Land use and transit ridership connections: Implications for state-level planning agencies

Arnab Chakraborty a,∗ , Sabyasachee Mishra b

a Department of Urban and Regional Planning, University of Illinois at Urbana-Champaign, 611 E. Lorado Taft Drive, M230 Temple Buell Hall (MC-619), Champaign, IL 61821, United States
b National Center for Smart Growth Research and Education, 054 Prenkert Hall (1112J), University of Maryland, College Park, MD 20742, United States

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A B S T R A C T

In this article we attempt to establish the connections between transit ridership and land use and socioeconomic variables, and project future ridership under different scenarios. We subdivided the state of Maryland, USA into 1151 Statewide Modeling Zones and developed a set of variables for the base year (2000). We estimated multiple models of transit ridership—using ordinary least squares and spatial error modeling approaches—for the entire state. We also test for the determinants of ridership within urban, suburban and rural typologies. We find that land use type, transit accessibility, income, and density are strongly significant and robust predictors of transit ridership for the statewide and urban areas datasets. We also find that the determinants and their coefficients vary across urban, suburban and rural areas. Next we used a suite of econometric, land use and other models to generate two sets of future transit ridership scenarios under conditions of—(a) business as usual and (b) high energy price—for a 30-year horizon. We analyze these scenarios to demonstrate the value of our approach for state-level decision-making.

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Introduction

Planning for land use and transit in the United States often happens independent of one another. While land use planning is primarily done at the local level, the scale of transit planning depends on factors such as, the spatial extent of served areas, type and number of operating modes, and financing structure of the agency (Cervero and Landis, 1997; Badoe and Miller, 2000; Kitamura et al., 1997). This disconnect is evident in cases where, say, zoning restricts high-density development near transit stations. A number of studies implicate this lack of coordination to be in part responsible for the American auto-oriented landscapes and many underused transit systems (Volinski and Page, 2006; Shaheen et al., 2009).

Despite the potential to influence local decisions, larger scale planning agencies, such as state departments of transportation, have historically made few systematic efforts in harnessing the interdependencies between land use and transit. Consequently, the literature on frameworks of such coordination under existing governance structures remains underdeveloped (Garrett and Taylor, 2003).

Transit has been argued to be a catalyst to refocus developments in dense, mixed-use, and mixed-income communities (Badoe and Miller, 2000; Boarnet and Crane, 2001; Cervero, 1996; Cervero and Landis, 1997; Kitamura et al., 1997). According to these studies, proliferation of such communities can be associated with lower consumption of natural resources, residential and transportation energy savings, reduction in government expenditures in infrastructure and service provisions, and better resiliency to uncertainties in future energy prices. At the same time, higher densities and accessibility to transit is associated with better transit services and making higher ridership more viable (Tong and Wong, 1997; Messenger and Ewing, 1996; Moudon et al., 1997; Levine and Inam, 2004; Levine et al., 2005; Boarnet and Greenwald, 2000). Accordingly, researchers and practitioners have attempted to identify factors that encourage and sustain higher densities and transit use, such as design principles for new subdivisions, accessibility to stations and regional urban form, all factors influenced by local land use policy (Ewing and Cervero, 2001; Krizek, 2003; Miller et al., 1999; Heath et al., 2006). Advocates have promoted the incorporation of these ideas in urban plans and ordinances, and in transit siting decisions.

Many of these principles have been adopted at certain scales or in a piecemeal fashion. For example, land use change models consider transit services in determining development potential and attractiveness of land (Deal, 2001; Landis, 1994, 1995; Landis and Zhang, 1998; Waddell, 2002; Deal and Schunk, 2004), which could...
then be taken into account when planning for, say, transit-oriented developments or municipal zoning change (Cervero, 1994; Cervero et al., 1993; Taylor et al., 2004). Similarly, land use characteristics are routinely included in travel demand models that are sometimes used by transit planners.1

