports statewide model improvement by establishing different subcommittees with each subcommittee responsible for a particular aspect of model development. The committee is also in charge of the environmental program, such as climate change and green house gas emissions (GHG), which are emerging issues in transportation planning. In other states, outreach activities are more oriented toward model implementation. Florida DOT model task force (MTF) is an example, which focuses on the improvement of the statewide model by establishing a Model Advancement Committee. This committee identifies opportunities for Florida model improvement based on current planning and policy needs such as toll modeling, time of day considerations, and dynamic traffic assignment. Virginia DOT's Transportation Modeling program (VTM) develops policy and procedures that provide guidelines and standards for the Virginia's metropolitan area travel demand model and for a consistent modeling practice throughout the state. VTM newsletters inform politicians, agency staff, practitioners, and researchers about model advancement and recent VTM activities.

Several statewide model outreach activities identified in this section could be implemented in Maryland to support MSTM improvement, promote MSTM applications at all levels, train potential MSTM users, and build strong stakeholder/user groups. These possibilities are discussed in greater detail in Section 4.7.

2.9 IMPLICATIONS ON THE MSTM IMPROVEMENT PLAN

2.9.1 Review Findings

As mentioned in previous sections, the current-version of the Maryland Statewide Transportation Model falls into the category of traditional four-step models with aggregate zone-level trip generation and distribution, utility-based personal-travel mode choice, standard traffic assignment procedures, and a truck-only freight module. The traditional four-step statewide models have also been developed in many other states and successfully applied to conduct important transportation planning and policy analysis, as reviewed in the previous sections. Even states with the most advanced statewide model have also started with traditional four-step models. The main conclusions from this review include:

1. A traditional four-step approach is theoretically and technically sound for statewide transportation modeling. It has proven successful in many other states in a variety of transportation planning and policy analysis projects.

2. Improvements to traditional four-step models can be costly and may take a long period of model development time, and therefore should be pursued only if these improvements are necessary to address transportation planning and policy needs that are important for the states. However, experiences in other states suggest that some improvements are almost always necessary.

3. Advanced four-step models could be cost-effective in enhancing certain aspects of the traditional four-step models, such as behavioral responses to congestion/pricing/new modes, multimodal freight analysis, and time-of-day considerations.

4. Developing fully activity-based microsimulation models can significantly enhance statewide models' capability in addressing modern transportation planning issues at the state level, such as congestion management, freight movement, and sub-area/corridor traffic analysis. They can cost a lot more (several times more) than traditional and advanced four-step models and take a long time to develop. While several states (some already committed and some not yet committed to activity-based models) found that the move to activity-based models would be inevitable in the future and that all efforts in moving toward an activity-based paradigm have taken an incremental model improvement approach.

5. Several states have developed integrated transportation-land use-economic models at the state level. This broader statewide modeling scope has several appeals: (1) It allows two-way feedback between the transportation system and the land use/economic systems, which has many theoretical advantages; (2) It supports the analysis of integrated land use-transportation policies such as smart growth and simultaneous transit investment; (3) It enables streamlined estimation of the impact of transportation improvement/investment on the state and regional economic growth and job creation. Despite these clear benefits, states should take a cautious approach in expanding their modeling scope to include land use and economic systems due to data availability and political realities.

2.9.2 Successful Improvements to Statewide Models in Other States

Based on the review findings, potentially cost-effective improvements of traditional four-step models that have proven successful in other states have been summarized in the following discussion.

Advanced four-step and tour-/activity-based microsimulation statewide models have been developed in a few states to address several known limitations of the traditional four-step modeling approach. First, the behavioral foundation of the traditional four-step is relatively weak, which often leads to limited model capabilities and model accuracy issues (especially in sub-area and corridor level analysis). Second, the representation of transportation system dynamics is also limited in the traditional four-step models, which usually significantly simplifies time-of-day choices and ignores dynamic routing. Consequently, they have limited value in supporting decision-making with regard to time-specific policies (e.g. HOV/HOT operations, dynamic tolling and congestion pricing, bus scheduling and service period extension, incident management), peak spreading, and corridor-level congestion management. Third, the truck-only freight module in many traditional four-step statewide models cannot estimate modal shifts between trucking and other freight modes such as conventional rail, double-deck rail, air, water, and intermodal modes. Fourth, the trip-based approach in traditional four-step models does not consider various travel constraints (e.g. interpersonal constraints, mode choice constraints among multiple trips on the same tour) and therefore may not be able to adequately analyze sophisticated travel demand management strategies, such as vehicle sharing programs and flexible work schedules. Finally, the introduction of a new mode of transportation or other new transportation improvements often requires new information regarding behavioral responses.

Having recognized these limitations, several states have improved their traditional four-step models to remove some of the limitations. The details of the model improvement options have been presented in the previous sections of this report. We briefly summarize them in the following paragraphs.

In the California model, a completely disaggregate representation in trip generation, distribution, and mode choice with advanced discrete choice models makes the model more sensitive to individual choices, and therefore produces reasonable sensitivities to the proposed new High Speed Rail proposal in California.

The tour-based four-step model with a time-of-day module in the New Hampshire model is an early attempt towards a behavioral modeling approach. Although the New Hampshire model still uses trips to generate tours without synthesizing households and explicitly considering activity patterns, it is able to capture travel demand responses more accurately, thanks to its advanced tour-based structure. The main advantages include the ability to better perceive individual choices to new transportation facilities, and to better analyze congestion management options, such as increases in highway tolls and transit fares.

The activity-based approach for travel demand forecasting has recently become a practical replacement for the traditional four-step model. It has been applied in various MPO models in a few states and in statewide models in Ohio and Oregon. The activity-based approach has a detailed representation of personal and household activity-travel decision making with its population synthesizing and activity allocation modules. The activity-based models have shown its great potential in supporting a variety of policy issues, long-range transportation planning, and sub-area/corridor traffic management analysis.

Increasing freight travel demand and level of congestion along major highway corridors have made freight modal diversion analysis important for many state DOTs that attempt to accommodate freight needs with diversion of truck traffic to alternative freight modes, especially rail. Florida and Indiana have developed multimodal commodity-based freight analysis modules in their statewide models. Oregon has added a socioeconomic forecasting module to represent the activity-based nature of freight transport, similar to its passenger model.

2.9.3 Promising Model Improvement Options for the MSTM

The research team has identified the following list of promising model improvement options for the MSTM based on the review findings and the transportation planning and policy analysis needs in Maryland identified in Task 1 of this SHA research project. These improvement options have been considered further in future tasks of this SHA research project (i.e. Task 4. Development of the MSTM Improvement Plan). An incremental model improvement approach is recommended no matter what improvement options are finally selected to meet SHA’s needs in this area.

- Advanced discrete choice analysis for trip frequency, destination, and mode choices.
- Tour-based approach.
- Population synthesizer.
- Time-of-day models and peak spread analysis.
- Pricing modules with calibrated sensitivities to congestion pricing, HOT, and tolls.
- Integration of the statewide model and sub-area/corridor microscopic traffic assignment model for congestion management analysis.
- Multimodal commodity-based freight analysis modules.
- Integration of emission/air quality, energy consumption, and green house gas post-processing modules into the statewide model.
- Vehicle ownership and availability module.
- Integration with land use and economic models at some level for integrated land use-transportation analysis, and for streamlined economic impact and job creation analysis.
- Trip/tour generation/distribution/mode choice analysis modules for smart-growth land development, such as compact development and transit-oriented development.
- Activity-based microsimulation with a phased implementation plan.
- A low-maintenance module that tracks the benefits of the MSTM in various applications for SHA, Maryland DOT, personal travel, freight shippers/carriers, and the economy.

CHAPTER 3: ASSESS DATA AVAILABILITY

3.1 INTRODUCTION

Task 1 of this project was conducted to synthesize current and emerging transportation planning and policy analysis needs in Maryland. Task 2 was conducted to review advanced statewide travel demand models successfully implemented in other States and to provide application examples, which could address similar issues for Maryland. This third task of the project was conducted to assess data availability for the development of the Maryland Statewide Transportation Model (MSTM) Improvement Plan. First, the existing data sources for travel modeling in Maryland are identified and the information contained in each data set is summarized. Then based on transportation planning and policy analysis needs in Maryland (identified in Task 1) and on advanced statewide travel demand models successfully implemented in other states (reviewed in Task 2), data needs and availability for the development of more advanced four-step and activity/tour-based models in Maryland are discussed. For each demand modeling module that may potentially become a part of the MSTM Improvement Plan, the corresponding data requirements are identified at several levels, ranging from minimally-required basic data to more advanced data supporting greater model capability and flexibility in planning and policy analysis.

After the introduction, this Chapter is organized in three sections (Sections 3.2, 3.3 and 3.4). Section 3.2 summarizes the existing and expected future data sources for travel demand modeling in Maryland. This includes recent household travel, transit, freight, and auto surveys conducted in Washington D.C. and Baltimore, in adjacent states including Delaware and Virginia, and at the national level. All datasets analyzed in this Section are summarized in Table 12.

Section 3.3 reviews datasets which have been successfully used to develop advanced statewide travel demand models in other states. This review should help the research team assess the data needs for MSTM improvement in Maryland. For each advanced statewide demand forecasting module observed in other states, two levels of data needs are summarized: the minimum data required and the preferred data. Additional model capabilities resulting from the preferred data are also identified. This methodology will allow the research team and SHA to realistically assess the marginal value of collecting travel data in addition to what is minimally required for model development. The summary of data requirements based on the review of the model development practices in other States is presented in Table 13.

Finally, Section 3.4 summarizes the findings from the research efforts in Task 3 in terms of data availability, data needs, and the extent to which the MSTM could be improved depending on just the available data.

3.2 AVAILABLE DATA SOURCES FOR TRAVEL MODELING IN MARYLAND

This Section aims at identifying the existing and expected data sources for transportation modeling in Maryland. The data which could potentially be used to improve the Maryland Statewide Transportation Model (MSTM) is summarized by categorizing data set into 6 categories as shown in Table 11.

Table 11. List of Available Data Sources

Data Category	Data Name
1. Household Travel Surveys	1.1 TPB/ BMC 2007/2008 Household Travel Survey
	1.2 NHTS 2001
	1.3 NHTS 2008/2009
2. Auto Surveys	2.1 Auto External Survey (COG/TPB) 1994
	2.2 Vehicle and Person External Trips Survey (BMC) 2006
3. Transit Surveys	3.1 Metro Rail On-Board Survey (WMATA) 2007
	3.2 Metro Rail On-Board Survey (WMATA) 2008
	3.3 Regional Bus Survey (COG/TPB) 2008
4. Freight Surveys and Network Data	4.1 Truck Internal Survey (COG/TPB) 1996
	4.2 Truck External Survey (COG/TPB) 1996
	4.3 Commodity Flow Survey (BTS) 2007
	4.4 TRANSEARCH Database
	4.5 National Transportation Atlas Database (BTS) 2009
5. Air Travel Surveys	5.1 Baltimore Washington Air Passenger Survey (COG/TPB) 2007
	5.2 Baltimore Washington Air Passenger Survey (COG/TPB) 2009
6. Available Data in Adjacent States	6.1 Delaware Trip Monitoring Survey (DelDOT) 2008
	6.2 Virginia Household Travel Survey (VDOT) 2009

For each data set, the information in terms of data collected, data collection time frame, sample size, and the availability of the data set are described. This information is helpful in assessing the adequacy of data for the improvement module and in identifying additional data collection for the model improvement plan.

3.2.1 Household Travel Surveys

3.2.1.1 TPB/BMC 2007/2008 Household Travel Survey

The survey was conducted by the National Capital Region Transportation Board (TPB) and the Baltimore Metropolitan Council (BMC) from February 2007 through May 2008. Data collected include information on all the trips taken by every household member within the day (previous weekday) including origin/destination trip purpose (i.e. home to office) and address, trip departure time, mode choice including access and egress mode for transit, estimated trip distance, travel time, travel party composition and socioeconomic characteristics (income, race) of all household members. This data set includes both internal and external trips. The data set contains information on 14,365 households, 31,330 individuals and 108,110 trips. 11,437 households were within the TPB model area while another 9,740 households were within the BMC model area (some of which were within both model areas). The data was geo-coded in the TAZ system. This data set has already been obtained.

3.2.1.2 The National Household Travel Survey (NHTS) 2001

This data set includes 5 major components: household data, person data, vehicle data, short distance and long distance data. Household data includes information in terms of household size, household composition, gender, age, work status, driver license status of the household head, relationship of each household member to the household respondent, number of vehicles, race, household location, income and number of telephones. Person data include information for each member of the household in terms of education level, work status, employer information, typical work trip, driver license status, annual miles driven and if they drive as a part of work. Vehicle data include information for each vehicle owned in terms of make, model, model year, number of months vehicle owned, annual miles driven, primary driver, and odometer readings. Short trip data were collected by travel diary over the 24 hour period in terms of departure time, trip purpose, distance to destination, travel time, main mode of transportation, access and egress modes used, and household vehicle used. Long distance data include trip purpose, main transportation mode, furthest destination, trip duration and whether the trip was a recurring trip, traveler companion, access and egress modes, overnight stops, transportation mode, and stop purpose. The data set for the state of Maryland contains observations from 4,240 households, including 9,224 individuals and 34,211 trips. This data set has already been obtained.

3.2.1.3 The National Household Travel Survey (NHTS) 2008/2009

The survey focuses on household members ages 18 and older. The data includes household size, vehicle ownership and associated vehicle information (make, model, year, and type), housing type, and respondent socioeconomic characteristics. Data on all trips in the household over a 24-hour period were collected as well as data for long distance trips, defined as greater than 50 miles, over a 28-day period. Daily trip data includes trip departure and arrival times, modes, purposes, vehicles used, travel time, travel distance, day of the week, and travel group composition. Long distance trip data includes date of travel, whether the trips are recurring, purposes, primary modes, destinations, types of lodging, overnight stops, and access and egress information for air, bus, and rail modes. The data set for the state of Maryland contains information from 354 households, 810 individuals and 2,515 trips. This data set has already been obtained.

3.2.2 Auto Surveys

3.2.2.1 Auto External Survey (COG/TPB) 1994

This intercept type survey was conducted in the fall of 1994. The survey was focused on auto trips crossing the expanded cordon in the TPB area, inbound direction. The data set includes information in terms of trip time of day, trip purpose and origin/destination address, mode choice (auto driver, auto passenger), type of trips (i.e. internal-external), and vehicle information in terms of plate registration state, vehicle occupancy and vehicle ownership. The total collected data consist of 12,655 trips. The data were geo-coded in TAZ system. This data set has already been obtained.

3.2.2.2 Vehicle and Person External Trips Survey (BMC) 2006

The survey was conducted to improve the travel model system within the Baltimore Metropolitan Region. The survey focused on trips between internal and external areas of the region. The data set includes information from Frederick County, Montgomery County, Prince George’s County, and the District of Columbia which is external to the region but internal to the model. The data collection was conducted through distribution of survey flyers that respondents were requested to fill out and return. The survey sites were situated on major corridors of BMC, which are I-95, MD 3, MD 30, MD 45 and US 40. Data collection was conducted on weekdays at least two days apart from weekend, when school was in session and weather conditions were relatively clear. The collected data includes information on origin/destination rough address (by street name, TAZ), trip time of day (by hourly interval), trip purpose by origin/destination, trip frequency (how frequent the trip is made within a week), vehicle type, and vehicle occupancy. The total sample includes 3,700 trips where 599 trips, 1,830 trips, 209 trips, 471 trips, and 604 trips were obtained from I-95, MD 3, MD 30, MD 45, and US 40 respectively. The data were geo-coded in TAZ system. This data set has already been obtained.

3.2.3 Transit Surveys

3.2.3.1 Metrorail On-Board Survey (WMATA) 2007

The survey was conducted by the Washington Metropolitan Area Transit Authority (WMATA) from April 17 to June 22, 2007. It consists of 66,321 samples. The data contains trip information in terms of origin/destination by station, boarding and alighting station, trip purpose, mode of access and egress, fare type, home jurisdiction, home address, vehicle ownership, employee of federal government eligibility and monthly transit benefit eligibility (rail mile, travel time, and fare paid were calculated accordingly). A total of 44,531 samples were geo-coded in the TAZ system. This data set has already been obtained.

3.2.3.2 Metrorail On-Board Survey (WMATA) 2008

The 2008 Metrorail survey was aimed to complement the 2007 data by including traveler household income. However, the 2008 transit survey did not include mode of access to the Metro for all the observations, thus the reweighting was applied to obtain the mode of access to the Metro and to calculate the total number of the metro rail trips. The data has not been obtained.

3.2.3.3 Regional Bus Survey (COG/TPB) 2008

This is an on-board survey conducted by NuStats, Inc. between April 15 and June 30, 2008. The survey focused on transit trips between Maryland, Washington DC and surrounding areas. The data includes information in terms of origin/destination rough address (by city and TAZ), time of day (AM peak or PM peak), origin/destination by purpose, access egress modes, number of buses taken per trip, fare, socioeconomic characteristics, vehicle accessibility and vehicle availability on the day trip is taken. The total sample includes 28,420 observations. This data set has already been obtained.

3.2.4 Freight Surveys and Network data

3.2.4.1 Truck Internal Survey (COG/TPB) 1996

The survey was conducted in 1994 to obtain information on the travel patterns of local truck operators within the Washington region. A random sample was established from state vehicle registration data. Information collected included trip diary information on origin/destination locations, vehicle characteristics, cargo types, etc. The completed data (without missing values) consists of 1,861 trucks records. The cleaned data was geo-coded in TAZ system. This data set has already been obtained.

3.2.4.2 Truck External Survey (COG/TPB) 1996

The survey was conducted in the spring of 1996. The survey consisted of a roadside interview survey of trucks traveling into or through the Washington region. It was conducted at selected stations along the expanded cordon line. The data collected at each location were one-way, oriented toward the inbound direction. Only highway facilities with a functional classification of freeway, expressway or principal arterial were considered as possible data collection locations. The collected data includes the same information as the truck internal survey. The cleaned data consist of 4,892 truck records. The data set was cleaned and geo-coded in the TAZ system. This data set has already been obtained.

3.2.4.3 Commodity Flow Survey (BTS) 2007

The Commodity Flow Survey (CFS) is a joint effort by the Research and Innovative Technology Administration (RITA), Bureau of Transportation Statistics (BTS), the U.S. Census Bureau and the U.S. Department of Commerce. The data primarily represents national and state level statistics on freight flow in the United States. The survey is conducted every 5 years as part of the Economic Census. Selected samples from the 2007 CFS received a mailed questionnaire four times during the calendar year 2007. Each of the 4-weeks was in the same relative position of the calendar quarter. The establishments were asked to provide specific shipment information about a sample of their individual outbound shipments during a pre-specified one-week period in each calendar quarter.

The collected data includes commodity flow table in term of origin/destination by state, transportation mode, commodity value, Tons weight, average mile, value (CV), Tons (CV), Ton-miles, and averaged miles CV. A total of 493 and 476 observations were recorded in Maryland for the outgoing and incoming flow, respectively, with 10 transportation modes are considered. This data set has already been obtained from the BTS website.

3.2.4.4 TRANSEARCH Database

TRANSEARCH is a freight database that is available commercially from Global Insight. Its advantage over the Commodity Flow Survey (CFS) is the level of location detail which is represented in county (over 3,000 counties across the U.S.) and business economic area (BEA) (over 172 BEAs across the U.S.) while the CFS contains location at the state level. However, the purchase price depends on the number of zones requested. TRANSEARCH data contains variables including origins and destinations (by counties and BEAs), commodity type (purpose), and units of flow by mode; the flow for each record by mode is specified in annual tons. The TRANSEARCH zones can be aggregated at the district level to establish relationships between freight flow and economic variables, usually employment, which can then be applied to smaller geographic units.

