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ARTICLE

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Sabyasachee Mishra, Xin Ye, Fred Ducca, & Gerrit-Jan Knaap
National Center for Smart Growth Research and Education, University of Maryland, 1112J Preinkert Fieldhouse, College Park, MD 20742 USA (email: mishra@umd.edu)

The Maryland-Washington, DC region has been experiencing significant land-use changes and changes in local and regional travel patterns due to increasing growth and sprawl. The region's highway and transit networks regularly experience severe congestion levels. Before proceeding with plans to build new transportation infrastructure to address this expanding demand for travel, a critical question is how future land use will affect the regional transportation system. This article investigates how an integrated land-use and transportation model can address this question. A base year and two horizon-year land use-transport scenarios are analyzed. The horizon-year scenarios are: (1) business as usual (BAU) and (2) high gasoline prices (HGP). The scenarios developed through the land-use model are derived from a three-stage top-down approach: (a) at the state level, (b) at the county level, and (c) at the statewide modeling zone (SMZ) level that reflects economic impacts on the region. The transportation model, the Maryland Statewide Transport Model (MSTM), is an integrated land use-transportation model, capable of reflecting development and travel patterns in the region. The model includes all of Maryland, Washington, DC, and Delaware, and portions of southern Pennsylvania, northern Virginia, New Jersey, and West Virginia. The neighboring states are included to reflect the entering, exiting, and through trips in the region. The MSTM is a four-step travel-demand model with input provided by the alternative land-use scenarios, designed to produce link-level assignment results for four daily time periods, nineteen trip purposes, and eleven modes of travel. This article presents preliminary results of the land use-transportation model. The long-distance passenger and commodity-travel models are at the development stage and are not included in the results. The analyses of the land use-transport scenarios reveal insights to the region's travel patterns in terms of the congestion level and the shift of travel as per land-use changes. The model is a useful tool for analyzing future land-use and transportation impacts in the region.

KEYWORDS: land use, urban planning, models, traffic management, travel, transportation, economic conditions

Introduction

Traffic congestion in the Maryland-Washington, DC region causes an estimated loss of US$3 billion per year because of lost time and traffic delays and peak-hour traffic volume has increased more than 135% since 1985 (Schrank & Lomax, 2007). Along with more traffic, new development has spread farther from central cities, causing increased demand for transportation services in developing areas and placing strains on what once were rural road networks. Planning agencies need to understand the interactions between these changing land-use patterns and traffic and to develop strategies that will mitigate the effects of growth. The Baltimore Metropolitan Council (BMC) and the Metropolitan Washington Council of Governments (MWCOG) are the two metropolitan planning organizations (MPOs) in the region that currently have transportation models. The travel-demand models of BMC and MWCOG are well-suited for their respective jurisdictions. However, there are issues that must be addressed in the context of a multi-state region. These include: (1) the interaction of travel on the boundary between the two MPOs, (2) the modeling of transportation in regions outside the MPO boundaries such as western Maryland or the eastern shore of the Chesapeake Bay, and (3) the estimation of the impact of travel that passes through the multistate area, particularly freight travel. The MPO models can partially address these issues (or in some cases not address them at all), but to fully reconcile them requires a broader view supported by multistate analytic procedures.

The boundaries of the two MPOs are presented in Figure 1. The individual MPO regions only cover portions of Maryland and Virginia. The two major cities within the region are Baltimore and Washington, DC. The two beltways and all freeways in the region are shown in Figure 2.
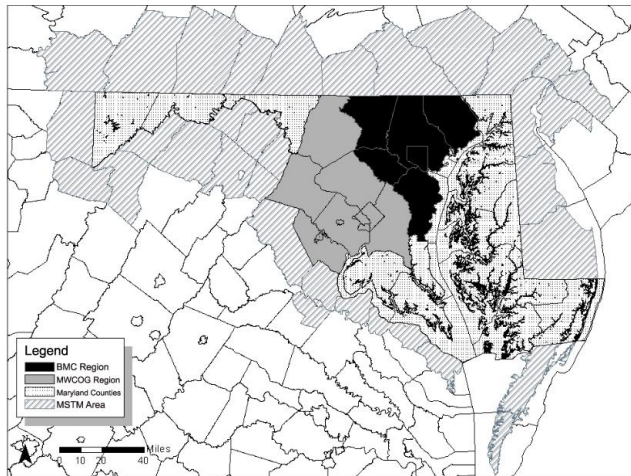
Figure 1 Baltimore-Washington, DC Region and surrounding area.

Figure 2 Major interstate highways in the Maryland-Washington, DC Region.

The transportation impact on Baltimore is sensitive to policy/travel changes in the Washington, DC region. The effect on a regional scale, such as the sensitivity of travel between the Baltimore and Washington, DC areas, can only be explored by a regional or statewide model. In addition, such models can be used to assess impacts on sustainability by measuring sprawl, congestion, and greenhouse-gas (GHG) emissions. The remainder of the article is structured as follows. The following section presents a literature review on national statewide modeling practices, followed by the scenario-development steps and regional model-development methodology proposed for this paper. The next section describes the integrated land use-transportation model. Data requirements are then presented followed by the results. Finally, we discuss our conclusions and future scope of the work.