While the above approaches serve specific short-term, operational purposes, they have several planning limitations. Designed to further local objectives or resolve narrowly defined local concerns, most analytical approaches take factors that are beyond a local agency's control as givens. For example, land use patterns are often considered as exogenous inputs in a travel demand model (Boarnet and Crane, 2001; Boarnet and Sarmiento, 1998; Kockelman, 1997). By failing to consider the implications of variations in these factors more carefully, such approaches forego potentially richer analysis. Further, analyses that are limited to local scales fail to consider regional implications of local decisions and, by extension, their interaction with broader uncertainties. Land use patterns and transit provisions often have spatial, financial, and other spillovers and it is the responsibility of larger scale agencies to balance negative regional externalities. For example, multiple transit agencies in a state may be looking to fund expansions of their own systems for a variety of reasons. Each may advocate in its own interest for state support. They might even compete for funds with yet other agencies, e.g., a municipality looking to support high-density land use development. However, a state agency with influence over both land use and transit ought to evaluate the overall outcome on its broader jurisdiction. The higher-level agency can harness possible interdependencies in making its own decisions by looking for trade-offs without regard to local interests and biases. Such analysis, however, needs a suitable analytical framework.

In this article, we develop such a framework. Using transit ridership as the key measure, we test how different outcomes in different futures may present a state agency with specific choices regarding planning. We chose the state of Maryland in the United States as our study area. Using a number of criteria, we subdivide the state into 1151 statewide modeling zones (SMZs) and, for each SMZ for the base year (2000), estimate a range of variables, including developed land under different uses, population and employment densities, developed land densities by industry category, auto-ownership, household income density, workers per household, free-flow and congested speeds of the existing transportation infrastructure, current transport capacities, and accessibility to different transport modes. Using the statewide SMZ dataset, we estimated ordinary least squared and spatial error regression models for the base year data. We also model the relationships on subsets of SMZ representing urban, suburban and rural typologies. We find that characteristics of land use, transit accessibility, income, and density are strongly significant and robust predictors of transit ridership for the statewide and urban areas datasets.

We then used a suite of econometric and land use models to generate two sets of development outcomes for a planning horizon year (2030) – one under ‘business as usual’ conditions and the other under ‘high-energy prices’. We use these conditions and our key ridership model to generate two distinct sets of scenarios for future transit ridership. The scenarios are constructed to separate the choices over which the decision-makers can exercise some control, from uncertainties or regional forces that are beyond their control. Drawing upon their differences, we discuss how such analysis can inform decision-making.

We proceed as follows. In the next section, we establish the connections between transit ridership and land use through a review of modeling practices to derive and frame the key planning questions. In the following section, we discuss the datasets, the rationale behind the choice of our study area, and the modeling framework for our empirical analysis; and in the next two sections, we present findings of this analysis and apply our model to develop scenarios for the horizon year and discuss implication for state level decisions, respectively. We offer concluding remarks in the final section followed by caveats and future scope of research.

Existing research on transit ridership modeling and decision making

Ridership is a commonly used measure to capture the effect of clustered development, diversity, density, transit supply, system efficiency, and surrounding land uses on transit use. Studies abound that attempt to model ridership on a variety of factors (Kockelman, 1997; Boarnet and Crane, 2001; Du and Mulley, 2007; Lin and Gau, 2006). However, for specific considerations on how ridership varies with land use and what that means for state level choices, we organize the available literature in the following streams: (1) land use considerations in transit models; (2) the lessons from, and limitation of such models in large-scale decision making; and (3) ongoing practices in large-scale decision-making.

Ridership estimation models are frequently studied in public transit and have been reviewed multiple times (see, for example, Kain and Liu, 1999; Abdel-Aty, 2001; Wang and Skinner, 1984; Horowitz, 1984; Taylor et al., 2004; Ben-Akiva and Morikawa, 2002). Not surprisingly, these studies are framed for transit agency related questions and purposes. Taylor et al. (2009) group ridership determination factors into two categories from a transit agency perspective: external and internal. External factors include population, economic conditions, auto ownership levels, and urban density; all factors over which agency managers have no control. Internal factors, in contrast, allow transit agency managers to exercise some control. They include the amount of service the agency provides, the reliability of service, service amenities, and fare. Taylor et al. (2009) show that understanding the influence of these factors is important to transportation system investments, pricing, timing, and deployment of transit services.