However, TRANSEARCH freight traffic flow data has limitations with respect to trucks trip distribution. First, primary coverage of truck traffic is limited to non-manufactured products. Second, intermodal rail or air freight movements originating by trucks in warehouses, distribution centers or drayage do not have information in terms of cargo types. Third, the flow patterns are based on the movement patterns of domestically sourced goods in the same market area and are not the actual import/export movements. However, the inland or surface movements of import and export traffic volumes to locations outside of North America are included in the data set.

3.2.4.5 National Transportation Atlas Database (BTS) 2009

The National Transportation Atlas Data (NTAD) is a set of transportation-related geospatial ESRI data for the United States. The data consists of transportation networks, transportation facilities, and other spatial data used as geographic reference. This data includes nationally significant roads, railroads, waterways, airways, and transit ways where transportation terminals or interchange facilities, junctions, or intersections with other geographic features are represented. The dataset for the state of Maryland in region3 (with District of Columbia, Delaware, Pennsylvania, Virginia, and West Virginia) provide freight analysis network information in terms of rail and highway as well as intermodal terminal facilities. This data set has already been obtained from the BTS website.

3.2.5 Air Travel Surveys

3.2.5.1 Baltimore Washington Air Passenger Survey (COG/TPB) 2007

The Baltimore Washington Air Passenger Survey is conducted every 2 years at the three major airports in the Washington-Baltimore Region: Ronald Reagan Washington National Airport (DCA), Washington Dulles International Airport (IAD), and Baltimore/Washington International Thurgood Marshall Airport (BWI). It was conducted by the National Capital Region Transportation Board (TPB) in 2007 and jointly funded by the Metropolitan Washington Airports Authority (MWAA) and the Maryland Aviation Administration (MAA) of the Maryland Department of Transportation (MDOT). The sampling frame was based on the flight schedule. Approximately 27,300 passengers out of a total of 55,500 enplaning passengers on 685 flights were interviewed at the departure gate. More than 19,000 survey questionnaires were completed. The dataset includes airport ground access trip information in terms of departure and arrival time to the airport by ground access, flight origin/ destination, trip purpose, ground access mode choice, the most preferable airport in the Baltimore Washington airport as well as factors affecting airport choice decisions. This data set has not been obtained.

3.2.5.2 Baltimore Washington Air Passenger Survey (COG/TPB) 2009

This survey was intended to obtain information about travel patterns and user characteristics of air passengers in order to address airport terminal and groundside needs. The survey was conducted twice from October 11 to October 24 and from October 25 to November 7 in 2009. The survey collected passenger data in terms of access/egress mode of ground transportation (in case of non-connecting passenger) and connecting flight information (domestic or international with airline name), destination address (by airport and city name), trip purpose, method of ticket purchase, trip origin of the ground transportation mode/connecting flight (by city name), travel time of ground transportation, trip departure and arrival time to the airport, number of arrival companions (number of people traveling together), number of boarding companions, number of checked bags, whether the passenger was dropped by ground transportation at curbside, airport parking location, parking duration, factors influencing airport choices, most preferred airport in the Baltimore Washington region, airport choice set considered, passenger's current address (by city and zip code) and socioeconomic demographic including age, income, number of nights spent in the area, number of nights spent away, flight airline name, waiting time at the airport from arrival time and scheduled departure time, flight departure time, and final destination airport and region. The data includes 21,162 completed observations where 9,171 samples, 5,568 samples, and 6,423 samples were collected from BWI, DCA, and IAD respectively. The data were geo-coded in TAZ system. This data set has already been obtained.

3.2.6 Available Data in Adjacent States

3.2.6.1 Delaware Trip Monitoring Survey (DelDOT) 2008

The survey was conducted by the University of Delaware's Center of Applied Demography and Survey Research (CADSR) on behalf of the Delaware Department of Transportation. It was conducted as part of the Delaware Statewide Model Improvement Project. The survey focused on travel behaviors and drivers' preference of adults across the state on workdays. The survey was conducted by telephone; an adult of age 16 years and older, randomly chosen from each household, was called to respond to the questionnaire.

The data set includes trip diary information of up to 9 trips per day including origin/destination address, trip purpose by origin/destination, trip departure/arrival time, mode choice, vehicle occupancy. In the case where no trips were reported, respondents were requested to justify their behavior. The survey also includes respondent socioeconomics in terms of household characteristics, and EZ-Pass enrollment. A weighting technique was applied to the data collected, which allows the data to represent the entire state population and to avoid bias from survey instruments. The data consists of 2,962 individuals and 6,700 trips recorded. The data were geo-coded in a model grid system. This data set has already been obtained.

3.2.6.2 Virginia Household Travel Survey (VDOT) 2009

The Virginia household travel survey is an add-on to the 2008-2009 National Household Travel Survey effort conducted by the Federal Highway Administration (FHWA). The survey consists of 15,000 samples for all Virginia metropolitan planning organizations (MPO), with some additional sampling in other areas for statewide planning purposes. The data collection was completed by Westat, Inc. in May, 2009. The corresponding NHTS 2008/2009 data for the state of Virginia contains a total of 15,231 households including 33,096 individuals and 106,088 trips. This data set has not been obtained.

The summary of the existing data sources described in this Section is presented in Table 12.

Table 12. Summary of Available Data

Data Name	Sample Size	Survey Area	Collected Data	Collected Data Horizon
1.1 TPB/ BMC 2007/2008 Household Travel Survey	14,365 hh	TPB, BMC modeled area	Origin/destination trip purpose and address, departure time, mode choice, trip distance, travel time, travel party composition, and socioeconomic of all the household members	24 hour trip diary on weekday
1.2 NHTS 2001	4,240 hh	Maryland	Household characteristics, household member socioeconomics, vehicle information, short distance trip information as travel diary over the 24 hour period in term of departure time, trip purpose, distance to destination, travel time, main mode of transportation, access and egress modes used, household vehicle used, and long distance trip information	24 hour trip diary on weekday
1.3 NHTS 2008/2009	354 hh	Maryland	Household characteristics, household member socioeconomics, vehicle information, short distance trip information as travel diary over the 24 hour period in term of trip times, modes, purposes, vehicles used, travel time, travel distance, day of the week, and traveler group composition, and long distance trip information	24 hour trip diary on weekday
2.1 Auto External Survey (COG/TPB) 1994	12,655 trips	Expanded cordon of TPB area inbound direction	Trip time of day, trip purpose and address by origin/destination, mode choice, type of trips (i.e. internal-external), plate registration state, vehicle occupancy, vehicle ownership.	Single trip
2.2 Vehicle and Person External Trips Survey (BMC) 2006	3,700 trips	Internal and external of BMC region	Origin destination rough address (by street name, TAZ), trip time of day (by hourly interval), trip purpose by origin/destination, trip frequency, vehicle type, and vehicle occupancy.	Single trip

Data Name	Sample Size	Survey Area	Collected Data	Collected Data Horizon
3.1 Metro Rail On-Board Survey (WMATA) 2007	66,321 obs	WMATA Network on board passenger	Origin/destination by station, trip purpose, mode of access and egress, fare type, home jurisdiction, home address, vehicle ownership, employee of federal government eligibility, monthly transit benefit eligibility (calculated rail mile, travel time, and fare paid)	Single trip
3.2 Metro Rail On-Board Survey (WMATA) 2008	NA	WMATA Network on board passenger	NA	Single trip
3.3 Regional Bus Survey (COG/TPB) 2008	28,420 obs	Trips between Maryland and Washington DC and surrounding areas	Origin/destination rough address (by city and TAZ), time of day (AM peak or PM peak), origin/destination by purpose, access egress mode, number of buses taken for trip, fare method, socioeconomics (income, race), vehicle accessibility, vehicle availability the day trip is taken.	Single Trip
4.1 Truck Internal Survey (COG/TPB) 1996	1,861 obs	Washington region (expanded Washington-Baltimore region)	Trip diary information of origin/destination locations, vehicle characteristics, cargo types, etc.	24 hour trip diary on weekday
4.2 Truck External Survey (COG/TPB) 1996	4,892 obs	Washington region inbound direction (beyond the expanded region)	Trip diary information of origin/destination locations, vehicle characteristics, cargo types, etc.	24 hour trip diary on weekday
4.3 Commodity Flow Survey (BTS) 2007	493, 476 obs (outgoing, incoming from MD respectively)	Maryland	Freight flow data in term of types, origins and destinations (by state), values, weights, modes of transport, distance shipped, and ton-miles of commodities transported	Total by mode
4.4 TRANSEARCH Database	NA	Maryland	Freight flow data in term of origins and destinations (by counties, BEAs), commodity type (purpose), and units of flow by mode, the flow for each record by mode is specified in annual tons.	Total by mode
4.5 National Transportation Atlas Database (BTS) 2009	-	Maryland	Rail and highway, and intermodal terminal facilities in ESRI shape file	-

Data Name	Sample Size	Survey Area	Collected Data	Collected Data Horizon
5.1 Baltimore Washington Air Passenger Survey (COG/TPB) 2007	NA	Departure gates of airports (BWI, DCA, IAD)	NA	Single Trip
5.2 Baltimore Washington Air Passenger Survey (COG/TPB) 2009	21,162 obs	Departure gates of airports (BWI, DCA, IAD)	Access egress mode, departure and arrival time to the airport, flight origin/destination airport, trip purpose, ticket purchase method, trip origin address, group size, airport parking type, parking duration, the most preferable airport in the Baltimore Washington region, factor affecting airport choice decision, airport choice set considered, flight airline, residence address, socioeconomic	Single Trip
6.1 Delaware Trip Monitoring Survey (DelDOT) 2008	2, 962 obs	Statewide home phone interview	Origin/destination address, trip purpose by origin/destination, trip departure/arrival time, mode choice, vehicle occupancy and reason if no trip has been reported, household characteristics, EZ-Pass enrollment.	Single weekday trip diary (up to 9 trips)
6.2 Virginia Household Travel Survey (VDOT) 2009	15,000 hh	Virginia metropolitan planning organizations (MPO) with some additional sampling in other areas	Household characteristics, household member socioeconomics, vehicle information, short distance trip information as travel diary over the 24 hour period in term of trip times, modes, purposes, vehicles used, travel time, travel distance, day of the week, and traveler group composition, and long distance trip information	24 hour trip diary on weekday

Note: For freight surveys, the Commercial Vehicle Survey (COG/TPB) 2005 exists but is not described in here since the data and its corresponded information was not obtained.

3.3 ADVANCED TRAVEL DEMAND MODELS IN OTHER STATES AND THEIR DATA REQUIREMENT

The current MSTM model based on the traditional four-step framework could be improved to address transportation and policy needs. Based on the improvement plan prepared for MSTM in Task 2, this Section reviews and summarizes the types of data that have successfully been used in other statewide model systems. For each module, the minimum data required and the preferred data as well as their associated policy implications have been identified.

3.3.1 Advanced Discrete Choice Analysis of Trip Frequency, Destination, and Mode Choices

The Atlanta Regional Commission (ARC, 2008) developed a discrete choice model of trip frequency as part of the trip production module. The model estimates the daily trip frequency at the individual level. The trip frequency model was primarily calibrated on a home interview survey held in 2000 that contains information from 8,000 households. The collected data includes travel patterns for each household member over two consecutive days and a total of 100,000 trips. The large sample allowed the estimation of a logit model that successfully predicts the number of trips by purpose and by different socioeconomic characteristics. The trips were then aggregated to calculate the overall number of trips per traffic zone in the study area.

The California High Speed Rail Interregional Model (HSR) is another good example of advanced discrete choice methods applied to trip frequency, destination, and mode choice models (Cambridge Systematics, Inc., 2006). The statewide model considers both urban and interregional trips. Discrete choice models for trip frequency, destination choice, and mode choice were incorporated as sub-modules in the interregional model to allow for induced travel demand from the interregional market. The trip frequency model predicts the number of interregional trips that individuals in the household will make based on the household characteristics and location. The destination choice model predicts the destinations of the trip generated in the trip frequency component and it is based on zonal characteristics and travel impedances. The mode choice model predicts the mode that travelers would choose based on the mode service level and on travelers' and trips' characteristics.

The primary data source for this model system is the 2000/2001 Statewide Household Travel Survey. The survey was a travel diary including all in-home and out-of-home activities over a 24-hour period and was executed on weekdays. An additional Global Positioning System (GPS) Survey was conducted to identify under-reported trips. Three urban area household travel surveys were conducted to supplement the statewide travel survey, which are the Southern California Association of Governments (SCAG), Bay Area Metropolitan Transportation Commission (MTC), and Sacramento Area Council of Governments (SACOG). The survey data includes information in terms of number of trips by purpose, mode and distance. Air, Rail, and Auto Passenger Surveys were conducted in addition to the household travel survey. This survey collected revealed preference (RP) and stated preference (SP) mode choice data for air, rail, and auto passengers. The air passenger survey was conducted at boarding gates and outside the security area at six major airports in California. Rail passenger surveys were conducted by telephone using a database provided by Amtrak and included users of two commuter rail systems. These additional data sources combined with the household travel survey provided sufficient information to model travel behavior by trip purpose, mode, and distance and for each market segment considered in the model.

The highway network was constructed by incorporating the urban model networks into the statewide model network. Since the primary objective of this statewide model system was the estimation of HSR ridership, only the part of urban highway network within a five mile radius from the proposed high speed rail stations was considered. For the air network, 18 out of the 28 airports in California, representing 99 percent of the market, were chosen to resemble the California air network. The passenger rail network includes both intraregional and interregional services. Passengers were subdivided by mode; metro rail (i.e., BART), conventional rail (intercity and commuter services), and light rail were included into the analysis. The urban area transit network from MTC, SACOG, SCAG, SANDAG, and Kern regional systems were also included.

Socioeconomic data were incorporated in the model by combining socioeconomic data by traffic zone with CALTRANS statewide socioeconomic data and the U.S. Census bureau data. The household classification model is developed to forecast number of households for each of the classes considered. This household classification model uses joint distributions of household in the travel demand models and Census Public Use Microdata Sample (PUMS) to stratify the marginal distribution of households provided by the statewide and by the urban area models.

3.3.2 Tour-Based Approach

Tour-based models are in use among several MPOs and are currently implemented in a number of statewide model systems including those developed for New Hampshire, Ohio, and Oregon. General data required for tour-based models are household travel and activity data, spatial data in terms of land use, population and household demographics, and employment. Travel and activity data is normally collected through travel diaries, which record time use of household members throughout the day and usually include both in-home and out-of-home activities.

New Hampshire is a good example of a tour-based model system including a time-of-day module (Sharma *et al*., 1995). The model was intended to model travel by auto and transit modes for peak and off-peak periods during a summer weekday. The primary data for this model was the 1994/1995 New Hampshire Activities and Travel Survey. The survey collected data on activities and travel undertaken over a 24 hour period. A series of on board transit surveys was conducted in summer/fall 1994 to supplement the household travel survey for transit trips. This was essential because there were only a handful of actual transit trips in the main household survey. The vehicle intercept survey was conducted in 1994 to obtain data on external trips. The survey was conducted at 24 locations at major border crossings and three methods were adopted: the intercept survey, mail back survey, and license plate recognition (to match data from Division of Motor Vehicles). These data were essential in modeling trips by non-New Hampshire residents. In addition, a stated preference travel survey was conducted to capture rare or non-existent trip behavior especially for transit trips. Respondents were asked to make hypothetical choices given the availability of a new transit service, an increase in auto cost, or other potential changes to the transportation system. Stated preference data provided useful information about transit use and behavioral responses to improved transit level of service.

Highway network data from the NHDOT in addition to Geographic Design System (GDS) were used. Roadway characteristics were specified in terms of locations, roadway types, segment lengths, number of lanes and surface types. Transit operation data were collected to develop travel time and cost information needed for mode choice calibration and transit assignment. Intercity route service and commuter rail were considered and included information on fare structure, service frequency, travel time, and ridership rates. Relevant network data, such as TAZ network which is the transportation network representing specific highway and transit route, were used to estimate level of service variables.

Socioeconomic data were used to estimate the population and the number of households by type and for each zone. Socioeconomic data were obtained from the U.S. Census, New Hampshire Department of Employment Security, U.S. Census Public Use Microdata Sample (PUMS) for New Hampshire, and New Hampshire Office of Planning Population. Household forecasts were obtained at the community level while employment forecasts were available at the county level. In particular, the employment estimates were obtained from the New Hampshire Department of Employment Security. The socioeconomic forecasts were obtained from the New Hampshire Office of Planning at the municipality level. Moreover, the vehicle availability sub-model was added to complement the trip chaining approach and was based on household characteristics such as income, size and number of workers. The car ownership module was estimated by means of a multinomial logit model.

3.3.3 Population Synthesizer

The Population Synthesizer is generally used to generate a synthetic population of households that contains persons with demographic characteristics that resemble the Census data. The major data required for the Population Synthesizer development include census data such as the U.S. Census Bureau Public Use Microdata Samples (PUMS), land use data such as activity locations and characteristics, network data such as node and link files, and vehicle data.

The Atlanta Regional Commission model (Bowman and Rousseau, 1996) contains a good example of Population Synthesizer. The method adopted to generate synthetic households starts with the estimation of the number of households in each zone using several demographic categories. The base year population synthesizer analysis is based on the U.S. Census Data from the Public Use Microdata Samples (PUMS). The primary data from PUMS were the income, household size, employment status, and other related household characteristics.

The New Hampshire model is another good example of successful implementation of population synthesizer into a statewide model system (Sharma *et al.*, 1995). The New Hampshire Office of Planning has developed population and household forecasts at the municipality level. Their analysis was based on the base year 1990, since zone boundaries were chosen to be consistent with census geography, the estimation of population and number of households by type and for each zone was relatively simple.

3.3.4 Time-of-Day Model and Peak-Spreading Analysis

A time-of-day model could facilitate SHA in evaluating traveler response to time specific policy and dynamic routing. The simplest approach to account for time-of-day choice in a disaggregate model is to use household travel survey data. Bhat (1998) estimated a departure time choice model based on the San Francisco Bay Area household travel survey conducted by MTC in 1990. The survey is a single weekday travel diary where trip chaining of the family members in the household were recorded. With this approach, level of service data for each zonal pair in the study area on different time of day had to be generated based on OD trip tables. However, this approach lacks information in terms of trip flexibility and preferred traveler time windows.

The New Hampshire model (Sharma *et al.*, 1995) contains a time-of-day choice module. The primary data employed for calibration is the 1994/1995 New Hampshire Activities and Travel Survey, which contains data on activities and travel over a 24-hour period.

A stated preference survey could complement a household travel survey in order to estimate travelers' propensity to shift their departure/arrival time. The survey would be useful in collecting behavioral information on travel time flexibility for work and other trips, hours of activities at the destination and to estimate sensitivity to pricing, to travel time reliability and to the availability of alternative routes and modes. A good stated preference design for departure time choices can be found in Börjesson (2008).

3.3.5 Pricing Modules with Calibrated/Validated Sensitivities

A pricing module could be used to determine user's response to congestion pricing including HOV/HOT operation, dynamic tolling, and congestion pricing. Currently, there is no data in terms of traveler's response to toll pricing on the managed lanes in Maryland. Pricing modules with calibrated sensitivities to congestion pricing require stated preference data collection.

The survey design outlined by NuStats, Inc. (2005) could be conducted to examine the price sensitivity of managed lanes users. Nustats, Inc. conducted the Interstate 75 Stated Preference (SP) Survey for the Georgia State Road and Tollway Authority (SRTA) in collaboration with the Georgia Department of Transportation. Their survey provided respondents with hypothetical scenarios consisting of toll price and time savings experienced on HOT lanes. Future scenarios were pivoted from the recent trip made by the respondents, who were mainly commuters travelling during peak hours.