Literature Review

Statewide travel demand and forecasting models address significant planning needs by estimating, for a future date, the number of vehicles that use major transportation facilities in a state. Statewide models can forecast both passenger and freight flows, and include a variety of modes including highways, urban transit systems, intercity passenger services, airports, seaports, and railroads. The earliest experiments in statewide travel forecasting during the 1970s adapted methods that had been developed specifically for urban travel forecasting, but those early statewide modeling efforts were not elegantly designed to reflect realistic land-use development and travel patterns because of difficulties in adequately covering large geographic areas in sufficient detail. During the past ten years, state-transportation planners have seen dramatic improvements in socioeconomic and net-
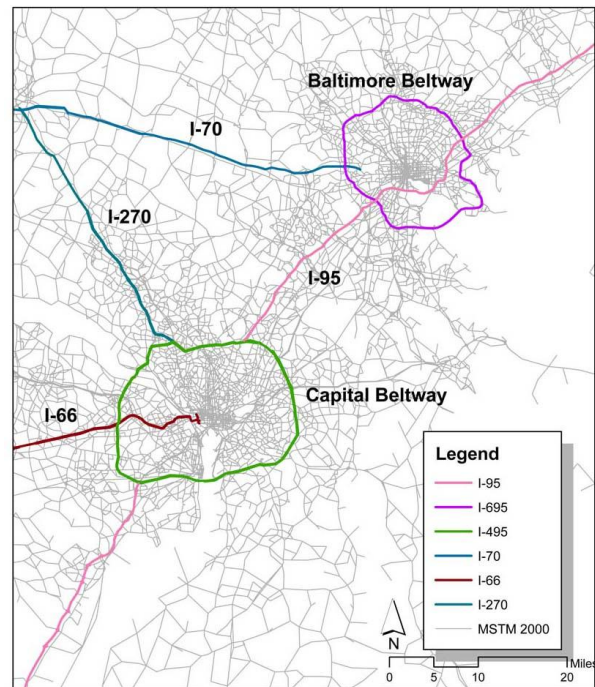
work databases, tools for accessing these databases, and computational power (NCHRP, 2006).

The most mature statewide passenger-travel models used in the United States are from Ohio (Parsons Brinckerhoff, 2010), Michigan (MDOT, 2006), Oregon (PBQ&D, 1995), and Indiana (BL&A, 2004). These models have undergone considerable refinement over the years and share many similarities. Michigan, in particular, has exhaustively documented each step and each assumption made, so it is possible to use this model as an indicator of the "state of the practice." Other states with existing models include Connecticut (ConnDOT, 1997), California (Caltrans, 2010), Florida (Bejleri et al. 2008), Kentucky (Wilbur Smith Associates, 1997), and Vermont (Weeks, 2010). A number of other states have models in various stages of development (NCHRP, 2006).

While several states use transportation models, very few have implemented integrated land use-transportation models into practice. Most notably, the California Department of Transportation (Caltrans) is exploring the feasibility and benefits of the potential implementation of a statewide integrated land use/economic/transportation model. Caltrans aims to test the model to assess and depict the interregional effects of land use, economics, and transportation on energy, the economy, and the environment.

While every state uses its own methodology to reflect travel behavior, the Maryland-Washington, DC region is unique, with significant daily work trips

from neighboring states. The MPOs have transportation models that are better suited to their individual areas. The lack of a single comprehensive statewide model provides an opportunity to develop a functional integrated land-use transportation model to reflect current and future travel behavior in the Baltimore-Washington, DC region. Collecting land-use data, transportation-network data (highway, transit (long and short distance), and feeder services), and special generators poses a challenge in developing a comprehensive travel-demand model. In addition, travel behavior in rural areas (western Maryland and the Eastern Shore) is a unique feature in this model. The objective of the research is to develop an integrated land use-transportation model and analyze the travel impacts in the Maryland-Washington, DC region and the immediate surrounding area by constructing land-use scenarios depicting future growth.

Scenario Development and Methodology

A modeling process to assess the region's future growth can be formulated in three steps: (1) construction of land-use scenarios; (2) development of a regional travel-demand model; (3) development and application of a functional regional integrated land use-transport interaction model covering the entire region.

Land-Use Scenarios

The National Center for Smart Growth Research and Education (NCSGRE) at the University of Maryland has been actively involved in the analysis of land-use patterns in the state for close to a decade. One of the activities of NCSGRE is to explore alternative futures for the state of Maryland and to identify what policies should be adopted today to maximize the likelihood of more desirable future outcomes. The land-use scenarios are based on a three-layer system, as presented in Figure 3. The three stages are: (a) national level, (b) regional level, and (c) local level.