Studies about the influence of external factors on ridership have employed a variety of methodological approaches, including case studies, interviews, surveys, statistical analyses of characteristics of a transit district or region, and cross-sectional statistical analyses. These studies find that transit ridership varies depending upon a number of factors, such as (i) regional geography (e.g., total population, population density, total employment, employment density, geographic land area, and regional location) (Ong and Blumenberg, 1998; Kuby et al., 2004; Hsiao et al., 1997; Wu and Murray, 2005; Zhao et al., 1997; Polzin et al., 2002; Peng and Duerer, 1995), (ii) metropolitan economy (e.g., median household income, income distribution) (Ingram, 1998; Cohn and Canada, 1999; Frisk, 1991; Thompson and Brown, 2006; Fuji and Hartshorn, 1995; Yoh et al., 2003; Hirsch et al., 2000; Kyes et al., 1988; Cervero et al., 1993), (iii) population characteristics (e.g., percent of captive and choice riders, or household with zero cars) (Cohn and Canada, 1999; Polzin et al., 2000; Ewing, 2008; Davies, 1976), and (iv) auto/highway system characteristics (specifically non-transit/non-single occupancy vehicle trips, including commuting via carpools) (Cervero, 2007; Lisco, 1968; Holtzclaw et al., 1994; Taylor and Fink, 2002; Gómez-Ibáñez and Fauth, 1980). They also

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1 The most common of these is the Four-step Travel Demand Model (TDM). Used for decades to determine both highway and transit demand, developing reliable TDMs can be expensive and time-consuming and require extensive computational effort. Modeling transit ridership component is particularly complex, as it requires creating a virtual transit network, conducting ridership surveys, and incorporating routes, stops, headways, and fare-matrix returns. As a result, only the transit planning agencies that have considerable resources use these practices.
confirm that availability of public transit is strongly correlated with the urbanization of the area. Overall, the relative importance of external factors, the interaction between them, and their impact on the transit ridership continues to be debated in the literature. To address this, a number of studies focus on examining the relative causal influences of internal and external factors on ridership. They generally find external factors more important in explaining ridership change (Kain and Liu, 1999; Taylor and Fink, 2002).

A number of studies, including some listed above (Pucher, 1980; Smith and Gihring, 2006; Pickrell, 1989; Puentes, 2000), note that few states base transit financing decisions on land use or other long-term considerations, or employ ridership modeling. Instead, their decisions are often driven by operational considerations and maintaining the existing fleet system. A number of past research shows that some states have mechanisms to allocate resources for a number of rehabilitation, remanufacturing, and replacement options (Khasnabis et al., 2007; Mishra et al., 2010; Mathew et al., 2010), but do not focus upon modeling future transit demand. For example, Mishra et al. (2010) discuss the resource allocation among 93 transit agencies in Michigan in a multi-year planning period, but only modeled a constant transit fleet system, which is insensitive to changes over time. Land uses and intensities however, change over time and will result in varying transit demand. In sum, the aforementioned studies do not provide adequate mechanisms for estimating future transit demand that can augment decision making for statewide transit planning agencies.

The state of Maryland can be considered as another example to demonstrate the need for a statewide transit ridership estimation model. The state of Maryland is adjacent to Washington, DC, and the Commonwealth of Virginia and parts of Maryland are served by regional transit service such as the Washington Metropolitan Transit Authority (WMATA). In addition, a number of counties and independent cities operate their own bus and feeder transit system. Currently, the state level financing of these myriad agencies happen without assessment of current and future interregional spillovers and shifting demands, nor is there any framework to identify decisions that can help achieve state level parity in services and expenditure.

As many of the above studies note, common modeling approaches have several limitations. First, the use of transit ridership estimation models are geographically limited as they are either too cumbersome to build and operate, or unavailable outside of large metropolitan areas, or are overlooked. They are also limited to one or two transit modes at a time and consider other services and variation in critical factors such as land use as exogenous to the model. Second, the internal/external separation of factors in the literature is usually framed from a regional transit agency perspective and is not directly translatable to, say, a state agency. A number of factors, such as urban densities, that are external to a transit agency may indeed be within the sphere of influence of the state. Conversely, specific transit agency choices such a service frequency and fares are not.

This suggests that to address transit ridership questions from the perspective of higher-level agencies, planners should – (1) consider transit interdependencies with a broader range of transportation services and regional urban form characteristics; and (2) reframe internal/external factors for the specific decision-making entity.