SP data collection is in general computer-assisted. Respondents residing within the buffer area of major freeways can be interviewed on the phone (CATI) or asked to access the questionnaire online, after receiving a flyer at freeway access or egress.

3.3.6 Integration of Sub-Area/Corridor Microscopic Traffic Assignment Model

This module requires corridor traffic data to produce microscopic traffic simulations. Zhang *et al.* (2008) developed a microscopic traffic assignment model to be used with PARAMICS; the software widely used by several agencies. In the work conducted in California, traffic data were extracted from the Freeway Performance Measurement System (PeMS) database. This dataset collected in March 2005 includes aggregate five-minute volumes and occupancy data from 2:00 PM to 3:30 PM on seven weekdays. The time interval chosen was based on the update interval required by the micro-simulator. It is desirable to collect traffic data on each link in the network; however, this requires tremendous data collection effort. Zhang *et al.* (2008) suggested that links with similar characteristics could be grouped together where only single or sets of representative link data need to be collected to represent each link group. For instance, in Zhang *et al*. (2008), links were categorized into 3 groups, namely simple bottlenecks, ramps, and intersections.

Radwan *et al*. (2005) implemented a microscopic traffic simulation to model emergency evacuation for the Florida Department of Transportation. The simulation was done using the INTEGRATION system. The U.S. Census data set was used to estimate trip departure rate by tracts, sections, and regions. The TAZ data were used to locate trip origins and destinations. Network data required for INTEGRATION are link characteristics (lengths, number of lanes, speed limit, turning movement restrictions), node characteristics (intersection and roadway geometry change coordinates), signal (timing and phasing), and origin/destination locations. The INTEGRATION network model was based on ArcInfo GIS data from Volusia County. Signal timing data was obtained from the Volusia County Traffic Engineering Department. The origin/destination data were obtained from the region's transportation network and TAZ data.

3.3.7 Multimodal Commodity-Based Freight Analysis Module

Two main methods exist to analyze and model freight transportation: (1) commodity-based models that focus on the amount of freight measured in tons and (2) truck based models that measure the freight movement in terms of truck traffic. The Quick Response Freight Manual II (FHWA, 2007) outlines the data needs for commodity-based freight modeling in the 4 step model as follows.

A trip generation process determines the commodity flows originating or terminating in geographic zones as a function of zonal or county population and industrial sector employment data. This robust and reliable approach for trip generation is based on regressions that predict total freight trips as a function of land use categories, number of employees and area characteristics. Data used for regular trip generation include socioeconomic data in terms of employment by industry and households/population, which is generally obtained from the U.S. Census Public Use Microdata Sample (PUMS). Special trip generator, such as trips at intermodal terminals, needs dedicated surveys that account for the activity corresponding to operations at intermodal sites and that report them to facilities available to carriers and shippers. The NCHRP Truck Trip Generation Synthesis 298 (TRB, 2001) outlines the three most widely used data collection techniques for developing truck trip generation data, which are vehicle classification counts, roadside intercept surveys and travel diary survey. The vehicle classification count involves visual observation of the vehicles and is based on number of axles, the vehicle configuration and body style. This type of survey is normally conducted at the access or egress locations of the sites of interest, such as intermodal facility or major freight corridor. The roadside intercept survey is normally conducted simultaneously with the classification counts. The intercept survey generally asks drivers about their trip origin-destination and about the characteristics of the end trip; this information can be related to socioeconomic data or land use variables for trip generation estimation. The 1998 truck intercept survey (ODOT, 2002) is a good source of data for the statewide freight model development. An intercept survey of freight trucks was conducted in Oregon where ports of entry, information in terms of weight, origin destination, and vehicle and commodity classification were collected. The 24-hour travel diary relies on a selected sample of registered trucks or business, and contains information in terms of origin, destination, trip mileage and duration, trip time of day, land use and activity at the trip end.

In the trip distribution step, the main data inputs needed are the total trips beginning in the first zone, the number of ending trips in the second zone, and the impedance of traveling. This information can be obtained from the commodity flow table or from the local vehicle survey data. For rail mode, the TRANSEARCH commodity flow database could be used.

In 1997, a dedicated commodity flow data collection was conducted in Oregon (ODOT, 2002) by the Metro in cooperation with the Port of Portland and ODOT. This survey collected information about the amount and type of goods being handled, whether they were headed within the region, transportation mode, and factors considered by businesses in making shipment decisions. The Iowa multimodal statewide freight transportation model is based on the TRANSEARCH database (ISU Center for Transportation Research and Education). The data is classified by Standard Industrial Commodity (SIC) code and the volume of freight by shipping mode in short tons. According to the Iowa model description, the TRANSEARCH data set purchased consists of several components: 1) Railroad Waybill Sample, 2) Commodity Flow Survey, 3) U.S. Census Survey of Manufacturers, 4) annual motor carrier industrial financial and operating statistics, 5) annual county employment and population data, and 6) actual truckload traffic flow data as reported by major truckload motor carriers.

For modal split, factors influencing mode choice decision are needed: goods' characteristics (commodity type, shipment size, shipment value), modal characteristics (speed, reliability, and capacity), total logistic cost (inventory cost, loss and damage cost, and service reliability cost), and overall logistics characteristics (length of haul, and shipment frequency). To estimate the modal shift between trucking and other freight modes, a dedicated survey of commodity flow data needs to be conducted. The preferred data would be a stated preference survey that includes factors influencing shipping mode choice decision of a company in goods transport (ODOT, 2002).

In network assignment, the most important factors to be included are: time of day factor (distribution factor by truck type and by time of day) and other related traffic indicators such as roadway capacity, volume delay function, and truck prohibitions.

Florida has implemented a good multimodal commodity-based freight analysis module (FHWA, 2007). Population and employment data were used as an input to the trip generation phase. Employment by commodity and employment data by industry sector were the principal variable used in the trip generation models. The forecast growth of external markets outside Florida were developed by factoring existing flows and by using the growth rates by industry and by state provided by the Bureau of Economic Analysis's BEA Projections. The intermodal facility data includes the activity (ton shipment) at major ports and intermodal terminals by commodity as well as the intermodal location. The intermodal facility locations were obtained from the 1999 National Transportation Atlas Database. In addition, the TRANSEARCH commodity flow database was purchased for Florida to represent existing freight flows.

3.3.8 Integration of Environmental Impact Post-Processing Module

This module deals with vehicle miles traveled (VMT) and with fuel efficiency. Vehicles are generally distinguished by type. The instate VMT by vehicle and fuel type is generally available from state DOTs. The fuel efficiency data is readily available as a default value in EPA's MOBILE6 model or from EIA's Annual Energy Outlook (Gallivan *et al*., 2008). The output of the statewide model in terms of trips by mode, vehicle type, and time of day needs to be converted to vehicle miles traveled (VMT), average vehicle speeds and operating conditions (which affect vehicle fuel economy) in order to compute the corresponding environmental impacts.

A promising tool to produce systematic bottom-up estimates of on-road transportation environmental impact is the MOVES model, currently under development by EPA (Gallivan *et al*., 2008). It enables motor vehicle emissions to be estimated at levels of detail as fine as a single county, a single hour of the day and a single vehicle type. Inputs to MOVES include data on vehicle population, fuel efficiency and VMT. The vehicle operating condition is generated by simulating actual vehicle drive cycles, including the effect of travel at different speeds.

However, inaccuracies in estimation could lead to errors in VMT calculations for different vehicle types and insufficient fuel efficiency data in national fleets might produce results that poorly represent state fleets. Thus, the primary challenge for estimating emissions within small areas is finding reliable data on fuel efficiency and on vehicle fleets. No comprehensive data on fleets is currently available below the national level. New York provides an example of a state that worked effectively with existing data resources to estimate the fuel efficiency of its fleet (Gallivan *et al*., 2008). In 2003, New York used data from EIA and FHWA to examine trends in fuel sales and VMT in recent years (Gallivan *et al*., 2008). Despite the fact that New York and New Jersey are a special case, with a distinct pattern of cross-border traffic, other states may be able to make similar improvements to their datasets. Another option for states is to develop altogether new datasets. California actually developed its own model to forecast fleet mix and fuel efficiency.

3.3.9 Vehicle Ownership and Availability Module

A vehicle ownership and availability module are needed to capture vehicle availability in a dynamic context, along with changes in household characteristics. The main data source for vehicle ownership module estimation is the national household travel survey (NHTS). NHTS 2001 is sufficient for the development of the vehicle ownership module for the State of Maryland. Other supplemental data include land use data, vehicle characteristics data and stated preference data. Land use data in terms of housing density, population, transit use levels and other related land use characteristics, which could influence vehicle ownership, would be desirable. Vehicle characteristics data are necessary to determine households' decisions over different vehicle types. Stated preference with hypothetical scenarios on vehicle characteristics (e.g. type, purchase price, operating cost, MPG, seats and other specifications) and for different policy scenarios (e.g. vehicle purchase tax, fuel tax, toll, deductions, etc), are able to capture an individual's preference over future technologies and attitude towards greener vehicles.

The New Hampshire statewide model is a good example of a vehicle ownership module. The vehicle availability sub-model was added to complement the tour-based model systems adopted to better explain trip chaining behavior. It is based on household characteristics such as household income, household size and number of workers. The method relies on multinomial logit model and predicts the number of vehicles per household. The vehicle availability module was incorporated in the trip generation process prior to tour generation to account for vehicle availability. The data necessary for the estimation were obtained from the U.S. Census Public Use Microdata Sample (PUMS) for New Hampshire.

3.3.10 Integration with Land Use and Economic Models

Ohio has successfully implemented an integrated land use/economic model. The land use module is based on PECAS (Production Exchange and Consumption Allocation System) (Hunt and Abraham, 2003) developed by the University of Calgary. According to Giaimo and Schiffer (2005), the Ohio land use module was based on the following data. The network data was primarily obtained from the Ohio DOT (ODOT). Network data outside Ohio were obtained from federal sources as well as from MPOs. Socioeconomic data include employment and wages data (ES 202) and U.S. Census Public Use Microdata Sample (PUMS). Land use and land value data were obtained from the Ohio Department of Natural Resources and County Auditors. The IMPLAN data set was purchased to develop models of local economies and to estimate a wide range of economic impacts.

The model developed in Oregon (ODOT, 2002), makes use of household stratified data (household size and household socioeconomics), which were obtained from the Public Use Microdata Sample (PUMS). The PUMS data allow for special tabulations that are not normally available for metropolitan areas. Land use and employment rates, together with other regional indexes were also used. Environmental constraints were used to capture potential development and to account for the presence of environmental sensitive regions. Furthermore, the cost to develop different types of land was accounted to ensure better accuracy in the analysis of the effects of land use changes. A stated preference survey of housing locations for movers was executed to study future land use policies, such as the impact of Transit Oriented Development (TOD) toward smart growth.

3.3.11 Trip/Tour Generation /Distribution/Mode Choice Analysis Module for Smart Growth Land Development

Data needs for this module are defined in Lund *et al*. (2004). This study focus on travel characteristics for transit oriented development in California. Survey data collection used for this analysis were based on dedicated data collection: 1) site intercept survey, 2) travel behavior survey, 3) resident survey, 4) office employee survey, 5) survey of retail patrons and 6) hotel guests and employee survey.

The site intercept survey was conducted at retail complexes, office buildings and hotels along major rail lines. The survey collected information in terms of parking supply and property management policies practiced by managers and agents. To assess pedestrian routes between sites and rail stations, census data were obtained and site visits were undertaken. Feeder transit service data were requested to transit agencies. A travel behavior survey was organized and different population groups identified within walking distance from rail stations. These groups include residents of high-density housing developments, employees of office buildings and hotels, shoppers and other patrons at major retail complexes, guests and employees of nearby hotels. The resident survey includes information on the respondents' household and personal characteristics, workplace, weekday travel choices and behaviors, commute-specific travel behavior and costs, employers' work policies, residential location, and past residential location and commuting behaviors. The office employee survey was similar in content to the resident surveys, but focused solely on work-related trips. The survey instrument included questions about the employees' household and personal characteristics, their commute trip (including costs), trips made during the workday, and past workplace locations and commuting behaviors. Surveys were distributed by employers to all employees at each site. The survey of retail patrons (including shoppers, employees and others) was conducted through an intercept method. Respondents were asked questions related to the purpose of their trip and their travel to and from the site; surveyors also estimated and recorded the respondents' age and race. The Hotel Guest and Employee survey was conducted to gain new information about the travel behaviors of hotel patrons staying near rail transit stations. This included information on hotel guests' activities and travel decisions during their stay at the hotel.

To fully account for dynamics in land use activity, a longitudinal activity-travel survey would be preferred. The longitudinal panel survey can significantly enhance the ability to understand and forecast travel behavior by identifying behavioral changes over time. The traditional travel survey generally records trip location as traffic analysis zone (TAZ). However, for the integration of land use development, location choices should include street pattern, density, surrounding uses, transit and pedestrian system characteristics, safety and security among other features. This is because the geographic information about the destination is important to understanding why the location is chosen (Mckeever and Griesenbeck, 2009).

3.3.12 Activity-Based Model with Phased Implementation

The required data for activity-based models are mainly household travel surveys and transit surveys. The transit survey is normally used to complement household travel survey for transit trips. The necessary component for the household travel survey is the travel diary in which the time being spent on activities throughout the day need to be collected. The socioeconomic data being used by several current activity-based models are extracted from the Census Public Use Micro Data Sample (PUMS) data.

Oregon is a good example of a state that has successfully implemented an activity-based model (ODOT, 2002); in this case the activity based model was integrated with a land use module. The Oregon statewide activity-based module relies on several travel survey data. The household activity and travel survey was conducted in 1994 as a cross-sectional survey to support OMIP activity based model development. The survey entailed both stated preference and revealed preference data collection. In addition, the MWVCOG survey collected time-use activity data for a 48-hour period to capture day-to-day variation in travel behavior. Eight rural Oregon counties were chosen to collect travel behavior data in 2000 and to examine trip generation in a small-scale regional transportation model outside MPO areas in Oregon. The survey was based on a two-day household activity survey where the eight counties were selected to provide a good cross-section of Oregon's rural area. The longitudinal panel survey was conducted in 2003. It was aimed at enhancing the model ability to understand and forecast travel behavior in response to information acquisition and behavioral changes over time. While a cross-sectional household travel survey is generally adequate for activity-based modeling, the study by Lawton (1996) suggested that additional data sets might be needed for further and more detailed policy analysis. Stated preference data would enable the development of synthetic activity-travel patterns and the way they adapt in response to land use changes. Longitudinal panel surveys of activities and travel allow for the analysis of adaptation/response to long-term decisions such as location choices and automobile holdings transactions.

3.3.13 Tracking the Benefits of Statewide Travel Demand Models

Ohio has financed a benefit tracking module. In this model, the user's benefit due to congestion reduction was calculated based on the model and ODOT's congestion management post-processor. The detailed O-D survey was conducted to determine the diversion of traffic which enters the city while the amount of traffic diverted to a particular area was determined by the statewide model (Giaimo *et al*., 2005). One of the implications of the Jobs and Progress Plan in the Ohio model (Taft and Proctor, 2003) was the increase in highway safety. 1999-2001 crash data were used to guide ODOT in allocating funds for the roadway improvement in high crash locations.

The summary of suggested data based on the review of other states' development module is shown in Table 13.

Table 13. Data Requirement for Advanced Travel Demand Model in Other States

Development Module	Model Reviewed	Data Used in the model	Minimum data required	Preferred data
1. Advanced discrete choice analysis of trip frequency, destination, and mode choices	California HSR model	2000/2001 Statewide Household Travel Survey, GPS travel survey, 3 urban household travel survey, Air, Rail, and Auto Passenger Surveys, Highway network from urban model, Caltran statewide socioeconomic data from Caltrans, U.S. Census (PUMS) , and the U.S. Census bureau data	Operational data for major transportation modes	SP of household travel survey
2. Tour-based approach	New Hampshire model (NHSTMS)	1994/1995 New Hampshire Activities and Travel Survey, on board transit survey 1994, vehicle intercept survey 1994, SP travel survey, Highway network data (GDS), Transit operation data , Socioeconomic data from U.S. Census (PUMS) and household forecast by community, and employment forecast by county	Household travel and activity data	Spatial data including land use, population, household demographics, and employment
3. Population synthesizer	Atlanta model (ARC), New Hampshire model (NHSTMS)	U.S. Census (PUMS), land use data , network data, and the vehicle population data	U.S. Census PUMS data	Land use data (activity locations and characteristics), network data, vehicle populations data
4. Time-of-day model and peak-spreading analysis	New Hampshire model (NHSTMS)	1994/1995 New Hampshire Activities and Travel Survey	Household travel and activity data	SP survey of travel propensity to travel time shift

Development Module	Model Reviewed	Data Used in the model	Minimum data required	Preferred data
5. Pricing modules with calibrated/validated sensitivities	Interstate 75 Stated Preference (SP) Survey for the Georgia State Road and Tollway Authority (SRTA)	SP survey of toll price and time savings from HOT lane	SP survey of Toll Pricing	SP survey of freeway toll pricing
6. Integration of sub-area/corridor microscopic traffic assignment model	Florida DOT	Aggregate five-minute volume and occupancy data, network GIS data. signal timing data, origin/destination TAZ data	Network GIS data. signal timing data, origin/destination TAZ data	Aggregate five-minute volume and occupancy data
7. Multimodal commodity-based freight analysis module	Florida statewide freight model	Population and employment data, Employment by commodity and employment data by industry sector, Highway network from Statewide Model , the National Highway Planning Network, TRANSEARCH, intermodal facilities location in coordinates	Employment by industry and households/populations (by TAZ), freight intermodal data, commodity flow table (or local vehicle survey data)	Intermodal transfer data and SP survey of factor influencing mode choice decision
8. Integration of environmental impact post-processing module	MOVES model (EPA)	Fuel efficiency and vehicle miles traveled (VMT) by vehicle and fuel type from EPA's MOBILE6 model or from EIA's Annual Energy Outlook, output of statewide model in term of trips by mode, vehicle type, and time of day	National data of fuel efficiency and instate VMT by vehicle/fuel type	State level data on fuel efficiency

Development Module	Model Reviewed	Data Used in the model	Minimum data required	Preferred data
9. Vehicle ownership and availability module	New Hampshire model (NHSTMS)	U.S. Census (PUMS) for New Hampshire	U.S. Census PUMS data	SP of vehicle characteristics
10. Integration with land use and economic models	Ohio Statewide Model	Network data (ODOT), Socioeconomic data included employment and wages data (ES 202) and U.S. Census (PUMS), Land use and land value data, IMPLAN data	Network data, Socioeconomic data from PUMS, Land use and land value data	IMPLAN data, Employment and wages data (ES 202), land use plan and the regional forecast , land use environmental constraint, development cost , SP survey on housing location for mover
11. Trip/tour generation /distribution/mode choice analysis module for smart growth land development	Lund *et al.* (2004) Transit Oriented Development in CA	1) site intercept survey, 2) travel behavior survey, 3) resident survey, 4) office employee survey, 5) survey of retail patrons, and 6) hotel guests and employee survey	1) site intercept survey, 2) travel behavior survey, 3) resident survey, 4) office employee survey, 5) survey of retail patrons, 6) hotel guests and employee survey	Longitudinal activity-travel survey, street pattern, density, and mix of surrounding uses, transit and pedestrian system characteristics, and safety and security among other features
12. Activity-based model with phased implementation	Oregon Statewide Model	Household activity and travel survey 1994, MWVCOG time-use activity survey, Rural Oregon travel behavior survey 2000, longitudinal panel survey 2003, Census Public Use Micro Data Sample (PUMS)	Census Public Use Micro Data Sample (PUMS), household travel activity survey and transit surveys	SP household travel survey, longitudinal panel survey of activities and travel
13. Tracking the benefits of Statewide travel demand models	Ohio Statewide Model	Detailed OD survey data, 1999-2001 crash data	-	-

3.4 SUMMARY

In this Chapter, data availability for the MSTM is identified and data requirements for future improvements are discussed. A key component of this analysis is the review of various advanced demand modeling approaches successfully implemented in other statewide travel model systems. This section summarizes Task 3 research findings on data availability and needs.