- National econometric model:[1] The national econometric model consists of two submodels: (1) The Long-term Interindustry Forecasting Tool (LIFT), a macroeconomic input-output model operating at the national economy level, forecasts more than 800 macroeconomic variables that are then fed into (2) the State Employment Modeling System (STEMS) to calculate employment and earnings by industry for all 50 states and the District of Columbia. Output from

Figure 3 Multilayer land-use model.

LIFT serves as input to STEMS. Results from the STEMS model are then allocated by region (political boundaries are imprecise predictors of demarcations for labor markets and economic regions) using current proportions of state-level forecasts for each sector. A detailed description of LIFT and STEMS can be found in the literature (McCarthy, 1991; Inforum, 2010).

- Regional Model: The regional model depicts land-use variables at the county level. At the regional level, the forecasting approach is based on near-total reliance on empirically calibrated relationships. The calibrated model involves 40 equations using progressively more inclusive sets of predictors. The allocation model incorporates review of the benchmark forecasts (Hammer, 2007).

- Local Model: The local model results in land-use outputs at the statewide modeling zones (SMZ) level.[2] The initial allocations are made based on transportation costs and the basic employment distribution. At the local level, a Lowry model-based allocation is used to assign household and employment by five income categories from the counties to the SMZs.

From the perspective of development patterns, two broad future scenarios are discussed in this article:

- Business-As-Usual (BAU)
- High Gasoline Price (HGP)

The BAU scenario is generated by introducing the path of real oil prices and the Long-Range Transportation Plan (LRTP), the proposed strategic improvement program for the transportation system. In

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[1] Econometrics is a tool that can be deployed to model land-use characteristics. A set of discrete choice models is used to model national-level population, household, and employment.
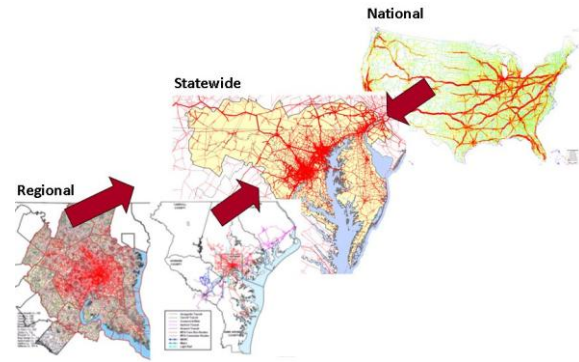
[2] SMZs are polygon structures used in the statewide model and can be considered similar to Traffic Analysis Zones (TAZs) in transportation planning. The SMZs in the statewide model are equivalent to TAZs in high-density development areas, or TAZs are nested under SMZs in low-density development areas.
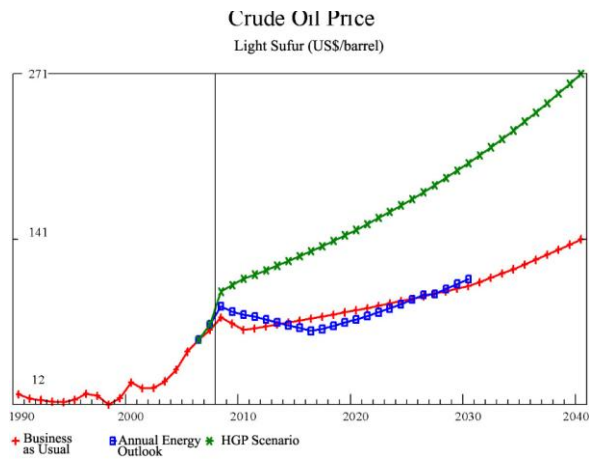
Figure 4 Crude oil price path.

Figure 5(a) Regional Modeling Zones in MSTM.

Figure 5(b) Statewide Modeling Zones in MSTM.

the high gasoline-price scenario, four key parameters are considered: (1) increase in crude oil price, (2) increase in agricultural commodity prices, (3) increase in federal defense spending, and (4) increase in employment in professional service. These factors were selected by a scenario-advisory committee with the rationale of identifying exogenous trends that would provide clustered urban development, more jobs and housing close to transit stations, less development on green infrastructure, fewer new impervious surfaces, and fewer vehicle miles traveled (VMT) without any change in government policy. The path of higher oil prices is presented in Figure 4. The three trend lines represent: BAU, annual energy outlook (data from United States Energy Information Administration), and the HGP scenario (data input into LIFT). Similar graphs for other agriculture commodities, federal defense spending, and employment in professional service are considered in the HGP scenario. The changes in the key parameters (including higher gasoline price) in the land-use model result in different patterns of employment by industry sector and spatial distribution of households. The top-down land-use model is used to allocate employment and households from state to counties to SMZs. The HGP scenario results in clustered urban development as opposed to sprawl.