Firstly, the regional land use and transportation system interactions have been studied extensively in the regional planning and urban modeling literature. It cites commuting costs, housing and employment locations, housing prices, institutional considerations, and history of investment in transportation systems among factors that have reinforcing effects on transit accessibility and ridership (Murray, 2003; Murray and Wu, 2003; Litman, 2004; Beimborn et al., 2003). Lacking institutional frameworks for regional planning in US, the policy efficacy studies are fewer in US (e.g. Portland, OR) and draw heavily upon European experiences in integrated spatial planning (Badoe and Miller, 2000; Boarnet and Greenwald, 2000; Kain and Liu, 1999; Cervero and Kockelman, 1997; Newman and Kenworthy, 1996). This literature has also illuminated the benefits of transit in providing energy use and air quality benefits and in promoting more equitable urban form in the future under higher energy price fluctuations. This is an important motivation for our work and in our study area, which includes a high variation in transit services and densities. As we discuss later in detail, such considerations can help fine tune policies to specific spatial typologies.

Secondly, internal/external framing of factors is important and apply to state level analysis as well, albeit in an adjusted format. Internal/external frame has been used often in the modeling literature to separate controllable “choices” (internal) from uncontrollable “forces” (external) or uncertainties (Chakraborty et al., 2011). It allows modelers to generate scenarios that reflect different combinations of choices and uncertainties. The scenarios reflect alternative futures, not as a result of choices alone but how they interact with external conditions. Comparing scenarios can then identify decisions that are (1) robust under most likely set of external conditions, and/or (2) useful for unlikely yet important contingencies, or (3) resilient over a range of uncertainties. As the internal and external factors can be adjusted to suit specific decision-makers, it can help organize the institutional complexities in a region with layers of overlapping jurisdictions and influences. As we explain later in this paper, considering land use as an internal factor from a state agency perspective can be useful in making decisions.

Developing a statewide ridership model

Data

Our objective was to develop a transit ridership model for the entire state of Maryland and demonstrate its usefulness in state-level decision-making, especially a more integrated land use and transit planning. In this section we focus on the first part using datasets for the year 2000.2 The state of Maryland consists of 23 counties and one independent city and had a total population of 5.8 million and a total employment of 3.4 million in the year 2010 (BEA, 2011; Census, 2010). It also has seventeen types of public transportation systems including metro rail, commuter rail, local bus and long distance buses. To develop our dataset, we subdivide the state into 1151 Statewide Modeling Zones (SMZs). The SMZ development went through an iterative process including several reviews by the State Highway Administration and was part of a larger modeling project. We identified the broader study area using 2000 Census Transportation Planning Package (CTPP) data to encompass the bulk of labor flows in and out of Maryland. Within this larger boundary, six regions were identified for SMZ formation. The outline of the state and the broader region with its sub-regional components is shown in Fig. 1. The transit ridership model developed here is restricted to the SMZs within Maryland.

The main criteria for SMZ delineation included, conforming to census geographies and nesting within Counties, separating traffic sheds of major roads, and employment activity centers, and a frequent grouping of adjacent TAZs, where they existed. SMZs also delineate areas with good accessibility to Metro rail stations.

2 This remains the latest time period for which this data is continguously and consistently available. Some beta releases are coming out for 2007 data but are not expected to be available for our entire region in the near future. We also believe that this does not affect the important purposes of our analysis.
and, to the extent possible, distinguish rural from urban/suburban development and zoning boundaries. The variations in land use patterns across the state are characterized in Fig. 2. Both household and employment density maps show the concentrated growth in the central portion of the state, while there is relatively less dense development in counties east of the Chesapeake Bay and in western counties of Maryland.

To account for variations in relationship between land use patterns and ridership across the state, we used a combination of household and employment densities to classify SMZs under three spatial typologies – urban, suburban, and rural. The defined values under each category are presented in Table 1.

The classification ranges were based on composite measure of household and employment densities, approach consistent with the Maryland State Highway’s long range planning. For example, an area is classified Rural when the household density is less than 0.15 households/acre and employment density is less than 0.20 households/acre. Table 2 shows the classification map and the number of SMZ units under each typology.

Next we built an extensive dataset at the SMZ level for year 2000. Our key dependent variable, transit ridership, is based on ridership data provided to the State Highway Administration by MPOs and other local agencies. Though data by individual transit services are available, we chose to combine them to create a total daily transit ridership value for each SMZ that includes all boarding and alighting. In our dataset, there are 1151 SMZs, 900 of which have non-zero transit ridership, and 240 of which have a transit stop (access point). This means that there are a large number of SMZ where transit riders originate though they do not access a transit service in that SMZ. Transit ridership data is based on the point of origin of a trip; for example, a home-based park-and-ride trip will be counted in transit ridership value of the SMZ where the rider resides, not where s/he board a transit service.