For the discrete model of trip frequency, the existing travel survey data (TPB/BMC 2007/2008, NHTS 2001) could be sufficient to develop a trip frequency model similar to the one adopted by the Atlanta Regional Commission (ARC, 2008). The development of an integrated trip frequency, destination, and mode choice model with characteristics similar to the California High Speed Rail (HSR) model needs additional data. In terms of destination choice, an interregional travel survey dedicated to rail and auto passengers is suggested. The air passenger survey is currently available from air passenger survey 2009, although only revealed preference data have been collected. The most complete source of data is a combination of revealed preference and stated preference data that allow for the representation of trips by purpose, mode, and distance and ensure a good coverage for each market segment in the model. To account for destination attraction characteristics, two additional data sets are suggested. First, level-of-service data providing information on travel between TAZ is needed. Second, the zonal-level land use characteristics file containing land use data at the TAZ level is needed (Pozsgay and Bhat, 2002).

For tour-based approach, our existing data do not contain all the information used to develop a model framework similar to the New Hampshire model. However, the information contained in the available household travel surveys (TPB/BMC 2007/2008, NHTS 2001) allows reconstructing tours out of the trips to be used for model estimation. In terms of transit data, transit operation data are necessary to develop realistic travel time and cost information for mode choice and transit assignment process. Socioeconomic data will be needed to estimate the population and number of households by type for each zone. However, apart from this data gap, other existing data such as the transit on-board survey and auto intercept survey are sufficient for the implementation of a tour-based modeling framework.

For population synthesizer, the U.S. Census Bureau Public Use Microdata Samples (PUMS) would be needed. This module could improve the trip generation process by achieving a greater level of accuracy for household classification forecasts. This could also enhance the discrete trip frequency model that is based on household characteristics and location.

For time-of-day model and peak-spreading analysis, the existing travel survey data (TPB/BMC 2007/2008, NHTS 2001) could be sufficient for the estimation of the model proposed by Bhat (1998). Household travel survey contains, in fact, details on trip chaining data and household socioeconomic data. However, with this approach, other time-of-day related factors including work hour flexibility and preferred departure time window could not be accounted for. The stated preference survey of traveler propensity to travel time shift would be suggested to account for those factors. This stated preference survey could also be integrated with the pricing modules that consider toll price by time of day and the preferences of travelers in shifting their departure time (Börjesson, 2008).

For microscopic traffic simulation module, the U.S. Census data could be used to estimate trip departure rate by tracts, sections, and regions. The TAZ data would be suggested to locate trip origin and destination. The network data and origin/destination data could be obtained from the region's transportation network and TAZ data. It would be preferred to obtain the aggregate five-minute volume and occupancy data on weekdays; links with similar local characteristics could be grouped together and only subsamples of link data within the group would be collected.

For a multimodal commodity-based freight module, the dedicated data collection at trucking facilities including freight terminals and ports would be preferred for the freight generation and distribution process. The commodity flow survey (CFS) together with the existing truck intercept survey could be used to identify state level locations; however, for better location accuracy, TRANSEARCH database would be suggested. To facilitate the multimodal freight mode share analysis such as truck and rail freight, the dedicated commodity flow data collection outlined in ODOT (2002) would be suggested. This information is essential in calibrating factors influencing mode choice decisions. The population and employment as well as employment by commodity and employment data by industry sector as outlined in the Florida model (FHWA, 2007) would also be preferred to facilitate the trip generation process. In terms of freight highway network, the National Transportation Atlas database 2009 could be used for Maryland and other states in the U.S.

For the integration of an environmental impact post-processing module, the instate VMT by vehicle and fuel type could be available from the Maryland DOT. The fuel efficiency data is readily available as a default value in EPA's MOBILE6 model or from EIA's Annual Energy Outlook. The instate data on vehicle fleet would be desirable to achieve better accuracy in the determination of the environmental impacts.

For vehicle ownership and availability module, the National Household Travel Survey (NHTS) 2001 is sufficient for the development of a vehicle ownership module for the State of Maryland. However, other supplement data including land use data, vehicle characteristics data, and stated preference survey of vehicle ownership could be incorporated to account for the factors influencing vehicle ownership and to test passenger's responses towards future policy scenarios related to taxation and vehicle technology.

For the integration with land use and economic models, socioeconomic data including employment and wages data (ES 202) and U.S. Census Public Use Microdata Sample (PUMS) would be needed as well as land use and land value data. The IMPLAN data would be suggested for the development of models related to local economies and for the estimation of a wide range of economic impacts. Environmental constraints are supposed to capture the potential development of environmentally-sensitive land where the land cost has a high impact on land use changes. Furthermore, a stated preference survey of housing location for movers could address land use policy, such as the impact of Transit Oriented Development (TOD) toward land use.

For a four step analysis module of smart growth land development, the dedicated data collection of : 1) site intercept survey, 2) travel behavior survey, 3) resident survey, 4) office employee survey, 5) survey of retail patrons, and 6) hotel guests and employee survey would be suggested. The preferred data includes the longitudinal activity-travel survey, street pattern, density, and mix of surrounding uses, transit and pedestrian system characteristics, and safety and security among other features. All this information is needed to capture the passengers' response to land use changes and the influence of destination characteristics toward destination choice.

For an activity-based model with phased implementation, the existing data could be sufficient in terms of travel survey and transit survey. The existing travel survey contains trip diary data, which support the activity-based model. The socioeconomic data could be obtained from the U.S. Census Public Use Micro Data Sample (PUMS) data. The preferred data to account for synthetic activity-travel patterns and responses to change in household location decisions include stated preference household travel surveys and a longitudinal panel survey of activities and travel.

For a benefit tracking module, a variety of data could be used to track the benefit of the MSTM in various applications such as personal travel, freight shippers/carriers, and the economy. For instance, detailed O-D surveys could be used to track benefits from congestion management policy by evaluating bypass traffic. Crash data could be used to improve the evaluation of the benefits deriving from improved safety conditions and to guide fund allocation towards high crash locations.

CHAPTER 4: MSTM IMPROVEMENT PLAN

4.1 INTRODUCTION

This Chapter summarizes findings from Task 4 of the project, and proposes a draft improvement plan for the MSTM based on current and emerging transportation planning and policy analysis needs in Maryland. After receiving SHA comments and suggestions, the UMD research team will finalize the proposed MSTM Improvement Plan. The final product should help SHA as well as the research team determine how to improve the current version of MSTM to better address important planning/policy issues and to meet other emerging needs.

4.2 BACKGROUND AND REPORT ORGANIZATION

In the U.S., more than thirty State Departments of Transportation (DOTs) have developed statewide transportation models with varying degrees of sophistication that go beyond traditional Metropolitan Planning Organization (MPO) boundaries to address transportation issues at the corridor, statewide, and regional levels. Chapter 2 of this report provides a detailed synthesis of these statewide transportation models, and discusses their methodology, data requirements, and relative advantages/disadvantages. Many states have taken an incremental approach to improve their demand models to meet emerging planning needs. Investment in model improvement should be strategically planned at State DOTs based on data sources, planning needs, policy initiatives, resource availability, and methodological feasibility.

The current version of the MSTM is based on the traditional four-step travel demand modeling paradigm, which still represents the state of the practice in statewide travel demand modeling. It is capable of providing demand estimates by various market segments (e.g. income, trip purpose) for highway, transit, and truck-related freight planning and policy analysis. The MSTM in this present form can meet many existing and emerging demand modeling needs in Maryland, such as corridor-level congestion management, evaluation of alternative socio-economic, demographic and land use scenarios, multimodal investment analysis, long-distance travel analysis, truck travel demand forecasts, and performance monitoring. There are also opportunities to further improve the MSTM to either enable new planning and policy analysis applications or to enhance model accuracy, precision, and reliability.

The development of the MSTM Improvement Plan has undergone a three-step process. The current and emerging transportation planning and policy issues that have high priorities for SHA are summarized in Section 4.3. A more detailed presentation of these issues is also available in Chapter 1. If the current MSTM is already capable of addressing a particular issue, there is no further improvement need. If the current MSTM cannot address a specific issue or only partially address it, various model improvement options are identified. In Section 4.4, all MSTM improvement options listed in Step 1 are discussed in greater detail with regard to their data requirements, other feasibility considerations, value added to the MSTM, and relative priorities according to the importance of the planning issues they address. In Section 4.5, a model maintenance and version control for the MSTM is proposed. In Section 4.6, a timeline for MSTM improvement is proposed. Model improvement options that are based on readily available data, have high priorities, and require the minimum to moderate SHA resources[5] are

[5] Model improvement options that are funded or cost-shared by other federal (e.g. FHWA) and state agencies are also considered short-term needs, even if their priorities for SHA are not extremely high.

categorized as short-term model improvement needs. Model improvement options, either relying on large new datasets, or having low priorities, or requiring extensive resources are considered long-term model improvement needs. The remaining model improvement options are considered mid-term improvement needs. Finally, the MSTM outreach activities are proposed in Section 4.7

4.3 PLANNING AND POLICY ANALYSIS NEEDS IN MARYLAND

As a working and comprehensive planning tool, the current MSTM is able to perform almost all traditional travel demand forecasting and planning analysis tasks, such as traffic volume and transit ridership forecasts, trip generation analysis, OD estimation, and major investment analysis (see Table 14.). Emerging planning and policy analysis needs in Maryland have been categorized into six additional groups in Table 14: (1) Performance measuring and monitoring; (2) Congestion management; (3) Multimodal transit; (4) Freight transportation; (5) Socio-economic and land use scenario analysis; and (6) Planning and policy analysis needs beyond MDOT and SHA. In case the current MSTM does not or only partially meet a particular need, one of more model improvement options are identified and listed in the table.

Table 14. Planning/Policy Analysis Needs and MSTM Improvement Options

Planning and Policy Analysis Needs	Can Current MSTM Meet This Need?	MSTM Improvement Options
1. Traditional Demand Forecasts and Planning Analysis		
1.1. Highway Traffic Volume Forecasts	Yes	
1.2. Transit Ridership Forecasts	Yes	
1.3. Vehicle Miles Traveled Forecasts	Yes	
1.4. Trip Generation Analysis	Yes	
1.5. OD and Route Diversion Analysis	Yes	
1.6. Major Investment Analysis	Yes	
2. Performance Measuring and Monitoring		
2.1. Mobility	Yes	
2.2. Safety	No	• Integration of safety into planning models • Linking MSTM with the new Highway Safety Manual crash forecasting procedure
2.3. GHG Emissions and Climate Change	Partially	• GHG Emission post-processor for urban/rural areas and passenger/freight vehicles • Linking the MSTM and traffic simulation models with sophisticated emissions analysis capabilities
2.4. Environmental Impacts	Partially	• Integrated post-processing modules for environmental impact analysis • Integration of the MSTM and MOSAIC
3. Congestion Management		
3.1. Managed Lanes	Partially	• Empirically estimated value of time distribution • Dynamic traffic assignment • Enhanced mode choice model with consideration for HOV/HOT options • Integration with traffic simulation models • Tour/activity-based approach

Planning and Policy Analysis Needs	Can Current MSTM Meet This Need?	MSTM Improvement Options
3.2. Tolling and Congestion Pricing	Partially	• Empirically estimated value of time distribution • Time-of-day choice model • Dynamic traffic assignment • Enhanced mode choice model sensitivity to highway tolling and pricing • Integration with traffic simulation models • Tour/activity-based approach
3.3. Comprehensive Highway Corridors Program	Partially	• Mesoscopic models that integrate travel demand and traffic simulation models • Tour-/activity-based model • Environmental/Sustainability impact post-processor • Integration of the MSTM and MOSAIC
3.4. Peak Spreading	No	• Time-of-day choice model • Tour-/activity-based model
3.5. Integrated Corridor Traffic Management	Partially	• Integration with traffic microsimulation models • Time-of-day choice model • Enhanced traffic assignment model • Enhanced mode choice model with sensitivity to corridor traffic management strategies • Tour-/activity-based model
4. Multimodal Transit		
4.1. Intra-City Transit Planning	Yes	• Re-calibrated mode choice model coefficients • Auto-ownership module • Enhanced transit network and transit assignment
4.2. Inter-City Transit Planning	No	• Re-calibrated mode choice model • New inter-city multimodal transit module • Inter-city transit network development
4.3. Transit Operations	Partially	• Enhanced mode choice model specification that capture transit operational characteristics
4.4. Non-Motorized Modes	No	• Expanded mode choice set • Non-motorized travel network development
5. Freight Transportation		
5.1. Trucking Analysis	Yes	• Enhanced trucking module with more truck types and sensitive to cost changes
5.2. Rail Freight Analysis	No	• Simplified truck-rail route diversion module • Commodity-based multimodal freight module • Rail network development
5.3. Air and Water-Borne Freight Analysis	No	• Commodity-based multimodal freight module • Air and water transportation network development
5.4. Major freight corridor analysis	Partially	• Trucking only with the current MSTM and need multimodal freight module and networks
5.5. Multimodal Freight Analysis and Intermodal Transfers	No	• Commodity-based multimodal freight module • Intermodal transfer facility network development

Planning and Policy Analysis Needs	Can Current MSTM Meet This Need?	MSTM Improvement Options
6. Socio-Economic and Land Use Scenario Analysis		
6.1. Transit Oriented Development (TOD)	Partially	• TOD trip generation, distribution, and mode choice module
6.2. Major Land Development Project	Partially	• Integrating travel demand and traffic simulation models with a mesoscopic approach
6.3. General Smart Growth Scenario	Yes	
6.4. Economic Development Scenario	Yes	
6.5. Economic Impact of Transportation Improvements	No	• Integrated economics and transportation model • Economic impact analysis post-processor
6.6. Land Use Impact of Transportation Improvements	No	• Integrated land use-transportation model • Land use impact post-processor
7. Planning and Policy Analysis Needs beyond the MDOT and SHA		
7.1. Natural resource, environmental, integrated Chesapeake Bay watershed planning	No	• Integration of transportation, natural resource, watershed, and environmental planning models
7.2. Long-distance passenger travel	Yes	• On-going FHWA efforts in long-distance passenger travel modeling at the national level; MSTM long-distance passenger travel module can be updated based on the FHWA study findings
7.3. Long-distance freight travel (Airports and Water Ports in Maryland)	Partially	• Special freight trip generator module • Multimodal freight analysis module
7.4. Mega-region planning crossing state borders	No	• Mega-region transportation models that consider multiple states such as the I-95 coalition model or the FHWA EAR mega-region modeling project

4.4 MSTM MODEL IMPROVEMENT OPTIONS

The various MSTM model improvement options identified in the last column of Table 14 are described in greater detail in this section. Table 15 focuses on the discussion of the data requirement, feasibility, value to SHA, and priority for each model improvement option. There are also additional model improvement options that do not necessarily address a specific planning issue, but can improve the performance of the MSTM in general and therefore benefit a number of MSTM applications. Examples include:

1. Rural Parameters: Recalibrating MSTM model coefficients for rural Maryland;
2. Feedback Loops: Introducing feedback loops that enhance consistency among various MSTM modules;
3. Algorithm Improvement: Reducing model running time by developing more efficient computational algorithms for traffic assignment and other model steps; and
4. Population Synthesizer: Better representation of different market segments both expand model capabilities and enhance model accuracy.
5. Advanced Discrete Choice Model: Enhance various MSTM modules (e.g. trip frequency, destination, mode, and route choices) with nested and other advanced choice models

Table 15. MSTM Improvement Option Details

Model Improvement Options	Description and Value	Priority	Data Available?	Additional Data Sources
Integration of Travel Demand and Traffic Simulation Models	These improvement options take advantage of both the capabilities of demand models in capturing broader behavior responses and the superior network traffic and congestion representation in traffic simulation models. This integration have applications related to congestion management, tolling, pricing, major land use project impact analysis, pollution and GHG emission analysis, and evacuation planning and operations.	High	Partial	Need behavioral data regarding time of day, route and possibly model choices
Integrated MSTM Post-Processors	Post-Processors that enable SHA to apply the MSTM for various impact analysis, e.g. pollution and GHG emission, energy and environment, natural resources, economic impact, land use impact analyses. Post-processor can be developed independently. MSTM may also be integrated with MOSAIC for these applications.	High	Yes	
Enhanced Multimodal Transit Module	Re-specify, re-calibrate, and re-validate the transit model to include additional modes (e.g. HOV/HOT, non-motorized modes) and to make mode choice sensitive to tolling, pricing, traffic management, and transit systems operations. Improved transit network data and transit assignment algorithms. Nested mode choice model that recognize correlation among transit alternatives.	High	Partial	Need multimodal transit network data, RP or SP data on mode choice, and highway and transit systems operations data.
Commodity-Based Multimodal Freight Analysis Module	Consider various truck types, rail, air and water freight modes with commodity-based market segmentation. This mode improvement meet emerging multimodal freight analysis needs. Methodological options range from simplified multimodal freight diversion module to fully developed commodity-based multimodal freight OD, modal shift, and route assignment modules. The scope should also include special freight trip generator analysis (i.e. airports and water ports) and intermodal facility analysis. Multimodal freight network and zone system should also be enhanced.	High	Partial	Commodity flow data at the county-level or FAF zone levels are available. National multimodal freight network and intermodal transfer facility data in FAF and other sources can be used to build the multimodal freight network for Maryland. Need additional data on special generators. Possibly need more detailed data on network and intermodal transfer facilities in MD.
Time-of-Day, Peak Spreading, and Dynamic Network Modules	Current MSTM is static on both the demand and network sides. Time-of-day and peak spreading models introduce demand-side dynamics. Dynamic or pseudo-dynamic traffic assignment introduces network dynamics. The consideration of these dynamics is necessary for modeling the impact of tolling, congestion pricing, HOT, integrated traffic management, economic and land development, and any other scenarios where peak spreading and dynamic routing are likely.	High	Partial	Need value of time information from RP or SP surveys. Need time-of-day choice and dynamic routing information from RP, SP or other data sources (e.g. GPS).