Development of a Regional Travel-Demand Model

The regional travel-demand model, titled the Maryland Statewide Transportation Model (MSTM), is designed as a multilayer model working at national, regional, and local levels. The study area covers all of Maryland, Delaware, and Washington, DC, along with portions of New Jersey, Pennsylvania, Virginia, and West Virginia (with 64 counties in the region).
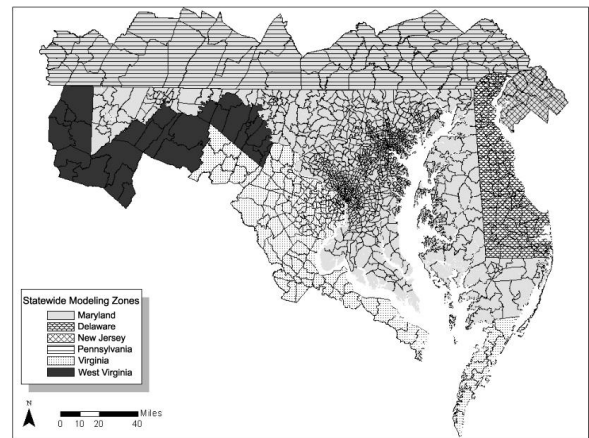
The MSTM model consists of 1,607 SMZs and 132 regional modeling zones (RMZs).[3] The 132 RMZs cover the complete United States, Canada, and Mexico. Maps of SMZs and RMZs are presented in Figures 5(a) and 5(b) respectively. A four-step travel-demand model is developed to forecast passenger-travel demand between origin-destination (OD) pairs by various travel modes and time-of-day periods. The next section discusses details of the transportation model.

Integrated Land Use-Transportation Model

The integrated land use-transportation model is presented in Figure 6. As previously discussed, the land-use model consists of three stages: (a) an econometric model at the state level; (b) a regional

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[3] Regional Modeling Zones (RMZs) are larger polygon structures used in the statewide model to incorporate the source of long distance, visitor, and external travel. The RMZs are much larger in size compared to SMZs, as SMZs are used to incorporate the source of intrazonal trips.
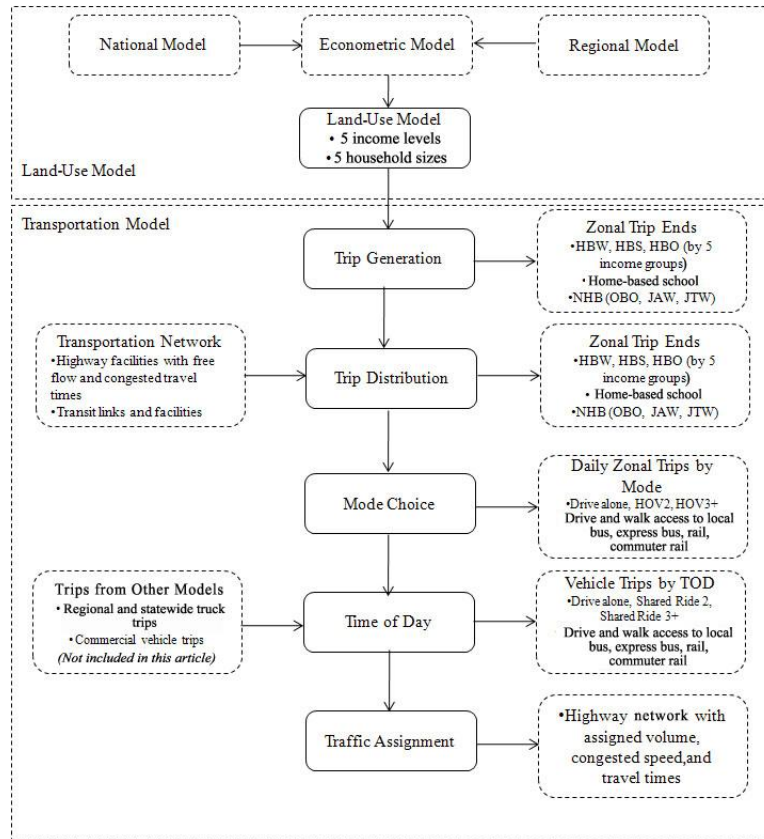
Figure 6 Integrated landuse-transportation model.

model at the county level; and (c) an econometric model at the SMZ level. The transportation model contains the following steps (NCSGRE, 2009):

- *Trip generation* is a cross-classified model for production and attraction of nineteen types of trips (home-based work, home-based shopping, and home-based other trip purposes interact with five travelers' income levels (fifteen trip purposes); home-based school, journey to work, journey at work, and nonhome-based other).[4]
- *Trip distribution* is a gravity model for distributing nineteen types of trips into OD trip matrices.[5]
- *Mode choice* is a nested logit model for splitting OD trip matrices into eleven travel modes (three automobile modes and eight transit modes).[6] The three automobile modes refer to single-occupant vehicles (SOV), high-occupant vehicles with two occupants (HOV-2), and high-occupant vehicles with three or more occupants (HOV-3+).