The accessibility to transit ridership is a dummy variable is based on whether an SMZ has a transit access point. These include light rail and heavy rail stations, and bus stops. Fig. 3 below shows ridership distribution in the central Maryland region and locations of transit stops classified by bus, local rail (Metro), regional rail (MARC), and long-distance rail (AMTRAK). Bus stops from throughout the state are included in the analysis, including regional services such Washington Metropolitan Transit Authority (WMTA), Maryland Transit Authority (MTA), Montgomery County’s Ride On, and Prince George County’s The Bus. In addition, stops from 18 separate bus services provided by several cities and counties, and bus stops from major universities such as University of Maryland College Park, John Hopkins University are also included.

We develop a number of land use and network characteristics from a variety of datasets and through GIS analysis. MPO regional employment data is used for the MPO regions and Quarterly Census Employment and Wages (QCEW) data is used for employment in the non-MPO covered areas. The MPO and QCEW data are aggregated to determine the employment by categories such as retail, office, industrial, and other. Household income data is collected from MPOs and Census for the MPO and non-MPO region, respectively. The transportation network datasets from Census TIGER files, and Maryland Department of Transportation (MDOT) datasets are used to determine the total freeway distance, average free flow speed, average congested speed, and presence of a bus stop.

\(^3\) QCEW (formerly known as ES202) is an employment data source prepared by the Department of Labor, Licensing and Regulations (DLLR).
Maryland Department of Planning’s (MDP) Property View dataset is used to determine specific square footages land used for health care, housing, shopping, industry, office, recreation, dining, and warehouse, and other commercial establishments. The descriptive statistics for the key datasets discussed in the empirical analysis section below are presented in Table 3.

**Empirical analysis**

We regressed the daily transit ridership in an SMZ with a number of explanatory variables using two approaches: ordinary least squares (OLS) and spatial error model (SEM). OLS is a strong though simple linear modeling approach that we apply here and draw upon later in the paper to demonstrate our proof-of-principle in scenario analysis and decision-making application. SEM is a stronger approach that is adopted when there is a high likelihood of spatial autocorrelation. Together, these models provide comparisons across different specifications, tests for robustness, and allow us to capture the importance of spatial interactions and transit interdependencies.

Table 4 presents the results for a number of alternative specifications for the statewide dataset. Models I and II are based on the entire state’s SMZs where as Models I-A, I-B and II-A and II-B include only those SMZs that have non-zero transit ridership. Also, the spatial error models include a contiguity weight factor (Lambda) that account for the effects due to the characteristics of surrounding SMZs. This matrix is separately estimated for the statewide and the non-zero transit ridership datasets.

Overall, the results follow a priori expectations and are robust across specifications. Among the OLS models, Model I, based on

**Fig. 2.** Household and employment density ranges (in households/acre) for SMZs.

<table>
<thead>
<tr>
<th>Household Density</th>
<th>&lt;=0.200000</th>
<th>&gt;=0.20 - &lt;=2.0</th>
<th>&gt;2.0</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Employment Density</th>
<th>&lt;= 0.15</th>
<th>&gt;=0.15 - &lt;=3.0</th>
<th>&gt;3.0</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Household density ≤0.15</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household density &gt;0.15 and ≤2.0</td>
<td>Rural</td>
</tr>
<tr>
<td>Household density &gt;2.0*</td>
<td>Suburban</td>
</tr>
</tbody>
</table>

* While net urban densities tend to be higher, we chose 2 HH/Acres as our cut-off. This is because we estimate gross densities that include the whole area of the SMZ as a denominator in both household and employment density calculations. Also, our visual inspection of aerial imagery under SMZs with different typologies confirms this characterization.
Table 2
Area types and counts for typology subsets.

<table>
<thead>
<tr>
<th>Typology</th>
<th>SMZ count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>414</td>
</tr>
<tr>
<td>Suburban</td>
<td>312</td>
</tr>
<tr>
<td>Urban</td>
<td>425</td>
</tr>
<tr>
<td>Total</td>
<td>1151</td>
</tr>
</tbody>
</table>

SMZs for the whole state, shows that transit ridership increases with household and employment density, is higher in areas with lower income and lower car ownership. This is consistent with urban economic theory and confirms findings from past studies that were previously limited to metro areas.

More specifically, the results of Model I reflect the fact that majority of employment is located in the urbanized areas and is concentrated around transportation networks. Also, location decisions for siting employment centers often take transit into consideration and vice versa. Transit ridership increases with...
decreasing auto-ownership and decreases with amount of freeways miles in an SMZ and drive alone density, or number of drivers per unit of land area in the SMZ, both consistent with expectations.