Model Improvement Options	Description and Value	Priority	Data Available?	Additional Data Sources
Algorithm Development and Enhancement	Reducing model running time by developing more efficient computational algorithms for traffic assignment and other model steps	High	Yes	No additional data needs
Rural-Area Parameters	Many current MSTM modules are estimated with urban data. Model coefficients for rural zones should be recalibrating with rural data.	Medium	Partial	Not enough rural data in Maryland. Rural data from Delaware and Virginia are available and can be used.
Intercity Multimodal Transit Module	Transit systems that cross traditional MPO boundaries should be analyzed with the MSTM, including the MARC trains and intercity buses. This module needs to be developed.	Medium	Partial	Need intercity transit network and operations data. Also need travel behavior or existing ridership data regarding intercity transit in Maryland.
Automobile Ownership Model	As a pre-processing module, it is more sensitive to future policy scenarios related to taxation and vehicle technology and permits more accurate trip generation and mode choice analysis.	Medium	Partial	Household-level auto-ownership data are available for DC and Baltimore area. Rural data is lacking, but data from adjacent states may be used.
Population Synthesizer	This module can improve the trip generation process by achieving greater level of accuracy for household classification and composition forecasts. It could also help the discrete choice models and other MSTM modules that are based on household characteristics.	Medium	Yes	Socioeconomic and demographic data in Maryland are available from various sources, e.g. Census Public Use Microdata Sample, recent household surveys in Maryland.
Transit Oriented Development Analysis Module	This module recognizes the difference in trip generation, distribution and mode choice characteristics between TOD zones and other non-TOD zones. Mixed-development, compact-development, and other smart-growth land use strategies may also be considered in this module.	Medium	No	Limited empirical data in Maryland or elsewhere. TAZ-level trip generation model with land use characteristics as independent variables is probably the most promising practical approach.
Tour /Activity/Agent-Based Demand Model	Move to the tour/activity/agent-based paradigms that are superior to the four-step trip-based approach in theory. Tour-, activity- and agent-based models are also typically more capable in addressing demand and network dynamics. MSTM applications related to pricing, tolling, demand management, integrated traffic management, and many other planning and policy issues can benefit.	Medium	Partial	May be developed with existing data only. But ideally, more detailed disaggregate travel behavior data, land use data, and multimodal transportation network data should be obtained.
Advanced Discrete Choice Modeling and Feedback among MSTM modules	Advanced discrete choice models, such as nested logit models, allows greater model sensitivity to market segmentation, accessibility, and the characteristics of origin and destination zones. They also enhance model consistency by integrating multiple MSTM modules (e.g. trip frequency, destination, mode, time of day, and route choices). Model consistency can also be enhanced with feedback loops (e.g. consistent travel time and cost in distribution, mode choice, and route assignment modules).	Medium	Yes	Mode-specific surveys, household surveys, SP/RP surveys in Maryland can provide sufficient demand-side data at least for the urban areas. Level-of-service data (time, cost, etc.) and zonal land use and economic characteristics are also available.

Model Improvement Options	Description and Value	Priority	Data Available?	Additional Data Sources
Safety Module	To monitor the impact of planning and policy decisions on safety, the MSTM needs to incorporate a safety module that estimates future accident rates and severities under alternative planning scenarios. The module can be based on existing SHA initiatives in the Safety area.	Low	Yes	Need to collect some additional roadway, traffic, and safety data to produce Maryland-specific safety model parameter; Alternatively, HSM parameters may be used.
Integrated Economic-Land Use-Transportation Model	It enables two-way feedback between the transportation system and the land use/economic systems. It should improve the analysis of transportation planning and policy scenarios with expected significant impact on land use and/or regional economy.	Low	No	Need data on the regional economic system by economic sectors, housing price, business building rents, and other economic and land use system characteristics.
Integrated transportation-water shed-natural resource planning model	The ideal method for integrated transportation, watershed, and natural resource planning.	Low	No	Need extensive data on green infrastructure, Chesapeake Bay watershed, natural resources, and the connection between transportation and natural systems in Maryland.
Long-distance passenger travel module	Current module in MSTM is not sensitive to planning and policy alternatives. The improved module can forecast future long-distance passenger travel demand. The OD pattern, mode share, and route choice should be sensitive to price signals and transportation system performance. Mega-region models that cross Maryland borders are currently being developed.	Low	No	Getting accurate and representative data regarding long-distance passenger travel is a challenging task. FHWA is currently investing major resources in this area.

4.5 MODEL MAINTENANCE AND VERSION CONTROL

Model maintenance activities help keep statewide transportation models up to date in terms of transportation network structure, socioeconomic and demographic data, link data, and calibration data. Generally, model maintenance is a continuous process. While there is less need for maintaining newly developed modules, mature models require constant maintenance.

States have adopted different approaches for statewide transportation model maintenance. Missouri maintains its statewide model every two years with new traffic count information. Ohio's interim model is maintained annually with employment and network data updates. In addition, the Ohio model has also been adjusted or updated based on project analysis needs. The New Jersey statewide model is usually updated with new inputs and revalidated when needed for a particular transportation project analysis task.

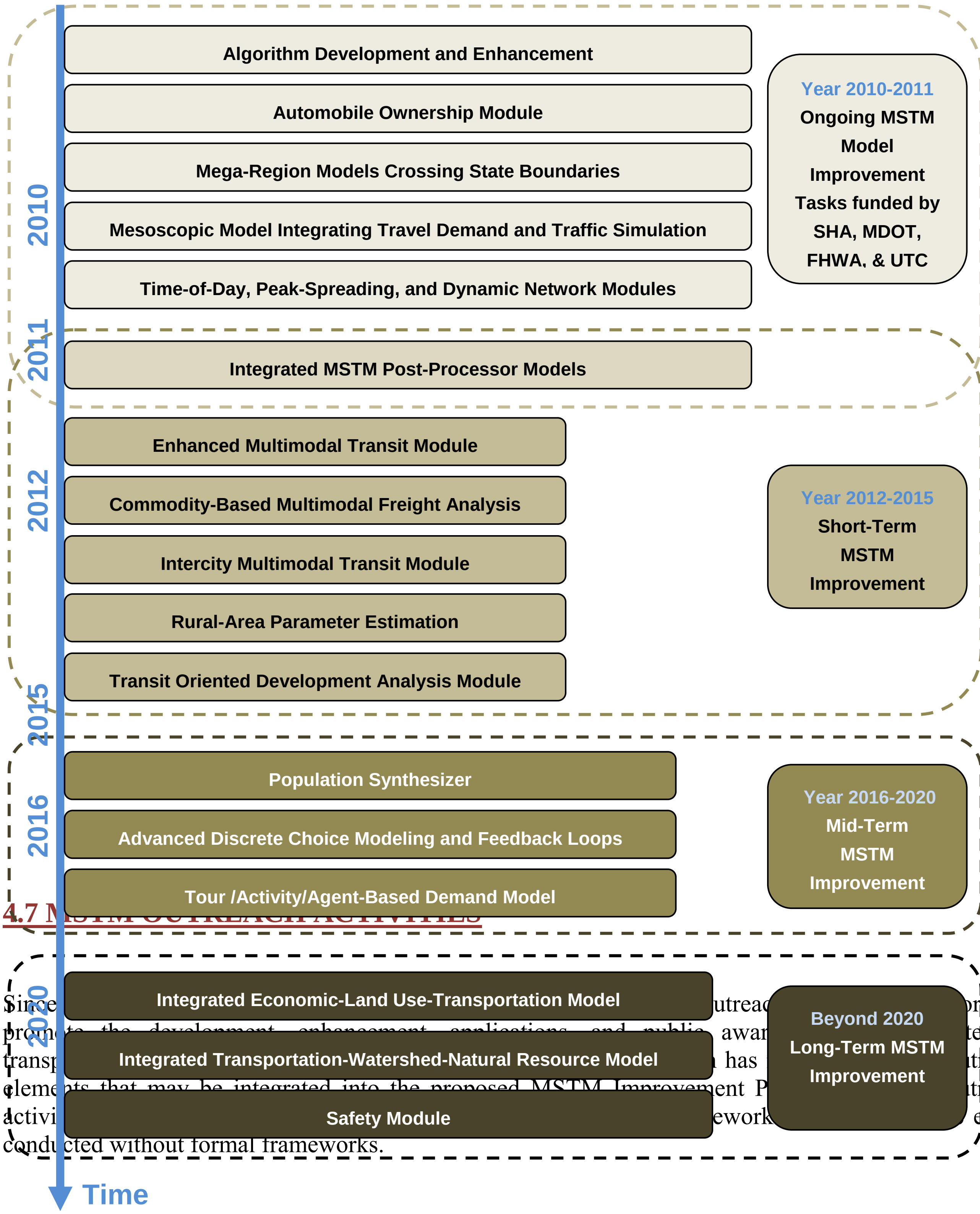
Unlike the more routine and frequent model maintenance activities, model version updates are usually less frequent and on an as-needed basis. In best practices, the version updating cycles tend to coincide with statewide planning updates. Most states tend to update their transportation plans every five years, while some indicate a 10-year cycle for major model revisions (e.g. Connecticut and Ohio). There are also cases where model version updates are driven by specific projects or analysis needs. For instance, Massachusetts noted that their next statewide model version update is likely to be driven by air quality conformity analysis needs. Indiana updates its statewide model largely based on major investment projects, e.g. I-69 corridor project.

Statewide model maintenance and version control strategies developed for the Virginia statewide model is described in greater detail herein as a somewhat unique case. Virginia's statewide model was built from MPO models and employs an incremental approach for model improvement. The model version control is undertaken with two separate tracks: (1) The "fast-track model" slated for a rapid deployment and focused on highways and trucks; and (2) the "full-featured model" that considers multimodal and intermodal person and freight movement. In terms of model maintenance (though not formally established yet), VDOT intends to utilize established resources to maintain and update their statewide model. The in-state highway network will be frequently updated by the Virginia's Highway Traffic Records Information System (HTRIS), while the external roadways would likely be updated as per the FHWA National Highway Planning Network (NHPN) database. In addition, the future-year network will be updated according to completed and planned highway projects. On the freight side, private-sector data will be purchased to keep freight activities and supply information up-to-date.

The best current practices suggest that the release of major new versions of statewide transportation models be based on the cycle of statewide transportation plan updates. This will avoid having two different versions of the statewide models in the same statewide transportation planning cycle (e.g. MSTM Version 1 for the current statewide plan cycle; MSTM Version 2 for the next statewide plan cycle). Major model improvements that can significantly alter model outputs may be scheduled concurrently with major MSTM version updates. In some cases, urgent transportation planning and policy analysis needs (e.g. a major investment project such as HOT lanes, or major intercity transit investment) may also justify model enhancements and a new version of the statewide transportation model, which could be accommodated with minor MSTM Version Updates (e.g. Version 1.0 updated to Version 1.1 within the same statewide transportation plan cycle). Routine model maintenance activities can be scheduled regularly (e.g. annually or bi-annually) or scheduled to coincide with the release of major model input data (e.g. network data, household survey data, census data, land use data). If necessary, model maintenance may also be conducted based on specific project analysis needs. Since any input data updates and other maintenance activities could impact model outputs, a new version may be generated following each scheduled model maintenance activity (e.g. Version 1.1.1 updated to Version 1.1.2 after a model input data update).

4.6 PROPOSED MSTM IMPROVEMENT PLAN

Based on the identified planning and policy analysis needs and their priorities in Maryland, a Strategic MSTM Improvement Plan (SMIP) is proposed and illustrated in the graph below. The plan incorporates four groups of model improvement tasks: (1) 2010-2011 ongoing tasks already funded by various sponsors; (2) 2012-2015 short-term MSTM improvement tasks; (3) 2016-2020 mid-term MSTM improvement tasks; and (4) Beyond 2020 long-term MSTM improvement tasks.



4.7 MSTM OUTREACH ACTIVITIES

Since ... utreac... rt and promote the development enhancement applications and public awar... tewide transp... has ... treach elements that may be integrated into the proposed MSTM Improvement P... treach activi... ework ... easily conducted without formal frameworks.

4.7.1 Outreach to MSTM Stakeholders: Maryland Multimodal Modeling Committee

This committee can be modeled after the Oregon Modeling Steering Committee, which has been successful in promoting travel model development and applications in Oregon. The Maryland Multimodal Modeling (M3) Committee may serve as a stakeholder steering committee with several key missions:

- Identify multimodal transportation modeling needs in Maryland not sufficiently addressed with MPO models;
- Serve as a stakeholder group with representatives from agencies that are interested in MSTM because they are MSTM developers, users, beneficiaries, and/or funding sources;
- Prioritize MSTM improvement needs and build transportation modeling capacity in Maryland through research, training, and outreach;
- Coordinate transportation survey and modeling efforts among state, regional and local agencies in Maryland;
- Promote MSTM applications and support transportation related decision-making in Maryland.

The committee may be led by SHA with representatives from MDOT, other State transportation modal agencies, Maryland Department of Planning, Maryland Department of Housing and Community Development, Maryland Department of Natural Resources, MPOs, local governments, air and water port authorities, freight interest groups, and universities. The M3 Committee may establish a website and regularly publishes newsletters and brochures to disseminate information and document MSTM development activities, applications, and outreach efforts. Subcommittees and task forces may be established under the M3 committee leadership to address specific needs and tasks. Based on current needs, a Peer Review subcommittee/panel may be established first. Additional subcommittees related to user groups, survey and data, research and capacity building and applications may be created later if necessary.

4.7.2 Establishing MSTM Credibility: Peer Review Panel

One of the best approaches for establishing model credibility is to have the model reviewed by an external peer review panel (i.e. reviews not conducted by model developers or those with conflict of interests) and improve the model based on review comments. A peer review panel for MSTM could be part of the larger MSTM steering committee (see Section 4.7.1) or as a separate entity. The panel members would review current models and make recommendations for future model improvement. The nature of the peer review panel should be advisory. SHA, as the primary MSTM developer, may or may not follow panel recommendations. Two levels of peer review may be established. Major MSTM version updates and model improvement plans may be reviewed by a panel of nationally and internationally renowned modeling experts (similar to the Peer Review Panel for the Oregon Modeling Steering Committee and the Oregon Transportation and Land Use Model Integration Program). Minor MSTM version updates and individual model improvement tasks may be reviewed by a local peer review panel.

CHAPTER 5: PROTOTYPE TIME-OF-DAY CHOICE MODEL

5.1 INTRODUCTION

Time-of-Day and Peak Spreading are considered high priority improvement options for the MSTM as described in Chapter 4. They introduce demand-side dynamics, which enable for network dynamics through dynamic traffic assignment. The consideration of these dynamics is necessary for modeling the impact of tolling, congestion pricing, HOT, integrated traffic management, economic and land development, and any other scenarios corresponding to peak spreading and dynamic routing.

This chapter aims to propose the prototype time-of-day choice model for the state of Maryland. This model accounts for departure time shift and peak spreading under different time-of-day traffic conditions. The chapter is organized as follows: Section 5.2 summarizes literature reviews of departure time choice model focusing on data used, methodology, and applications. Based on the review findings in Section 5.2, the methodology is selected and the prototype departure time choice model is proposed in Section 5.3. The proposed model is estimated from the simulated data for the morning commute in I-270 corridor in 2010. In Section 5.4, the ongoing effort in collecting dedicated survey data for departure time choice model for the state of Maryland is outlined. The survey was designed to investigate travelers' departure time according to the hypothetical time-of-day congestion pricing scheme on the Capital Beltway (I-495). The findings of this chapter are summarized in Section 5.5.

5.2 SUMMARY OF REVIEW FINDINGS

5.2.1 Fundamental Approaches in Modeling Departure Time Model

Literature on departure time choice models is mainly based on two approaches: discrete and continuous models. The majority of the departure time choice models for academic and real applications are developed under the discrete choice framework. Continuous departure time choices are formulated as a finite number of discrete time periods where the choice of these time periods is modeled using the random utility theory framework.

Discrete choice alternatives could be defined in different ways. Discrete departure time models generally refer to the method proposed by Small (1982), who used the multinomial logit (MNL) to model departure time. The problem with the MNL model is the property of independence from irrelevant alternatives (IIA) which in effect, results in adjacent departure time periods to be correlated. Various relaxations of this assumption have been proposed by researchers, which are described in more detail in the next section.

Continuous departure time model generally refers to the method developed by Vickrey (1969). His method is based on a single bottleneck where demand-supply equilibrium at this bottleneck is determined. This method has been named by Van Vuren *et al.* (1999) as 'Equilibrium Scheduling Theory' (EST). Vickrey (1969) model presented the formulation of disutility $V(t)$ with departure time t as following:

$$V(t) = \alpha T(t) + \beta \max\left(0, \left(\mathrm{PAT} - t - T(t)\right)\right) + \gamma \max\left(0, \left(t + T(t) - \mathrm{PAT}\right)\right)$$

Where, $T(t)$ is the travel time associated with a departure at time t; PAT is the preferred arrival time at destination; α, β, and γ are parameters to be estimated.

The continuous departure time model represents the more realistic departure time setting, which is continuous in nature by providing a fine resolution of time. However, it has several model limitations. Incorporating time-varying variables in continuous models, such as level of service, is challenging and generally requires specialized econometric software to be developed (Bhat *et al.*, 2003). Discrete time model, on the other hand, enables analysts to easily accommodate time-varying coefficients and covariates with commercially available software. The discrete time model is also more commonly used in practice and can be easily incorporated with travel demand frameworks of MPOs (Bhat *et al.*, 2003).

5.2.1.1 Choice Alternatives

The choice set generation process consists of defining an acceptable range of departure time intervals considered by the decision maker and the corresponding choice alternatives. Ben-Akiva and Bierlaire (2003) suggest that departure time intervals should be based on the range of feasible arrival times for each individual n $[PAT_{n,min};PAT_{n,max}]$, and let $[TT_{n,min};TT_{n,max}]$ be the range of travel times. Then, the interval of acceptable departure times is $[DT_{n,min};DT_{n,max}] = [PAT_{n,min}–TT_{n,max};PAT_{n,max}–TT_{n,min}]$. According to Ben-Akiva and Bierlaire (2003), the overestimation of acceptable departure time length will not cause the model error if the model is well-specified. However, underestimating the interval length can cause significant errors in the model.

5.2.1.2 Attributes

In discrete departure time models, the departure time choice approach is generally formulated in terms of trade off between time-of-day travel times and cost and the traveler's inherent preference for undertaking certain activities at certain times of day. The most commonly used approach is based on the schedule delays (Vickery, 1969). These variables represent the loss in utility associated with shifting a departure earlier or later relative to the preferred arrival time (*PAT*) or preferred departure time (*PDT*) of the existing trip. Depending on the collected information, the schedule delays could be computed-based on either preferred arrival time (*PAT*), or preferred departure time (*PDT*).

Ben-Akiva and Bierlaire (2003) specified a schedule delay variable based on the preferred arrival time (*PAT*) given that a penalty free interval is defined as the feasible arrival time; $[PAT_{n,min};PAT_{n,max}]$ of individual n. It is assumed that an individual suffers no penalty if the arrival time lies within the penalty free interval. Schedule delay early (SDE_n), and schedule delay late (SDL_n) are defined as

$$SDE_n = \text{Max}[PAT_{n,min}-AT_n,0]$$

$$SDL_n = \text{Max}[AT_n-PAT_{n,max},0]$$

Where the actual arrival time AT_n is equal to $DT_n+TT(DT_n)$, given $TT(DT_n)$ is the travel time if the trips starts at time DT_n.

Schedule delay could also be specified based on preferred departure time (*PDT*). Börjesson (2008) specified the schedule delay as

$$SDE_{in} = \text{Max}[PDT_n -DT_{in},0]$$

$$SDL_{in} = \text{Max}[DT_{in}-PDT_n ,0]$$

Where DT_{in} is the departure time of alternative *i* and individual *n*. *PDT* in that study is defined as the departure time the driver would choose if there are no queues on the road network. And *PAT* is defined as *PDT* plus the travel time the driver would face if there are no queues on the road network.

5.2.2 Model Structure and Specification

Modeling approaches for departure time choice model are grouped into three categories: (1) Multinomial Logit Model (MNL), (2) Nested Logit Model (NL), and (3) Error Component Logit Model (Mixed Logit). The research team reviewed the study corresponding to these modeling approaches focusing on the model specification, data used, and model application.

5.2.2.1 Multinomial Logit Model (MNL)

A) MNL Model of Departure Time Choice

A number of research studies for departure time choice are based on MNL; below is just a sample of the numerous papers on the subject.