- *Time-of-day allocation* is a model for splitting daily travel demand into demand over four daily time periods (AM peak, midday, PM peak, and night).
- *Traffic assignment* is based on a user-equilibrium method of assigning trips to the links by minimizing travel time.[7]

We are currently completing the development and integration of freight demand and long-distance travel components into MSTM. However, these components were not completed at the time this article was written.

Data

Data for MSTM are derived from a number of national, state, and local agencies. The socioeconomic data for the MPO region in Maryland and Washington, DC are collected from the cooperative-forecast data from BMC and MWCOG. The non-MPO region socioeconomic data in Maryland is derived from the Census Bureau's Census Transportation Planning Package (CTPP) and the Quarterly

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[4] The trip-generation step determines the number of trips produced and attracted to the SMZ.

[5] The trip-distribution step determines the origins and destinations of trips between SMZs.

[6] The mode choice computes the proportion of trips between each origin and destination that use a particular transportation mode.

[7] Traffic assignment allocates trips between an origin and destination by a particular mode to a route. Further, a route consists of a set of links in the transportation network.

Census of Employment and Wages (QCEW).[8] The land-use data for outside the Maryland-Washington, DC region are acquired from several sources including the Departments of Transportation in Virginia, Pennsylvania, and Delaware. The socioeconomic data are classified in households by number of workers, persons per household, and household by income. Five income categories are considered (less than US$20,000, US$20,000–40,000, US$40,000–60,000, US$60,000–100,000, and more than US$100,000). Four types of employment are considered: retail, office, industrial, and other. The base year (2000) socioeconomic data are collected from the aforementioned agencies.[9] The horizon year (2030) socioeconomic data are obtained by the three-stage land use-model approach. The transportation network is built on a regional scale after combining the portions of the networks received from various agencies.

The base-year network consists of more than 167,000 links, and contains sixteen functional classifications including all highway, transit, walk access, and transfer links. For external travel all the freeways are included outside the modeling region. The toll roads and HOV lanes are coded in the network with the current user charges. The network also contains all transit facilities in the region including metro rail, light rail transit (LRT), bus, and commuter rail (both regional and Amtrak). Proper connection is established between highway and transit in the form of park-and-ride, access, and transfer links.

Results

The results include a base case and two scenarios; a BAU scenario and a HGP scenario are presented in the following section.

Tables 1, 2, and 3 represent the trip flows among each of the states and the District of Columbia. Maryland, Delaware, and the District of Columbia are represented in their entirety while Pennsylvania, New Jersey, Virginia, and West Virginia are partially represented (see Figure 1). The trips represent home-based work, home-based shopping, home-based other, home-based school, and nonhome based (journey to work, journey at work, and other nonhome based). The freight and long-distance passenger components were not completed at the time this article was prepared and were not used in these scenario tests.

Origin and Destination of Travel

Table 1 presents the OD flows within and between states for the year 2000 in the number of trips per day. For this year, over 16.25 million (last column of Table 1) trip movements occurred in Maryland on an average day. Approximately 15.02 million trips originated and ended within Maryland. Similarly, for Washington, DC, over 1.80 million vehicular trips occurred on an average week day. Of these journeys, 1.20 million trips originated and ended in Washington, DC. For Delaware, over 2.39 million trip movements occurred on an average weekday, of which 2.15 million trips originated and ended within Delaware. The "other" column represents movements from Maryland, Washington, DC, and Delaware, to and from the neighboring states. The state-level OD matrix presents a measure of trip movement within and between states. The OD matrix is critical to the ultimate choice of link or route of travel. For the year 2000, a total of 36.59 million trips per day occurred in the MSTM. Very few trips are made between Washington, DC and Delaware in Table 1. The long-distance passenger-component results of MSTM are not presented here.

The OD matrix for 2030 BAU is presented in Table 2. For Maryland, total trip movements are 20.62 million (last column, second row of Table 2), compared to 16.25 million for the year 2000 (last column, second row of Table 1). For Washington, DC, total trips are 2.65 million (last column, third row of Table 2), compared to 1.80 million for the year 2000 (last column, third row of Table 1). A similar increasing trend is observed for Delaware and the neighboring states. The total trips in the region for 2030 BAU are 45.57 million.

Table 3 presents the 2030 HGP scenario OD matrix. The HGP scenario suggests that there is less travel when compared to the 2030 BAU. It is expected that with a high gasoline price fewer trips are made, with most development near the workplaces or the central business district of the corresponding regions. For example, in Maryland, 18.93 million trips are made per day (last column, second row of Table 3) compared to 20.62 million in 2030 BAU (last column, second row of Table 2), and 16.25 million (last column, second row of Table 1) in 2000. Similarly, fewer trips per day are observed in the 2030 HGP scenario when compared to the 2030 BAU scenario.

Finally, note that under the 2030 BAU scenario there are approximately 3.5 million more trips than under the 2030 HGP scenario (45,159,547 versus 41,628,927).[10] With higher gas prices, travelers

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Table 1 OD travel pattern between and within states–2000.