The effect of a number of subcategories of land uses in Model I viz. healthcare, housing, and recreation are also significant, though understandably smaller in magnitude. For example, presence of healthcare centers is negatively correlated with transit ridership. While this may reflect greater accessibility by emergency vehicles and personal automobiles, a good thing in the event of an emergency, the lower ridership may also reflect lower service suggesting inequities in service to those without automobile for routine treatments and visiting patients. The other variables show expected signs as ridership increases with increases in total square footage of housing and decreases with recreation square footage. Overall, the results (and R-square) from Model I show that SMZ level transit ridership model for the entire state is viable and can explain a large amount of variation in ridership across a number of transit systems.

The OLS models for SMZs with non-zero transit ridership only, though generally consistent, show some differences from the statewide model. For example, while the household density and income coefficients show a higher magnitude, the magnitude of employment density coefficient is lower. These relationships are further strengthened when the transit stop accessibility variable is removed, though the overall explanatory power of the model falls slightly.

The spatial error models for the statewide SMZ dataset and the non-zero ridership subset show very similar relationships with the OLS model outputs, though the coefficients of most variables get smaller. The weight matrix variable (Lambda) is strongly significant in all these models and reflects the importance of spatial interactions and transit interdependencies.

We find that the standard OLS approach reported in Table 4 (Model I) and its variations – re-estimating the relationships for non-zero ridership SMZs and comparing OLS model outputs with spatial error model – add to the depth of our analysis. While there are some differences in the magnitude of coefficients, general scale of the effect, directionality of the relationships and significance of the variables, are all consistent across these models. In the next section, we chose one of these models – Model I – for the purpose of developing transit ridership in two future scenarios. This is discussed later in more detail, though we should note here that based on the robustness of our key variables across different models and the proof-of-principle nature of our state planning analysis demonstration, we find it appropriate to use the coefficients of the statewide OLS model.

We also ran another set of OLS models where one model is tested for each typology subset (Models III, IV and V, for SMZs classified as Urban, Suburban and Rural, respectively). The results are presented in Table 5. The Models III, IV and V attempts to look at typology level associations for urban, suburban and rural areas, respectively (Table 5). The directionality and magnitudes of the effects of significant variables in these models are generally consistent with the findings of Model I. To synthesize the results, the following can be said: the constant is positive and significant for all the models, but its decreasing magnitude from Model III to V reflects the commonly known lower overall ridership difference between urban to rural areas. Lower income and higher transit accessibility are positively correlated and strongly significant across all models. Health care related developments remain negatively correlated with ridership and its effect increases in rural areas – lending credence to the logic that access to such services is even more difficult for households without automobiles in rural areas.

There are also some key differences across these models. While household and employment densities are both positively correlated with ridership, household density is not a significant determinant of ridership in suburban areas (Model IV) and employment density is not a significant determinant in rural areas (Model V). The SMZ with higher school enrollment is expected to produce more transit trips. The square footage for different land use types is differently related
to ridership. While beyond the scope of this analysis, this could be studied in greater detail. Also, a number of variables strongly significant in Model I lose their significance in subset-based models. For example, household density, employment density, and drive-alone density are not significant in Model III. A closer look at the data may explain why. The relationships may not be clear due to the relative similarity of urban form and transit services among SMZs within a typology, or lower variance among the explanatory variables. This may also explain why the coefficient of determination (R²) is highest for Model III and least for Model V. The lower magnitude of ridership might be one of the reasons of lower (R²) for Model IV and Model V. On the contrary, Model III has the highest (R²) as the ridership for urban area is the highest among all.

Irrespective of these differences, however, our analysis confirms the following: (1) overall, land use and other neighborhood characteristics are useful predictors of transit ridership at a statewide level and; (2) the variation in relationships by subarea typologies present a useful framework for fine-tuning policies and investment decisions.

Planning application: horizon year ridership scenarios

Having developed a model for statewide transit ridership, we present a general framework for applying it in decision-making, particularly at large scales by agencies such as state DOTs. To do this we first develop two sets of input variables for the horizon year 2030. Then we use Model I from the previous section to generate two transit ridership scenarios. We use this as a stylized case for assessing state level decision choices.