Bhat *et al.* (2003) estimate the MNL model for departure time choice for home-based trip. Data used in the analysis is the 1996 activity survey data collected by the North Central Texas Council of Governments (NCTCOG) in the Dallas-Fort Worth area. Four models were estimated independently for each trip purpose: recreational, shopping, personal business, and community trip. The departure time choice alternatives are represented by six temporally contiguous discrete time periods throughout the entire day. Variables included in the models are socioeconomics, employment related attributes, and trip related characteristics. This departure time choice model treats mode choice as being exogenous to the departure time.

In his doctoral dissertation, Jin (2007) used RP data sets from the 2001-2002 NHTS and 2000-2001 California Statewide Household Travel Survey to investigate the traveler decision on departure time choice for long-distance travel.

The extracted data from the NHTS data consist of 3,322 long distance trip records by 2,439 individuals from 1,924 households. Multinomial logit (MNL) model of departure time choice is estimated from NHTS data. The model includes six discrete time periods throughout the entire day. The six time periods are early morning (0:00 am-6:29 am), a.m. peak (6:30am-8:59 am), a.m. off-peak (9:00 am-11:59 am), p.m. off-peak (12:00pm-15:59 pm), p.m. peak (16:00 pm-18:29 pm), and evening (18:30 pm-23:59 am). The departure time choice was constructed throughout the day because the thesis focuses on long distance trips, which are generally not limited to the daytime period. The mode choice was based on three alternatives (car, airplane, and others) that were treated as dummy variables in the model. Based on NHTS data, the analysis found that household size and household structure (life cycle) are significant in the model when they entered the model separately. Other significant variables include number of non-household member in the trip, time spent at destination, age, sex, mode choice, weekend, worker, and purpose.

In the CA data, 4,527 distinct long distance trips made by 3,089 travelers from 2,795 households were used for the analysis. The MNL model is estimated with the same choice structure used for the NHTS model; results indicate that traveler’s work status, number of jobs, household income, and number of household worker are significant in departure time choice modeling.

In conclusion, Jin's (2007) analysis indicates that trip characteristics including trip duration, activity duration, trip purpose, and whether the trip takes place on the weekend has a strong effect on long distance departure time choice. Traveler socioeconomic (sex, age, work status, and education level) and household characteristics (household income, household size, number of workers and number of vehicle) are found to present a significant impact on departure time choice. It was also found that mode choice did not have a significant impact toward departure time choice, and therefore nested logit model was not considered. To conclude, a small scale SP survey was suggested in this study to capture traveler trade-off between the departure time and the related constraints, such as peak hour congestion, mode captivity, and work schedule.

Saleh and Farrell (2005) estimated a MNL model for departure time choice by accounting for variable congestion pricing and trip scheduling flexibility. Travel survey data (both RP and SP information) on congestion charging collected in the city of Edinburgh was used for the analysis. RP data consists of work trip information (mode choice, travel time, usual departure time, etc.), work and non-work schedules. The SP survey consists of three sets of congestion pricing scenarios related to mode choice, departure time choice, and combined mode and departure time choice. The choice considered in the model are (1) depart the same time as reported, (2) depart earlier than reported, and (3) depart later than reported. Variables introduced in the SP experiments are toll price, departure time change, and travel time saving. Variables included in the model are arrival time, travel time delay, departure time (in minute), travel distance (in miles), travel time, toll price, and the schedule delay. The arrival time is included as the categorical variable describing traveler's usual arrival time at work. The categorical value of arrival time represents six time intervals. Value of 1 to 5 represents five 30-minute time intervals from 7:00 to 9:30 am and 6 represents time after 9:30 am. The model calibrated supports the fact that work schedule flexibility affects departure time choice.

B). MNL Model with Latent Choice Set

Ben-Akiva and Boccara (1995) estimate the discrete choice model with the latent choice set using a choice set generation model. In their setting, it was assumed that the choice set considered by each decision maker could not be deterministically explained by observed data due to the existence of decision maker's perceptional and attitudinal effects. The data used for their study came from a travel survey conducted in Baltimore, Maryland in 1977. Three mode choices are considered (1) Drive Alone, (2) Shared Ride, and (3) Transit. They proposed a probabilistic choice set generation model that represents the probability that each choice set is considered by the decision maker. The estimation method is based on the data from the alternative availability information obtained from the survey question and the observed choice made. Their choice set generation model is treated as a latent process of constraint elimination where explanatory variable contains both latent variable and observable characteristics. It is assumed that situational constraints and preferences across individuals in the choice set generation process are heterogeneous. In the analysis, two models are compared, the MNL and the probabilistic choice set (PCS) model; the comparison is performed on mode shift sensitivity due to change in LOS. Increase in vehicle travel time for auto and decrease in service frequency for transit were used in two tested scenarios respectively. The MNL model shows higher mode shifts compared to the PCS model in auto and transit respectively. This is due to the fact that the PCS model gives full consideration to an alternative availability, which restricts some portion of the mode shift to be impossible to occur due to unavailability of that new alternative. The study concludes that the PCS model generally outperforms a simple MNL model when substantial heterogeneity in the choice set affects decision maker choices.

5.2.2.2 Nested Logit Model (NL)

Departure time models based on MNL do not account for correlation among time periods. This limitation is usually relevant when the time interval for each period is comparatively small, thus the consecutive time periods become very similar. A nested logit model (NL) is able to handle this correlation issue. In nested logit models, a uniform amount of correlation within each nest is allowed while alternatives in different nests are still uncorrelated. Apart from MNL and NL models, some studies have focused on the ordered generalized extreme value (OGEV) model. The special features of OGEV model is its capability to allow the estimation of a correlation parameter, for each pair of alternatives, which depend on the distance between the alternatives along the ordering scale, such as clock time in departure time choice. With this approach, the highest correlation is expected to be found for adjacent departure time alternatives, while departure time alternatives far away from one another will be independent as in the common MNL. Another approach in identifying correlation parameter is the paired combinatorial logit (PCL) model. The PCL model allows for different correlation between each pair of alternatives; however, the correlation factor does not depend on the distance between the alternatives in the OGEV.

A). Nested Logit Model (NL) of Mode Choice and Departure Time

Ozbay and Yanmaz-Tuzel (2008) estimate the NL model based on stated preference survey data to evaluate the New Jersey Turnpike time-of-day pricing program. They estimate the departure time choice as a result of time-of-day pricing. The NL structure was chosen for their model to account for the fact that travelers using E-ZPass tags are subjected to an off-peak period toll discount. In their NL model, the upper nest of the model is the transponder ownership choice model (E-ZPass tag or cash) and the lower nest is the choice of travel period conditional on the transponder ownership choice. Their departure choice is categorized into three alternatives: pre-peak period, peak period, and post-peak period. Socioeconomic variables in the upper nest include income, age, sex, education, employment, and E-Z Pass possession. Variables in the lower nest are LOS variables, including travel time, toll price, early arrival (minute), late arrival (minute), difference from departure time to preferred departure time, and travel distance.

Bhat (1998) estimates the NL model of mode choice and departure time choice for urban shopping trips. Data for the analysis is based on the 1990 San Francisco Bay area travel survey. The dataset comprises 4,516 home-based person shopping trips, which are obtained from the overall single-day travel diary sample. Three mode choices are considered: drive alone, shared ride, and transit. The departure time choice for shopping trips is represented by several temporally contiguous discrete time periods, which are AM peak (6AM-9AM), AM mid-day (9AM-12Noon), PM mid-day (12Noon-3PM), PM peak (3PM-6PM), and other (6PM-6AM). The reason to aggregate travel time intervals relies on the fact that respondents are believed to choose among broad time periods rather than choosing to shop at a precise continuous point in time. His study also focuses on the effect of travelers from time-of-day pricing and peak spreading.

The study proposed three models for mode-departure time choice: the multinomial logit (MNL) model, the nested logit (NL), and the MNL-OGEV (ordered generalized extreme value) model. The NL and MNL-OGEV model consist of mode choice at the upper level and the departure time choice at the lower level. In MNL-OGEV model, the upper level is the MNL model where the lower level is the OGEV model. Socioeconomics are included in the mode choice model, while the trip destination attributes are included in both the mode choice and departure time choice. Trip destination attributes are the categorization of whether the destination is in SF downtown area or a Central Business District (CBD). LOS variables used in the analysis are: travel cost, travel time, and out of vehicle travel time over trip distance. The statistical test (Likelihood Ratio test) in his study showed that both MNL and NL are rejected due to mis-specification compared to the MNL-OGEV model. MNL and NL were found to be biased in terms of level of service estimates, which is inappropriate for transportation policy evaluations.

B). Continuous Cross Nested Logit Model (CCNL)

Lemp *et al*. (2010) estimated a continuous cross-nested logit (CCNL) model for departure time choice. The analysis is based on the 2000 San Francisco Bay Area Travel Survey (BATS) data focusing on the work-tour departure time of the 48-hour weekday sampling frame. The advantage of the CCNL model is its ability to provide continuous choice setting while allowing for correlation across similar choice alternatives (for instance those intervals that are close on a continuous time spectrum). The choice set is represented by departure time choices for trips from home to work over a continuous time period from 0 to 24 hours. Since the data is RP type, travel time by time-of-day is estimated from a speed regression equation. The nested structure model consists of allocation parameter and inclusion parameters. The allocation parameters define the degree to which an alternative is a member of the nest. In their setting, only departure time within one hour from the hour nest could have a positive allocation parameter. The inclusive parameter represents a correlation between a pair of departure times depending on their time difference. The empirical result concludes that CCNL perform better than continuous logit model in out-of-sample prediction where CCNL offers more flexible choice behaviors, as well as welfare estimation.

C). Paired Combinatorial Logit Model (PCL)

PCL model relaxes the NL restriction of identical correlation among all the alternatives in the common nest by allowing for different correlations for each pair of alternatives. This allows PCL to account for flexible error correlation structure compared to MNL, and NL while still exhibiting the computational advantage deriving from the closed form for choice probabilities. In the paper by Koppleman and Wen (2000), the PCL model performance is assessed in comparison to the MNL, and the NL models. The analysis is based on the intercity mode choice data from the Toronto-Montreal corridor in 1989, which contain three intercity modes of interest (air, train, and car). The corresponding PCL structures for these three modes are two pairs of alternatives: train-car, and air-car. The PCL models have three specifications based on common similarity structure: train-car, air-car, and train-car with air-car. These PCL models are compared with NL with two different structures (train-car nested, and air-car nested) and the MNL model. Their result indicates that PCL with two pairs structure (train-car with air-car), which could not be incorporated in the NL model, provides the best model based on log-likelihood and statistically rejects all other models. PCL models also show significant differences of direct and cross elasticities compared to NL and MNL model. The PCL enables the direct and cross elasticities result to provide a better prediction compared to NL, where elasticities obtained from two nesting structure either under or overestimate the elasticities. Their results show that by allowing for a pair-wise correlation structure in the PCL model, the result obtained from PCL is substantially different from MNL and NL, which highly affects forecasted passenger demand.

5.2.2.3 Error Component Logit Model (ECL)

Another line of research focuses on the mixed logit (ML). Amongst all its features, ML models allow the estimation of a complete variance-covariance matrix and handle asymmetric disturbances. The model that approximates all other known discrete choice random utility models (i.e. Multinomial Probit, OGEV, and PCL), can be used for a data set with repeated observations from the same individual.

A). Error Component Logit (ECL) of Joint Departure Time and Mode Choice

De Jong *et al*. (2003) estimated an error component logit model for the joint choice of time of day and mode choice based on stated preference data for car and train travelers in the Netherlands. The analysis was based on data derived from a SP survey where respondents were persons traveling in the extended peak periods (6:00-11:00 and 15:00-19:00) as car drivers or train passengers within the Netherlands. The interview was done with the computer-assisted personal interviews (CAPI) by WinMint software. The alternatives provided to respondents are: (1) depart the same time as reported (with the same mode as observed), (2) depart earlier (with the same mode as observed), (3) depart later (with the same mode as observed), (4) another mode of transportation (car for transit users and transit for car users) with the observed departure time. The stated preference data are tour-based. The attributes for both the outward trip and the return trip were presented in each of the scenarios proposed to the respondent. The attributes incorporated in the SP scenarios are departure time from home, arrival time at destination, departure time at destination, arrival time at home, tour travel time, duration of stay at destination, travel cost, peak charges, probability of a seat on the train, and train service frequency. The model includes three departure time alternatives of observed mode choice and one mode choice alternative that is different from those observed. The variable included in the model are travel time, travel cost, schedule delay late (SDL), schedule delay early (SDE), time difference between the presented time of day and the observed time of day as well as socioeconomic variables. Three utility functions were estimated independently from three sample segments: (1) home-based (HB) tours by car drivers, (2) non-home-based (NHB) business trips by car drivers, and (3) home-based (HB) tours by train travelers. The main difference from HB and NHB model is that HB model is specified as tour-based with trip attributes including both outward and returning legs while the NHB was specified as trip based. The analysis concluded that the error component logit generally outperforms MNL, and NL. Simulation results on the substitution pattern (by departure time of same mode, and mode versus time of day alternatives) and demand shift corresponding to increased travel impedance (i.e. travel time) were also presented.

Börjesson (2008) estimates a departure time choice model incorporating travel time variability. Her analysis is based on joint RP and SP data relative to the congestion charging trial in Stockholm 2006. In this survey, the respondents were randomly chosen among the car drivers traveling toward the city center during the extended morning period (06:00-10:00).

The RP survey consists of driver's trip information in term of observed trip (departure, arrival time, trip duration, preferred departure time, travel time) as well as socioeconomic information. Respondents were also asked what time they would have departed, and travel time the trip would have taken if there were no traffic backups. This information was used to derive indications on travelers' preferred departure time. The SP survey was mailed to the selected drivers on the next day. In SP survey, respondents were asked to choose among 2 car alternatives with different departure times, as well as switching to public transport (with reported departure time), bike and walk, or cancelling the trip. Variables in the SP survey include departure time, travel time, travel time uncertainty, and travel cost.

The joint departure time model consists of 21 choices from RP and SP alternatives. Three choices are SP alternatives, two car alternatives with different departure times, and one public transportation alternative. Another 18 choices are RP alternatives, assuming that the individual chooses to depart within the extended morning peak (5.15-9.45 a.m.) This time frame is divided into 18 groups of 15-minute departure time intervals. Variable included in the models are travel time, travel cost, travel time variability, schedule delay early (SDE), schedule delay late (SDL), and the respondent's possession of season tickets for the transit. The departure time shift was accounted in both the RP and SP choices by the schedule delay variable.

The review summary of departure time choice models is outlined in Table 16.

Table 16. Review Summary of Departure Time Choice Model Structure

Author	Choice	Data Used	Variable	Application
1. Multinomial Logit (MNL) Model				
1. 1 MNL Model of Departure Time choice				
Jin (2007)	Departure time choice of 6 periods	2001-2002 NHTS and 2000-2001 California Statewide HTS	Trip characteristics, socioeconomics	Long distance trip
Saleh and Farrell (2005)	Departure time choice of 3 alternatives (depart early, late, or as actual)	congestion charging in Edinburgh (RP, SP)	Arrival time, travel time delay, departure time, travel distance, travel time, toll price, and the schedule delay	Variable congestion pricing, schedule work flexibility
Bhat *et al.* (2003)	Departure time choice of 6 periods	1996 activity survey data (NCTCOG)	Socioeconomics, employment related attributes, and trip related characteristics	
1.2 MNL Model with Latent Choice Set				
Ben-Akiva and Boccara (1995)	Combination of Choice Set from 1) Drive Alone, 2) Shared Ride, 3) Transit	1977 Baltimore Travel Survey	Household characteristics for choice set generation, and LOS for choice model	Sensitivity to mode shift due to change in LOS
2. Nested Logit (NL) Model				
2.1 NL Model of Mode Choice and Departure Time				
Ozbay and Yanmaz-Tuzel (2008)	Transponder Ownership (upper level), and 3 departure time choices (lower level)	New Jersey Turnpike (NJTPK) Travel Survey Data	Travel time, toll price, early arrival, late arrival , schedule delay, travel distance, socioeconomics, and E-Z Pass possession	New Jersey Turnpike time of day pricing program
Bhat (1998)	Joint model of mode (3 choices) and departure time choice (5 choices)	1990 San Francisco Bay area travel survey	Socioeconomics, trip destination attributes, and LOS variables	Departure time choice for urban shopping trips
2.2 Continuous Cross Nested Logit (CCNL) Model				
Lemp *et al.* (2010)	Continuous Departure Time Model	2000 San Francisco Bay Area Travel Survey (BATS) data	LOS variables, socioeconomics interaction variables	Welfare estimation from toll policy
2.3 Paired Combinatorial Logit (PCL) Model				
Koppleman and Wen (2000)	Mode choice for Intercity trip (air, train, and car)	Toronto-Montreal Corridor Travel Survey	LOS variables including service frequency (train), in vehicle travel time, out of vehicle travel time, and travel cost	Ridership forecast for intercity train service

Author	Choice	Data Used	Variable	Application
3. Error Component Logit (ECL) Model				
3.1 ECL Model of Joint Departure Time and Mode Choice				
De Jong *et al*. (2003)	Joint model of departure time and mode choice (4 choices for each market segment)	RP/SP Data from car and transit users in the Netherland	Travel time, travel cost, schedule delay, time difference from scenario to observed, socioeconomics	Peak spreading, toll pricing
Börjesson (2008)	Joint RP/SP Model of 3 SP and 18 RP choices	Survey on congestion charging in Stockholm 2006 (RP,SP)	Travel time, travel cost, travel time variability, schedule delay, and transit season ticket possession	Time of day pricing

5.3 PROPOSED DEPARTURE TIME CHOICE MODEL

5.3.1 Data

Data used in this proposed model is simulated from the static O-D matrices, which are created from the I-270 corridor microscopic traffic simulation model developed as part of the I-270 Integrated Corridor Management (ICM) Phase-1 application by SHA, UMD CATT Lab and Caliper, Inc. The sub-area analysis conducted and that is based on a regional planning model, results in 399 origin destination pairs for the year 2010. These O-D matrices cover the a.m. peak period from 6:00 a.m. to 10:00 a.m., where the warm-up period from 3:00 a.m. to 6:00 a.m. is allowed for simulation purposes. These hourly matrices are divided uniformly into 15-minute interval O-D matrices as an input to the microscopic simulator.

Based on 15-minute interval O-D matrices, the I-270 corridors network is simulated with Transmodeler as shown in Figure 42. Roadways on I-270 network have very high connectivity, which enable the dynamic routing between several arterial and the main freeway routes alternatives. The drivers in the simulator have the potential to switch routes in response to recurrent congestion and incidents in this dense arterial network along the corridor. The data simulated from the15-minute O-D matrices over the a.m. peak period of 6:00 a.m. to 10:00 a.m. is then used as a data set for the prototype departure time choice model.