	MD	DC	DE	Other**	Total
MD	15,023,803	671,239	89,377	472,185	16,256,604
DC	377,266	1,200,544	*	224,511	1,802,473
DE	127,110	*	2,150,974	120,132	2,398,494
Other	847,650	580,215	312,911	14,401,642	16,142,418
Total	16,375,829	2,452,276	2,553,414	15,218,470	36,599,989

Table 2 OD travel pattern between and within states–2030 BAU.

	MD	DC	DE	Other**	Total
MD	18,743,367	904,481	149,920	823,045	20,620,813
DC	426,908	1,998,758	*	233,318	2,659,212
DE	136,217	*	2,812,907	151,809	3,101,325
Other	950,800	645,409	370,020	16,811,968	18,778,197
Total	20,257,292	3,548,940	3,333,075	18,020,140	45,159,547

Table 3 OD travel pattern between and within states–2030 HGP.

	MD	DC	DE	Other**	Total
MD	17,216,747	862,821	130,443	729,355	18,939,366
DC	435,166	1,583,163	*	222,863	2,241,382
DE	142,885	*	2,498,738	203,458	2,845,375
Other	894,510	629,077	346,996	15,732,222	17,602,805
Total	18,689,308	3,075,855	2,976,367	16,887,898	41,628,927

* There were fewer than 80,000 trips between these regions. These trips are not presented.
** "Other" represents neighboring states such as portions of Virginia, West Virginia, Pennsylvania, and New Jersey as shown in Figure 1.

change mode to transit or walk, accounting for some of the difference. In addition, trips become shorter. Very short trips are not represented in the highway network, accounting for the remainder of the differences.

Critical Link Analysis

Three critical locations (corridors) are considered in the study area for demonstration of traffic volume for the base year and two horizon-year scenarios. Figure 7 presents traffic volume for the Capital Beltway, the Baltimore Beltway, and the section of Interstate 95 connecting the two beltways. For the year 2000, both the Capital Beltway and Interstate 95 carried 90,000 vehicles per day (including cars and

trucks), while the Baltimore Beltway carried 68,000 vehicles per day. Traffic volume for the three critical link groups in the 2030 BAU scenario is higher than the 2030 HGP scenario. The lower traffic volume for the 2030 HGP scenario is the result of less travel under the higher gasoline-price scenario. Similar link-level traffic volume for other major and minor streets can be obtained in MSTM.

Statewide Transportation Impacts

The statewide transportation-impact results are presented with three measures of effectiveness (MOE): (1) vehicle hours of travel (VHT), (2) vehicle miles traveled (VMT), and (3) vehicles hours of delay (VHD).

and 4.21% transit trips. More transit trips are observed in the HGP scenario.
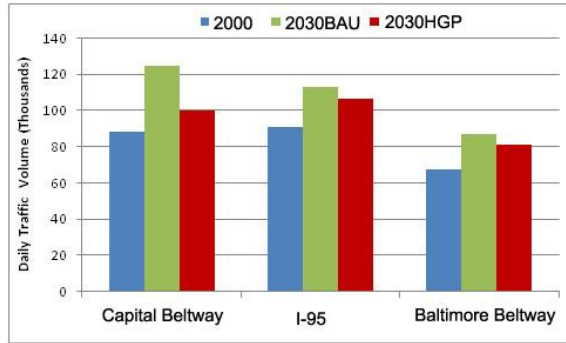
Figure 7 Daily traffic for three major facilities (Note: Interstate 95 runs between the Capital Beltway and the Baltimore Beltway).

Vehicle Hours of Travel: VHT represents the time spent by traffic at a system level, which is obtained by aggregating VHT at the link level. The link-level VHT is determined by multiplying the traffic volume and travel time (assigned travel time as opposed to free-flow travel time). The VHT for the states is presented in Figure 8. For the base year 2000, VHT for Maryland is more than 3.5 million hours per day and for 2030 BAU VHT is over 5 million hours per day. For the 2030 HGP scenario, the VHT is less (than 5 million hours per day) compared to the 2030 BAU scenario. Lower VHT for the HGP scenario can be justified as reduced travel due to higher gasoline prices. For Washington, DC and Delaware, similar VHTs are observed in Figure 8. The other group in Figure 8 represents the portions of Virginia, West Virginia, Pennsylvania, and New Jersey. The study region consists of parts of these states; therefore, the results are not specifically mentioned as state VHTs in Figure 8, but placed in the category "other."