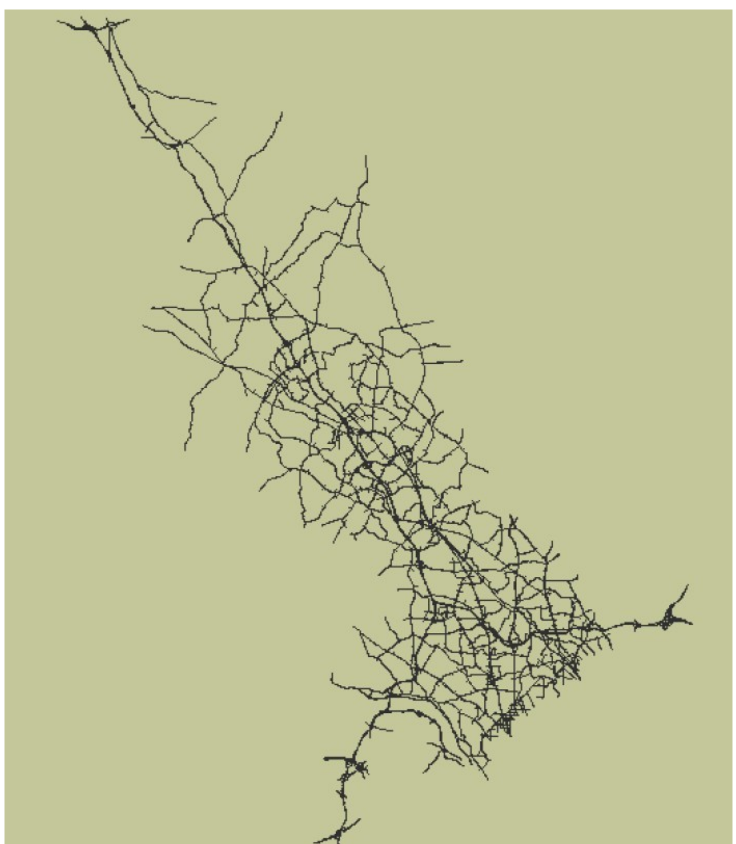


Figure 42. The Microsimulation of the I-270 Corridor

5.3.2 Model Specification

Based on the literature review, it is assumed that MNL is an adequate method for demonstration-level departure time choice analysis in spite of the limitation due to the IIA property. In fact, as argued by Small (1987), MNL approach is a satisfactory tool for exploratory work. When choosing to work with advanced methods the user is confronted by the trade-off between accuracy and simplification. Advanced models are often time-consuming and sometimes interpreting the results may be difficult especially when data are insufficient or the quality is not entirely adequate.

5.3.2.1 Departure Time Choice Model

It is assumed that travelers prefer to arrive at their destination as close as possible to the preferred arrival time (PAT) while avoiding time wasted in congestion (Small, 1982). Arriving earlier implies waiting to perform the planned activity while arriving later might compromise the scheduled sequence of activities. Utility functions based on these assumptions consist of delay time and schedule delay terms representing the impact of the arrival time variance. Based on the dataset, departure time is divided into 4 time periods: (1) 6:00 to 6:59 a.m., (2) 7:00 to 7:59 a.m., (3) 8:00 to 8:59 a.m., and 9:00 to 10:00 a.m. Let *n* denotes individual and *i* denotes choice alternatives. The utility function of individual *n* over 4 choice alternatives could be written as:

$$
\begin{aligned}
&i\text{=1 (6:00-6:59 a.m.);} && U(ni) = \theta_1.Delay_i + \theta_2.SDE_{in} + \theta_3.SDL_{in} + \varepsilon_i \\
&i\text{=2 (7:00-7:59 a.m.);} && U(ni) = \theta_1.Delay_i + \theta_2.SDE_{in} + \theta_3.SDL_{in} + \theta_4.M_n + \varepsilon_i \\
&i\text{=3 (8:00-8:59 a.m.);} && U(ni) = \theta_1.Delay_i + \theta_2.SDE_{in} + \theta_3.SDL_{in} + \theta_5.M_n + \varepsilon_i \\
&i\text{=4 (9:00-10:00 a.m.);} && U(ni) = \theta_1.Delay_i + \theta_2.SDE_{in} + \theta_3.SDL_{in} + \theta_6.M_n + \varepsilon_i
\end{aligned}
$$

The corresponding variables in the utility function are computed as follows: $Delay_i$ is the total delay time (minutes) for departure at time interval *i*. M_n is the trip mileage of individual *n*. SDE_{in} and SDL_{in} are the schedule delay early and schedule delay late respectively for choice *i* and individual *n*. Schedule delay represents the amount of time arriving earlier and later than preferred arrival time (PAT_n) respectively, which could be written as:

$$
\begin{aligned}
SDE_{in} &= \max[PAT_n - AAT_{in}, 0] \\
SDL_{in} &= \max[AAT_{in} - PAT_n, 0]
\end{aligned}
$$

Since the research team did not have travel time data of departure time other than what it had actually observed, delay time data generated by the micro-simulation to reflect the travel time variation was used. The delay time for choosing other departure time alternatives is synthesized using the average delay per mile d_i for that particular time interval *i* between the same O-D pair. Therefore, in the schedule delay equations, the actual arrival time AAT_{in} corresponding to each departure time choices is written as:

$$AAT_{in} = deptime_i + fft_n + d_i.M_n$$

In the equation, $deptime_i$ denotes alternative i departure time, which is simplified to be the median of the time interval i (6:30 a.m., 7:30 a.m., 8:30 a.m., and 9:30 a.m. respectively). fft_n denotes the free flow travel time, which is provided by the simulator.

5.3.2.2 Preferred Arrival Time

The preferred arrival time (*PAT*) is essential for the proposed model specification. Generally, *PAT* is not included in traditional travel surveys. However, for commuter trips, *PATs* are likely to be associated with the official work start time (Ettema, Tamminga *et al.* 2005). The *PAT* can be simplified by assuming that it is exactly the same time when the work starts (i.e. the official work start time t_w), which is usually included in the travel survey. In the case where preferred arrival time or work starting time data is unavailable, the *PATs* can be generated using a normal distribution (Lam 2004) with mean $\bar{t}_w$ and standard deviation σ_{t_w} . The method is adopted here in the proposed prototype model.

5.3.3 Model Result and Interpretation

The model results are shown in the Table 17. All parameters indicate significant impact on departure time choice. Delay time has the largest negative impact toward departure time choice. The schedule delay late is approximately twice the magnitude of schedule delay early, which indicates that, for morning commute trips, arriving at work later than *PATs* contribute to greater impact toward departure time choice compared to arriving early. Distance estimates imply that travelers' most preferred departure time is in the 2nd interval (7:00-7:59 a.m.), followed by 3rd interval (8:00-8:59 a.m.), and 4th interval (9:00 -10:00 a.m.) respectively, with the 1st interval (6:00-6:59 a.m.) being the least preferred departure interval. This effect increases as the trip distance increases.

Table 17. Departure Time Choice Model Result

Variable	Variable Name	Coefficient Est.	Std. Error	t Statistic
θ_1	Delay (minute)	-0.009379	0.174×10^{-3}	-54.0
θ_2	Schedule Delay Early (minute)	-0.0043146	0.570×10^{-6}	-126.2
θ_3	Schedule Delay Late (minute)	-0.007878	0.276×10^{-5}	-47.5
θ_4	Distance (mile)	0.1087	0.987×10^{-3}	110.1
θ_5	Distance (mile)	0.1052	0.931×10^{-3}	112.9
θ_6	Distance (mile)	0.07766	0.892×10^{-3}	87.1
Statistics Summary				
Number of Observations = 383,818				
Loglikelihood (At Zero) = -532,084.7				
Loglikelihood (At Const.) = -528,967.3				
Final Loglikelihood (At Optimal) = -515,270.1				
ρ^2 w.r.t. zero = 0.0316				
ρ^2 w.r.t. constants = 0.0259				

This prototype time-of-day choice model has been applied to the I-270 traffic microsimulation model to address the issue of unrealistic congestion observed in the simulator, which is a result of using OD tables produced by planning models. Unlike traffic microsimulation models, planning models allow the volume/capacity ratio to exceed 1. Thus, one of the main challenges here lies in applying the peak hour demand from the planning models to the traffic microsimulation model. To solve this problem, the time-of-day choice model was integrated to divert excessive travel demand to neighboring hours.

The time-of-day choice model effectively helped the I-270 traffic simulation model shift travel demand from the peak hour to the neighboring hours and mitigated the congestion level. The significant improvements are shown in Table 18. 200,000 more vehicles were able to be released onto the network and the average delay per trip decreased by 12.5%.

Table 18. Comparison of the Baseline and Scenario that Applies Peak Spreading

	Baseline	Applying Peak Spreading
Total Number of Departures	740,960	942,478
Total Number of Arrivals	483,900	616,674
Avg. Entry Delay (min)	50.02	36.70
Avg. Delay per Trip (min)	48.43	42.21
Avg. Stop Time (min)	44.09	31.74

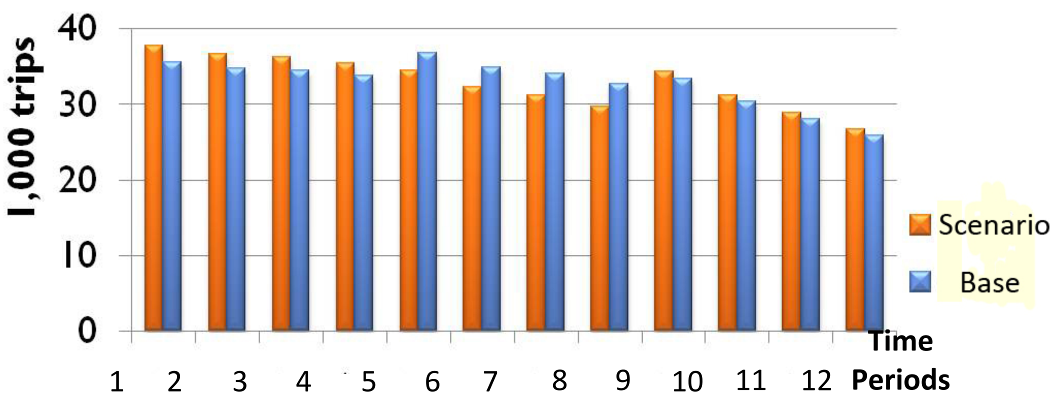


Figure 43. The Peak Spreading Sensitivity Test Result

The peak spreading sensitivity is tested and illustrated in Figure 43. By testing a scenario wherein the average delay time between 7 am and 8 am increases by 50%, the model is able to capture a peak spreading where 10,546 trips (8% of total trips) switch their departure times to time periods before 7 am or after 8 am. Among these trips with their departure time changed, about 64% decided to depart earlier, while the rest switched their departure time to 8 am or later.

This pilot study demonstrates the importance of a time-of-day switching analysis tool in the statewide models, and also emphasizes the great potential of integrating demand models, such as the time-of-day choice model, with the traffic microsimulation. As a powerful tool in corridor-level planning and operation control, traffic microsimulation is being implemented by planning agencies and consultants. Its capability is further enhanced by this integrated modeling structure. Since this prototype model is based on simulated departure time data, it is not recommended for immediate implementation in the MSTM for time-of-day shifts and peak spreading analysis. The model can be significantly improved with actual departure time choice data from RP or SP surveys. Sources of RP departure time choice data include recent household travel surveys in Maryland. As a part of a separate project, the research team is currently collecting RP data via a web-based survey (more details in the next section).

5.4 DEDICATED SURVEY FOR MARYLAND DEPARTURE TIME CHOICE MODEL

Based on data availability for the MSTM improvement plan in Chapter 4, the existing data is only partially available for departure time choice modeling in Maryland. To supplement the existing data, a dedicated survey for departure time choice model was designed. The survey aims to investigate traveler's departure time responses to time-of-day traffic conditions and congestion pricing on the Capital Beltway (I-495). The time-of-day congestion pricing is hypothetically assumed to be implemented as a HOT lane on I-495. The data collected from the survey is intended to explore the following aspects:

- **Potential impact of time-of-day pricing on departure time behavior:** The research team is interested in the estimation of individual socio-economic characteristics that affect HOT lane use and the impact of time-of-day pricing on departure time shift.
- **Willingness to pay (WTP) to avoid departure time shift:** The research team is interested in the traveler willingness to pay (WTP) to use HOT lanes and/or to avoid departure time shifts. Since departure time shift could be influenced by increased travel time, increased toll pricing and corresponding travel cost (fuel cost), all of these attributes will be included in our analysis.
- **Estimation of Value of Travel Time (VOTT) by time-of-day:** The research team is interested in estimating Value of Travel Time (VOTT) by time-of-day. Calibrated VOTTs on real data will be extremely helpful for MSTM application to real policy analysis cases.

5.4.1 Survey Design

The survey questionnaire is designed as a web-based survey interview. The survey is a stated choice (SC) experiment, in which different attributes and their levels of variations are varied systematically and combined into scenarios. Data relative to the current trip (RP data) will also be part of the data collection. Attributes in the SP survey include: travel time, travel cost, departure time, desired arrival time, and hypothetical time-of-day toll price. Behavioral data is being collected at several locations of I-495 during peak period on weekdays. The questionnaire has mainly two parts, the revealed preference (RP) and the stated preference (SP). The detailed survey description is in Appendix A, with the brief description as follows:

5.4.1.1 Revealed Preference (RP) Questions

RP questions ask respondents about their recent trip information in term of mode choice, number of passengers, trip purpose, departure time, preferred departure time given no roadway congestion, total travel time, travel time given no queue in the roadway, trip distance on the beltway and total trip distance, entry and exit ramp, fuel cost, parking cost, toll cost (if applies), experienced shortest and longest travel time on the beltway, and experienced shortest and longest travel time for the whole trip.

Socioeconomic questions in the RP consist of respondents' gender, age, household income range, education, occupation, number of worker per household, number of vehicle, car size the respondent usually drives, number of years the car has been used, and ZIP code of working area.

5.4.1.2 Stated Preference (SP) Questions

The stated preference (SP) survey is designed to capture traveler's departure time choice corresponding to different time-of-day traffic and congestion pricing schemes. The SP choice set consists of three lane alternatives: (1) normal lane, (2) HOT lane, and (3) HOV lane. Each lane alternative is described by different departure times, which are pivoted around actual departure times observed from the respondent. Other variables used in the design are total travel time range, arrival time range, fuel cost, and tolls.

These travel impedances are designed to account for time-of-day conditions by considering whether the actual response departure time occurs in the peak or off peak period. In the situation where the respondent's actual departure time occurs in the peak period (8:00-10:00 a.m., and 3:00 -7:00 p.m.), the travel impedances are designed to be higher with larger uncertainty (in terms of travel time range) compared to the case when actual departure time is in the off peak period. These travel impedances are total arrival time range, fuel costs, and toll costs. The toll cost is hypothetically assumed to be mileage-based.

5.5 SUMMARY

In this chapter, a departure time choice model for application to MSTM that is based on multinomial logit formulation is proposed. The model explicitly models travelers' departure time in response to time-of-day travel conditions. It is based on simulated data from I-270 corridor. This prototype model is able to deal with time-of-day and peak spreading analysis. The module, which could further be improved and developed, can be used in decision support and various policy/land use scenario analyses at the corridor/project level, regional level, and even statewide level. In particular, the model can be used to analyze the impact of increased future travel demand, major land development projects, congestion pricing, and other congestion management strategies that influence peak spreading and congestion.

The proposed multinomial logit (MNL) model is a good starting point for incorporating time-of-day and peak spreading considerations into either MSTM or other planning/operations models at SHA. The relative simplicity of the MNL formulation and estimation procedures is desirable. However, one may also develop more advanced models to relax the assumptions made in the MNL peak spreading model. Another weakness of the prototype model results from the simulated dataset, which may or may not represent real-world peak spreading behavior.

Future research and model development tasks on peak spreading analysis should focus on three issues: (1) Use existing travel survey data (e.g. recent Washington, D.C. and Baltimore household travel surveys) and/or collect additional travel behavior data (with reveal preference, stated preference, and/or GPS-based methods) regarding departure time choices in Maryland; (2) Develop more advanced and more reliable departure time choice models with nested, cross-nested and mixed logit methods; and (3) Integrate these empirically-estimated departure time choice models into MSTM and transportation planning and operations models at SHA (e.g. microscopic traffic simulation models, subarea/corridor analysis models).

CHAPTER 6: CONCLUSIONS

The current version of the MSTM is based on the traditional four-step travel demand modeling paradigm. A traditional four-step approach is theoretically and technically sound for statewide transportation modeling. The MSTM in this present form can meet many existing and emerging demand modeling needs in Maryland, such as corridor-level congestion management, evaluation of alternative socio-economic, demographic and land use scenarios, multimodal investment analysis, long-distance travel analysis, truck travel demand forecasts, and performance monitoring. However, some of the emerging transportation planning and policy issues cannot be fully analyzed by the MSTM in its present form. Examples include advanced pricing studies, detailed corridor-level integrated traffic management, and multimodal freight analysis.

Six broad categories of transportation planning and policy analysis needs in Maryland are discussed in this report: (1) Performance Measuring and Monitoring; (2) Congestion Management; (3) Multimodal Transit (4) Freight Transportation; (5) Socio-Economic and Land Use Scenario Analysis; and (6) Planning and Policy Analysis Needs beyond MDOT and SHA.

Information provided by MSTM, such as traffic flow and speed on highway facilities and ridership on transit facilities, is crucial for computing performance measures regarding mobility, energy, pollution emissions, climate change, and freight transportation. The current MSTM is capable of most of the performance measuring and monitoring tasks. It may be further improved to incorporate multimodal transit, multimodal freight, and air quality/GHG emission measures.

For congestion management measures, it is essential for MSTM to be able to account for users and non-users travel behavior such as route choice, departure time choice, mode choice, destination choice, vehicle occupancy choice, and trip frequency choice. The current MSTM may be improved with individual modules estimated from real-world scenarios that consider departure time choices, multimodal mode choices, multimodal freight shipper/carrier decisions, and (pseudo-) dynamic routing behavior.

For freight analysis, MSTM can be improved to consider multiple freight modes and intermodal transfers. Such improvement will enable SHA to examine congestion relief that can be obtained by shifting freight movements from highway to rail and other freight modes, or from congested corridors to uncongested/less congested corridors. The impact of truck-to-rail freight diversions on the local traffic near intermodal transfer facilities or major ports could also be studied. With an improved freight analysis module, the accuracy and reliability of major corridor freight studies can also be greatly enhanced.

Regarding land use and an economic development scenario analysis, it is necessary for the MSTM to consider the different travel demand patterns associated with different types of land development (traditional development, smart growth, transit-oriented development, mixed development, etc.). While a fully integrated regional economic-land use-transportation model is desirable, a new module in the MSTM for analyzing the economic and land use impact of transportation system changes may be a more practical short- to mid-term approach (i.e. with feedback but no full integration).

Various post-processing modules may also be developed for MSTM that estimate the transportation impact on various sustainability indicators, including pollution and green house gas emissions (the EPA

MOVES can address this), nature resources, other environmental indicators, energy consumption, equity, and other socio-economic indicators.

Advanced Four-Step and Activity-Based Models

The development of an advanced four step model (conditionally on funding and data availability) will contribute to the analysis of policies related to congestion management, multimodal freight analysis, and time-of-day considerations. Datasets that support traditional four step model development can generally be used with supplementary data depending on the design and the purpose of the model. In addition, the analysis of land use-transportation policies, such as smart growth and simultaneous transit investment require the development of an integrated transportation-land-use-economic model at the state level. Integrated models enable a streamlined estimation of the impact of transportation improvement/investment on the state and regional economic growth and job creation. Due to the data requirements, and the economic downturn, this improvement task should be taken into consideration with caution.

Our review finding indicates that in the future, the development of a full activity-based micro-simulation model (ABM) could be rewarding. ABM can significantly enhance statewide model's capability to address state-level modern transportation planning issues, such as freight movement and sub-area/corridor traffic analysis. The move toward the full activity-based microsimulation model requires an additional model development cost. It is recommended that the development toward this option be carried out incrementally. Model improvements toward ABM should be strategically planned based on data availability, planning needs, policy initiatives, resources required, and methodological feasibility.

Proposed Strategic MSTM Improvement Plan

Various approaches for improving MSTM have been identified in this research, and a preferred approach is recommended in the Strategic MSTM Improvement Plan (SMIP). A timeline for MSTM improvement is incorporated into the SMIP. Model improvement options that are based on readily available data have high priorities. And those that require the minimum to moderate SHA resources are categorized as short-term model improvement needs (2012-2015). These short term improvements include: Integrated MSTM Post-Processor Models, Enhanced Multimodal Transit Module Models, Commodity-Based Multimodal Freight Analysis, Intercity Multimodal Transit Module Models, Rural-Area Parameter Estimation, and Transit Oriented Development Analysis Module. Model improvement options that either rely on large new datasets, have low priorities, or require extensive resources are considered long-term model improvement needs (Beyond 2020) which include: Integrated Economic-Land Use-Transportation Model, Integrated Transportation-Watershed-Natural Resource Model, and Safety Module. The remaining model improvement options are considered mid-term improvement needs (2016-2020) which include: Population Synthesizer, Advanced Discrete Choice Modeling and Feedback Loops, and Tour/Activity/Agent-Based Demand Model.

APPENDIX A: SURVEY QUESTIONNAIRE

This survey aims to investigate traveler's willingness to use the HOT lane on the I-495 and the effects on departure time in response to time-of-day traffic conditions and congestion pricing. The questionnaire is designed as a web-based survey that can be found at www.travelsurveys.org/beltway/home/survey . The front page of the website is shown in Figure a-1. The sample population is commuting travelers on I-495 during weekday peak period. The survey recruitment was conducted by flyer distribution at several exits of I-495. Information on the flyer contains the website address and the questionnaire instructions to guide respondents in answering the questionnaire.

The questionnaire consists of revealed preference (RP) and stated preference (SP) questions. RP questions gather respondent's socioeconomic data and recent trip information. SP questions gather respondents' behavior on toll lane usage and departure time choice. The description for each part of the survey is described as follows:

Figure a-1. Front page of the survey website

1. Revealed Preference (RP) Questionnaire

The RP questionnaire consists of two sections: respondents' socioeconomics and recent trip information.

1.1 Socioeconomic Data

The socioeconomic data section gathers data about respondent's characteristics. The purpose of this section is to investigate socioeconomic data of the potential HOT lane users in I-495. The respondent is asked to describe his/her socioeconomic data via the following constructs:

- Gender
- Age
- Household income range
- Education
- Occupation
- Number of worker per household
- Number of vehicle in the household
- Vehicle type most used by the respondent
- Number of years the vehicle has been used
- ZIP code of work place

1.2 Most recent trip information on I-495

The recent trip information gathers data about the respondent's most recent trip on I-495. The purpose of this section is to use respondent's experienced trip condition as the pivot point when designing the stated preference (SP) question. This ensures that the stated scenario in the SP is realistic for each respondent. The respondent is asked to describe his/her most recent trip information on I-495 via the following constructs:

- Mode choice
- Number of passenger
- Trip purpose
- Departure time (DT)
- Preferred departure time given no roadway congestion (PDT)
- Total travel time (TT)
- Travel time given no queue in the roadway (BTT)
- Trip distance on the beltway (D) and total trip distance
- Entry and exit ramp
- Fuel cost (FC)
- Parking cost
- Toll cost
- Shortest (ST) and longest (LT) travel time experienced on the beltway
- Shortest (TT min) and longest (TT max) travel time experienced on the whole trip

Figure a-2 shows the revealed preference questionnaire interface on the website.

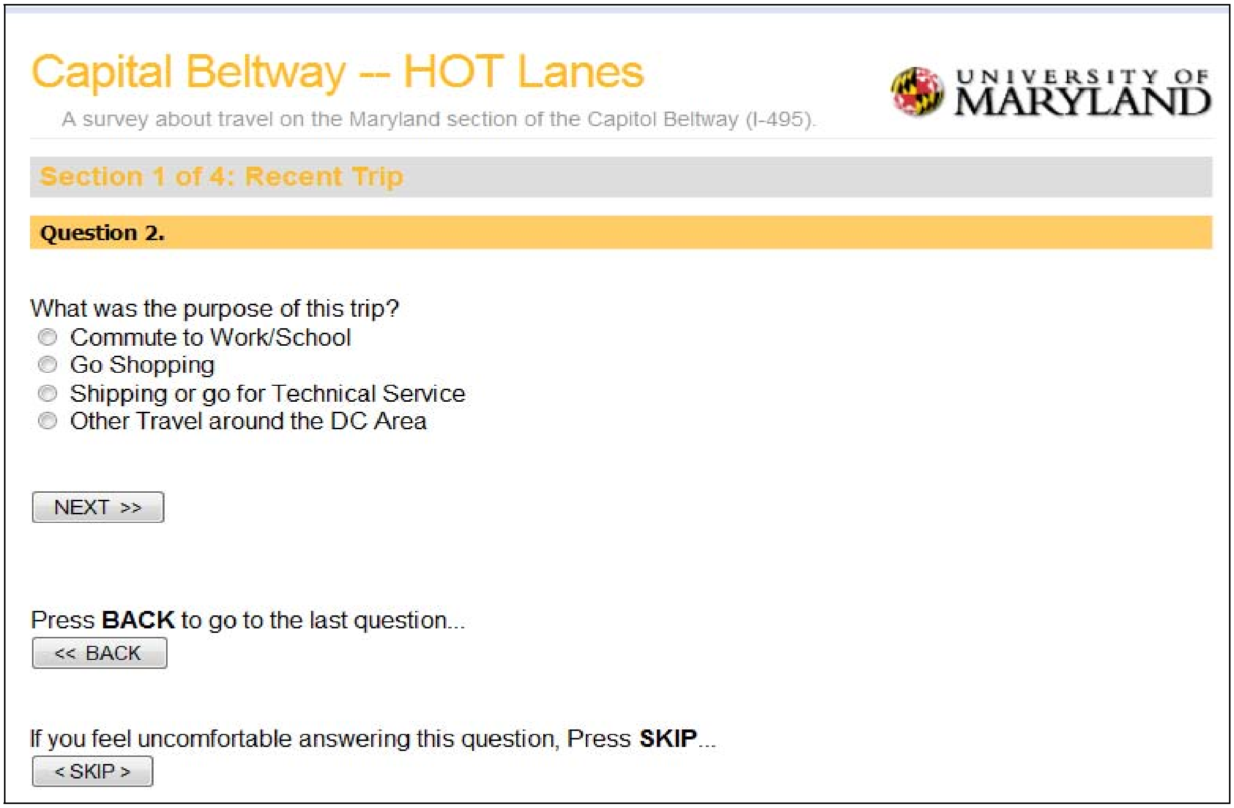


Figure a-2. RP questionniare interface

2. Stated Preference (SP) Questionnaire

The Stated Preference (SP) portion of the survey presents respondents with two stated experiment choices: (1) Toll lane usage, and (2) Departure time choice. Each stated choice game generates 9 scenarios to respondents where variables change from scenario to scenario. Respondents are instructed to make a realistic decision taking into account the situation presented during the scenarios.

2.1 Game1: Toll lane use

The HOT lane use game focuses on presenting respondents with different travel conditions on lanes alternatives to investigate the acceptability of toll lane on I-495 and the willingness to pay for reduced travel time subjected to congestion and uncertainty. This game consists of three alternatives and five variables. Each variable has up to three levels of variation per alternative.
Three alternatives are: (1) Normal lane (refers to regular lane with regular traffic), (2) High Occupancy Toll (HOT) lane (refers to toll lane with single driver subjected to toll fees), and (3) High Occupancy Vehicle (HOV) lane (refers to toll lane when the total passenger is greater than or equal to two and no toll fee applies).

The variable of interest in the toll lane usage game includes: normal travel time (without congestion), possible additional travel time due to congestion, possible additional travel time due to uncertainty (e.g. accident), fuel cost, and toll cost.

The toll lane usage game was designed to attract respondent with toll lane alternatives. We assume that, by using toll lanes, the total travel time will be significantly reduced due to less congestion and uncertainty. These multiple scenarios vary by level of variation to ensure that the presented alternatives are realistic based on the respondent's experience. The survey design rationale of each variable is described as follows:

2.1.1 Normal travel time: The normal travel time is the average travel time of the trip given no severe delay caused by congestion or accidents. Normal travel time is represented as two parameters, the normal travel time of the whole trip, and the normal travel time on the beltway (shown in the parentheses in the questionnaire interface).

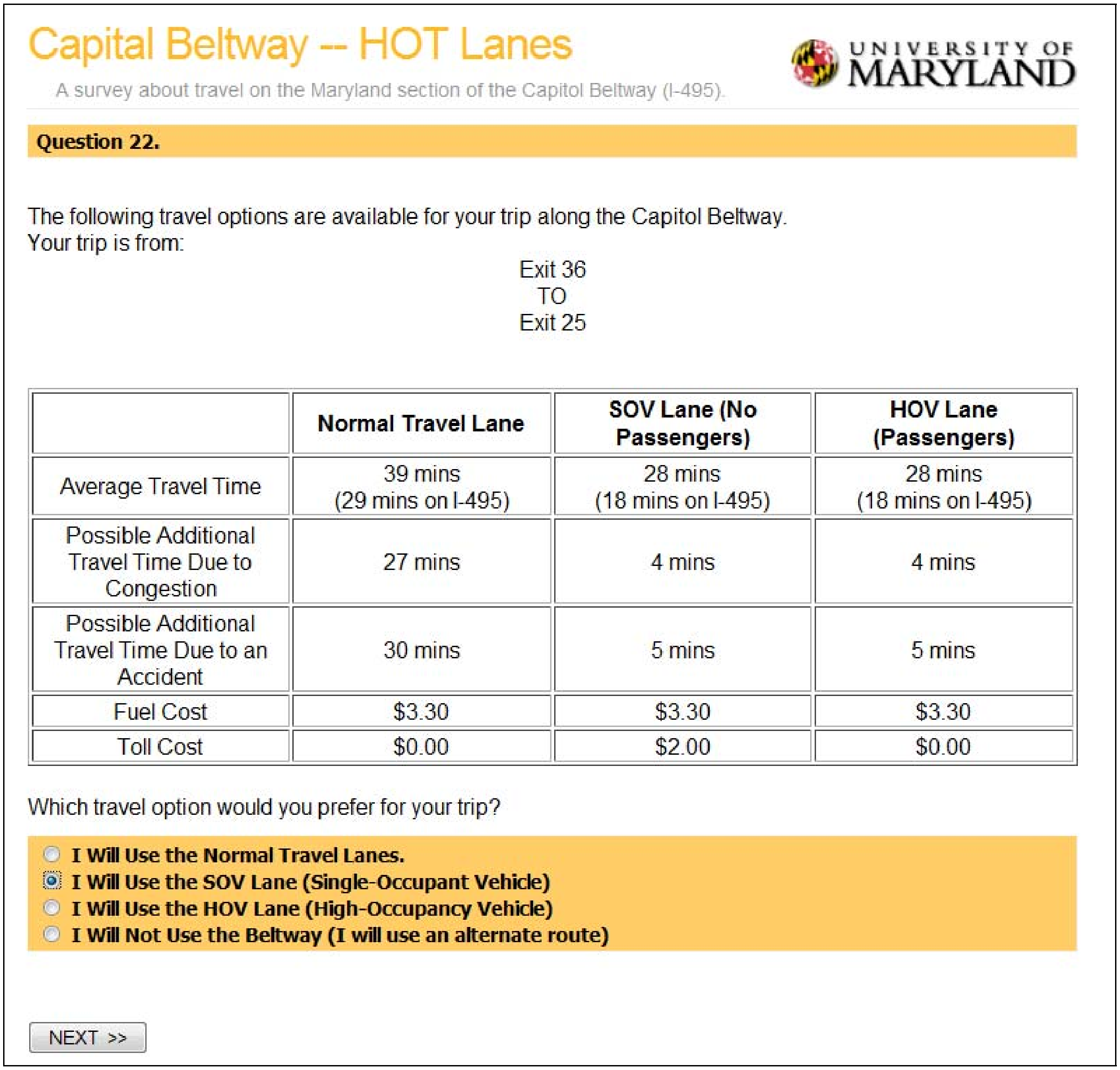
2.1.2 Possible additional travel time due to congestion: This is the travel time in addition to the normal travel time due to congestion. Additional travel time is designed to be realistic in reflecting higher congestion delay on the normal lane compared to the toll lane.

2.1.3 Possible additional travel time due to uncertainty: This is the travel time in addition to the normal travel time due to uncertainty such as accidents.

2.1.4 Fuel Cost: The fuel cost is designed to reflect higher expense in the normal lane due to longer travel time through level of variation. In the case of HOV, if the fuel expense is shared by the travelers (information obtained in RP), the fuel expense shown in the questionnaire will be divided by number of passengers.

2.1.5 Toll Cost: Toll cost for toll lane usage consists of a three price level. The toll price by time-of-day is further accounted for in SP Game2.

Figure a-3 shows the interface of the stated preference game1 on the website.



Capital Beltway -- HOT Lanes

A survey about travel on the Maryland section of the Capitol Beltway (I-495).

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Question 22.

The following travel options are available for your trip along the Capitol Beltway.
Your trip is from:

Exit 36
TO
Exit 25

	Normal Travel Lane	SOV Lane (No Passengers)	HOV Lane (Passengers)
Average Travel Time	39 mins (29 mins on I-495)	28 mins (18 mins on I-495)	28 mins (18 mins on I-495)
Possible Additional Travel Time Due to Congestion	27 mins	4 mins	4 mins
Possible Additional Travel Time Due to an Accident	30 mins	5 mins	5 mins
Fuel Cost	$3.30	$3.30	$3.30
Toll Cost	$0.00	$2.00	$0.00

Which travel option would you prefer for your trip?

- I Will Use the Normal Travel Lanes.
- I Will Use the SOV Lane (Single-Occupant Vehicle)
- I Will Use the HOV Lane (High-Occupancy Vehicle)
- I Will Not Use the Beltway (I will use an alternate route)

NEXT >>

Figure a-3. SP Game1 Questionnaire Interface

2.2 Game 2: Departure Time Choice

The Departure Time Choice game presents respondents with different travel conditions corresponding to different departure times on three lane alternatives. This game aims at investigating traveler departure time choice, and peak spreading corresponding to time-of-day traffic and congestion pricing scheme. This game consists of three alternatives and five variables. Each variable has up to five levels of variation per alternative.

This SP survey presents the respondent with three alternatives choices: 1) solo driver on normal lane, 2) HOT lane, and 3) HOV lane. Each lane alternative corresponds to different departure time which is pivoted around the respondent's observed departure time in the RP.

The variable of interest in the departure time choice game includes: departure time, travel time range, arrival time range, fuel cost, and toll. These five variables represent travel impedances, which are designed to account for time-of-day conditions by considering whether the respondent's observed departure time occur in the peak or off-peak period.

2.2.1 Departure time: The stated departure time is pivoted from respondent's observed departure time in the RP. This variable is an essential part in estimating the departure time choice model.

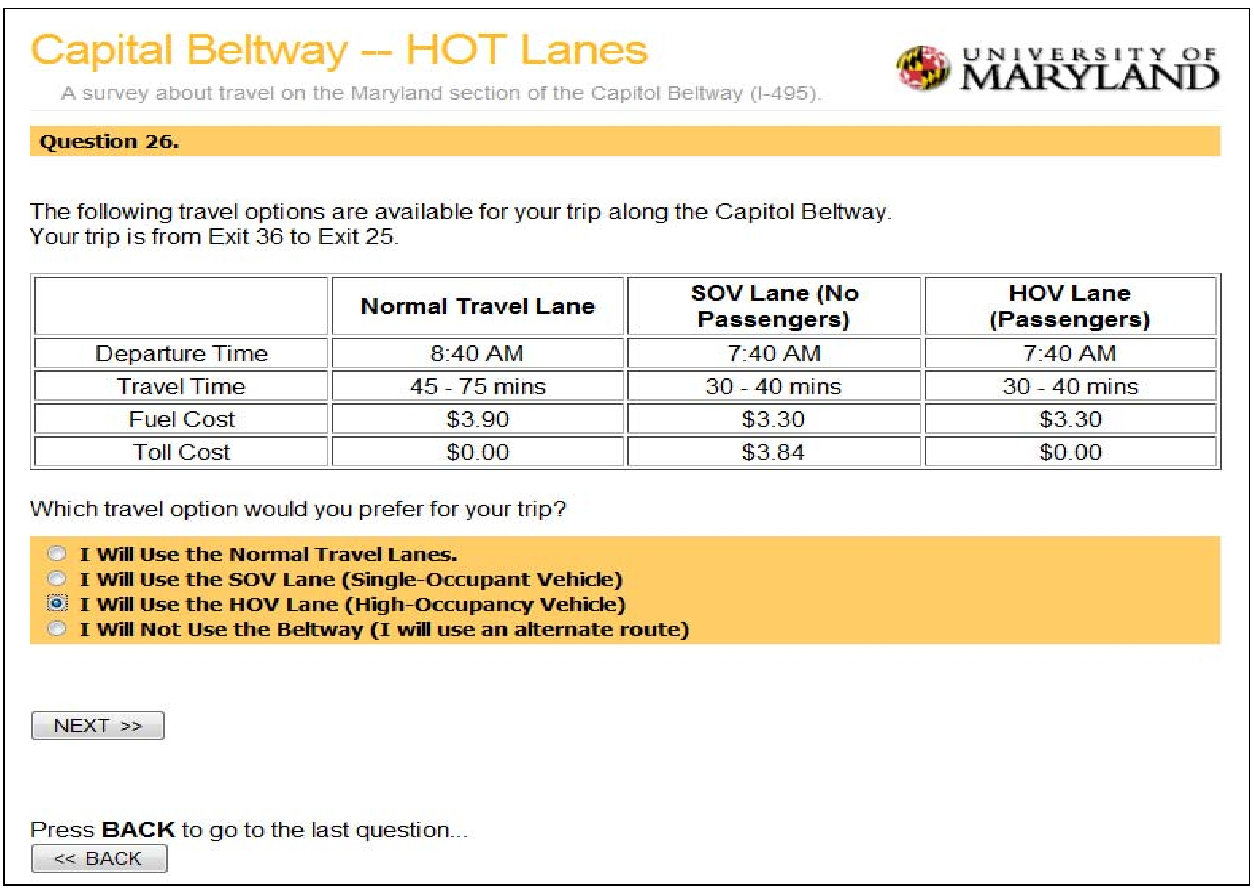
2.2.2 Total travel time range: This variable is designed to account for both time-of-day conditions based on the respondent's observed departure time and travel condition on toll lane.

2.2.3 Arrival time range: This variable is calculated on the departure time and travel time range of each stated scenario.

2.2.4 Fuel cost: The fuel cost is designed to reflect higher expenses in the peak period and on the normal lane.

2.2.5 Toll cost: The toll rate for the HOT lane accounts for the peak and non-peak period by consisting of two separate ranges of toll variation for peak and non-peak period. The toll price is mileage-based.

Figure a-4 shows the interface of the stated preference game 2 on the website.


Capital Beltway -- HOT Lanes

A survey about travel on the Maryland section of the Capitol Beltway (I-495).

UNIVERSITY OF MARYLAND

Question 26.

The following travel options are available for your trip along the Capitol Beltway.
Your trip is from Exit 36 to Exit 25.

	Normal Travel Lane	SOV Lane (No Passengers)	HOV Lane (Passengers)
Departure Time	8:40 AM	7:40 AM	7:40 AM
Travel Time	45 - 75 mins	30 - 40 mins	30 - 40 mins
Fuel Cost	$3.90	$3.30	$3.30
Toll Cost	$0.00	$3.84	$0.00

Which travel option would you prefer for your trip?

- I Will Use the Normal Travel Lanes.
- I Will Use the SOV Lane (Single-Occupant Vehicle)
- I Will Use the HOV Lane (High-Occupancy Vehicle)
- I Will Not Use the Beltway (I will use an alternate route)

NEXT >>

Press **BACK** to go to the last question...

<< BACK

Figure a-4. SP Game2 Questionnaire Interface

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