Vehicle Miles Traveled: VMT represents the total number of miles traveled and is computed by multiplying the traffic volume and the corresponding distance traveled. From the traffic-assignment results the link-level VMT is computed first and then aggregated to the state level. Figure 8 presents VMT for
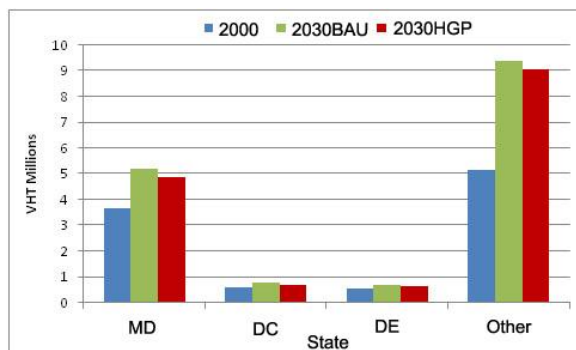
the states in the study region. For Maryland in the year 2000, VMT is over 120 million miles per day. A Maryland Department of Transportation (MDOT) report suggests that the observed annual VMT for the year 2000 was 50.6 billion miles (MDOT, 2010). The VMT presented in Figure 9, when converted to annual VMT, is estimated to be 45 billion miles. The difference of 5 billion annual VMT for Maryland is attributable to long-distance passenger and commodity travel. For Maryland, the 2030 BAU VMT is 158 million miles per day. The 2030 HGP scenario resulted in less VMT than the 2030 BAU. The HGP scenario results in fewer and shorter trips because of higher gasoline prices, thereby reducing the VMT. Similar results are observed for Washington, DC, Delaware, and neighboring states (Figure 9).

Vehicle Hours of Delay: VHD is measured by summing the delay experienced by all the vehicles in a link. Delay can be defined as the extra time needed for the vehicle to traverse the length of a link when compared with the free-flow travel time. Figure 10 presents the VHD for the states in the study region. The VHD for Maryland in the year 2000 is 0.8 million hours per day, and increases to 1.7 million hours per day in 2030 BAU. The VHD increases at a much larger rate than VMT. This can be explained by demand increasing at a much higher rate than supply (transportation-infrastructure development), which results in more congestion, and higher delay. The 2030 HGP scenario VHD is lower than the 2030 BAU. Similar results are observed for the other states in the region (Figure 10).

Summary

The transportation impacts for the base year 2000, horizon year 2030 BAU, and horizon year 2030 HGP are presented at the link level and at the state level. At the link level, three major corridors, the Capital Beltway, the Baltimore Beltway, and Interstate 95 between the two beltways, are selected to
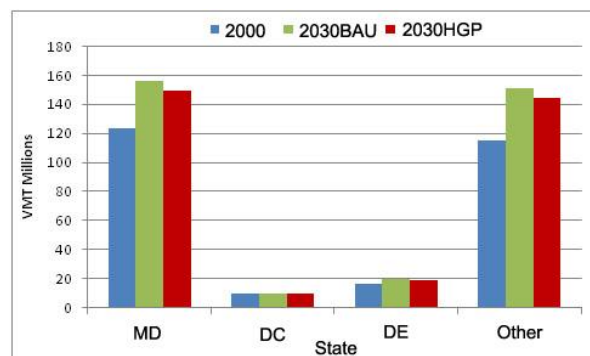

Figure 8 State vehicle hours of travel.
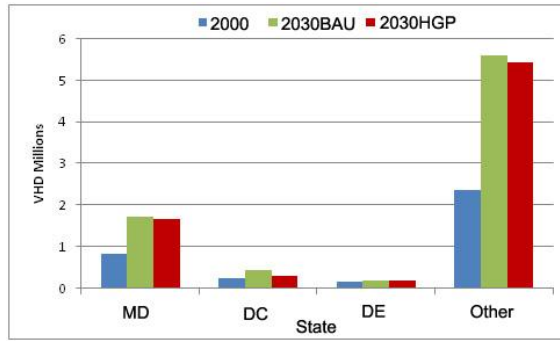

Figure 9 State vehicle miles traveled.

Figure 10 State vehicle hours of delay.

assess traffic-volume impacts. The Capital Beltway carried higher traffic volume than the other two facilities for all three years analyzed. Traffic volume for the three facilities in the 2030 BAU scenario is higher than the 2030 HGP scenario. Transportation impacts for the state level are presented with three measures of effectiveness: VHT, VMT, and VHD. As expected, the MOEs for the 2030 BAU are always higher than those for the 2030 HGP. The HGP scenario shifts development closer to city centers (estimated at a 17.34% increase in households). This change in development patterns combines with lower total commuting travel due to fewer and shorter trips.

Conclusion

With growing traffic congestion and continued urban development, it is critical that states have the capability to analyze the interactive effects of land use and transportation. The unique contribution of this research is twofold. First, this work develops an integrated land use-transportation model with realistic scenarios. Second, we apply the integrated model to determine consistent and defensible estimates of how different patterns of future land use will result in changes of key measures of transportation performance. The MSTM by design is a multilayer-modeling framework at national, regional, and local levels. Preliminary model results indicate that it can analyze travel patterns in the base and horizon years within the state of Maryland and the immediate surrounding area for different land-use scenarios. Two land-use scenarios, BAU and HGP, are analyzed. The BAU scenario is generated by introducing the path of real oil prices and LRTP, the proposed strategic transportation-improvement program for the transportation system. The HGP scenario is generated by introducing the path of increased oil prices and federal defense expenditures to reflect travel behavior in the region with changes in land use. The MSTM is a unique tool to analyze land-use and transportation impacts in the region.

The region-level OD matrix provided the travel pattern within and between the states. Link-level analysis demonstrated the traffic volume on selected critical corridors in the region. Sensitivity tests of the model respond well to alternative future scenarios, showing that higher energy prices result in fewer trips and decreasing VMT and VHT at the statewide level. These tests have shown that traffic volume in the Baltimore, Washington, DC, and connecting areas also declines with higher energy costs. The model is currently being improved with the addition of inter-regional trips and freight and long-distance passenger flow. The MSTM can be used to assess the impact of major facilities proposed or under construction, including the freeway-intercounty connector (ICC), new commuter rail lines being established by the Washington Metropolitan Area Transit Agency; major highway-rail freight flows, and electronic toll lanes on Interstate 95. This model provides a critically needed understanding and analysis of future land-use and transportation interactions and patterns in the Maryland-Washington, DC region. In the broader vision, MSTM can evaluate a number of integrated land-use and transportation scenarios including freight, improved transit, congestion pricing, and emission estimates in the region, as well as sprawl. The integrated land use-transportation model is a useful tool to model travel behavior and to determine transportation sustainability at statewide and regional scales.

References

Bejleri, I., Kim, D., & Yang, X. 2006. *A New Database Framework for Florida's Transportation Planning: Integrating Work Program, Multimodal Transportation Networks, Planning and Environmental Databases.* Gainesville, FL: University of Florida. http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_PL/FDOT_BD545_11_rpt.pdf.

Bernardin, Lochmueller & Associates, Inc. (BL&A). 2004. *Indiana Statewide Travel Demand Model Upgrade.* Technical Memorandum: Model Update and Validation. Evansville, IN: Indiana Department of Transportation. http://www.in.gov/indot/files/memorandum(1).pdf.

California Department of Transportation (Caltrans). 2010. State-wide Travel Demand Model. http://www.dot.ca.gov/hq/tsip/smb/swm_documentation.html. March 5, 2011.

Connecticut Department of Transportation (ConnDOT). 1997. *Modeling Procedure*. Hartford, CT: Connecticut Department of Transportation.

Hammer, T. 2007. *Regional Forecasting Procedure*. College Park, MD: National Center for Smart Growth Research and Education.

Inforum. 2010. Statewide Employment Modelings (STEMS) and Long-Term Interindustry Forecasting Tool (LIFT) Model. http://www.inforum.umd.edu/services/models/stems.html. October 10, 2010.

Maryland Department of Transportation (MDOT). 2010. *Annual Attainment Report on Transportation Systems Performance: Implementing the Maryland Transportation Plan and Consolidated Transportation Program*. Hanover, MD: Maryland Department of Transportation. http://www.mdot.maryland.gov/Planning/CTP/CTP_Documents/Final_CTP/2011_Attainment_Report.pdf.

McCarthy, B. 1991. LIFT: INFORUM's model for the U.S. economy. *Economics Systems Research* 3(1):15–36.

Michigan Department of Transportation (MDOT). 2006. *State Long-Range Transportation Plan 2005-2030*. Land Use Technical Report. Lansing, MI: Michigan Department of Transportation. http://www.michigan.gov/documents/mdot/MDOT_SLRP_TR_Land_Use_11-30-06_179791_7.pdf.

National Center for Smart Growth Research and Education (NSCGRE). 2009. *Maryland Statewide Transportation Model (MSTM): User Guide*. Baltimore: Maryland State Highway Administration.

National Cooperative Highway Research Program (NCHRP). 2006. *Statewide Travel Forecasting Models*. NCHRP Synthesis-358. Washington, DC: Transportation Research Board. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_358.pdf.

Parsons Brinckerhoff. 2010. *Ohio Statewide Model*. Columbus, OH: Ohio Department of Transportation. http://www.dot.state.oh.us/Divisions/Planning/SPR/ModelForecastingUnit/Documents/osmp.pdf.

Parsons Brinckerhoff Quade & Douglas, Inc. (PBQ&D). 1995. *Travel Demand Model Development and Application Guidelines*. Salem, OR: Oregon Department of Transportation. http://www.oregon.gov/ODOT/TD/TP/docs/TMR/General/guidex.pdf.

Schrank, D. & Lomax, T. 2007. *Annual Urban Mobility Report*. College Station, TX: Texas Transportation Institute. http://www.pagnet.org/documents/HumanServices/MobilityReport2007Wappx.pdf.

Weeks, A. 2010. *Vermont Statewide Travel Demand Model–A Preliminary Evaluation*. Report #10–007. Burlington, VT: Transportation Research Center. http://www.uvm.edu/~transctr/trc_reports/UVM-TRC-10-007.pdf

Wilbur Smith Associates. 1997. *Kentucky Statewide Traffic Model Final Calibration Report*. Frankfort, KY: Kentucky Transportation Cabinet.