To illustrate our application, we drew upon the work of Maryland Scenario Project (MSP), a large-scale visioning exercise led by the National Center for Smart Growth (NCSG) at the University of Maryland. For more on MSP, please refer to the past publications (Chakraborty, 2010, 2011). The growth principles of the scenarios were developed by the Scenario Advisory Group, an MSP-affiliated group of nearly 40 land use and transportation planning professionals. The Group identified a number of important yet uncertain sets of conditions that may affect development of the region. The most relevant among these for our purposes were growth rates of energy prices and federal expenditures. Building on these, we characterized one set of year 2030 conditions as (a) Business as Usual (BAU), where the past relationships between sectors, investment patterns, demographics, etc., continue unimpeded; and the other set of variables as (b) High Energy Prices (HEP), an alteration of energy prices where some past historical relationships will continue, and changes in energy prices reverberate throughout the economy and change economic, land use, and transportation outcomes. Under HEP, real crude oil prices rise faster than BAU at 1 percent above the projected inflation rate. In BAU, oil prices roughly follow the Energy Information Administration’s short-term projections. In addition, three key parameters are considered in the HEP scenario: (1) increase in federal defense spending, (2) increase in employment in professional service, and (3) increase in agriculture commodity price. These factors were selected by a scenario advisory committee and the

Table 4

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Ordinary least squares</th>
<th>Spatial error model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model I</td>
<td>Model I-A*</td>
</tr>
<tr>
<td>Constant</td>
<td>631.4***</td>
<td>4835.13***</td>
</tr>
<tr>
<td>Households density</td>
<td>(2.73)</td>
<td>(4.22)</td>
</tr>
<tr>
<td>Employment density</td>
<td>1.480***</td>
<td>2.15***</td>
</tr>
<tr>
<td>Drive alone density</td>
<td>(0.40)</td>
<td>(5.07)</td>
</tr>
<tr>
<td>Household without cars</td>
<td>0.7892***</td>
<td>0.45***</td>
</tr>
<tr>
<td>Household workers density</td>
<td>1.68***</td>
<td>11.72***</td>
</tr>
<tr>
<td>Number of school enrollment</td>
<td>1.901</td>
<td>14.28***</td>
</tr>
<tr>
<td>Total freeway distance</td>
<td>7.93***</td>
<td>3.16***</td>
</tr>
<tr>
<td>Average free flow speed</td>
<td>(7.21)</td>
<td>(10.55)</td>
</tr>
<tr>
<td>Accessibility to transit stop (0,1)</td>
<td>0.115</td>
<td>(0.64)</td>
</tr>
<tr>
<td>Health care square feet</td>
<td>−0.0046</td>
<td>−0.006***</td>
</tr>
<tr>
<td>Housing square feet</td>
<td>(−2.38)</td>
<td>(−3.03)</td>
</tr>
<tr>
<td>Recreational square feet</td>
<td>0.0042***</td>
<td>0.003***</td>
</tr>
<tr>
<td>Lambda</td>
<td>(4.35)</td>
<td>(2.41)</td>
</tr>
<tr>
<td>Sample size (n)</td>
<td>1151</td>
<td>900</td>
</tr>
<tr>
<td>R²</td>
<td>0.7383</td>
<td>0.7574</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.7358</td>
<td>0.7536</td>
</tr>
</tbody>
</table>

Dependent variable: total daily ridership; t-statistics (in OLS) and Z-values (in SEM) are in parentheses. *Model I-A, I-B, II-A, II-B include only those SMZ that have non-zero transit ridership.

- Significant at 90%.
- Significant at 95%.
- Significant at 99%.

rationale was to identify exogenous trends that would provide clustered urban development, more employment and housing close to transit stations, lesser development on green infrastructure, lesser new impervious surfaces, and lesser vehicle miles travelled (VMT) without major changes in government policy.

Next we leveraged a set of models developed for MSP to operationalize these conditions into specific variables for each SMZ under each scenario. The national economic model is based on the Long-term Interindustry Forecasting Tool (LIFT), forecasts outcomes of various macroeconomic policies and changes such as energy prices. The outcomes of this model, in turn, influence the regional and local demographic model, which determines households’ employment in various county and SMZ-level sectors. Since this paper is focused on the adequacy and accuracy of these models, we refer the reader to model documentation and published material elsewhere (Chakraborty et al., 2011; Mishra et al., 2011).

The aggregate socioeconomic data obtained from the MPO cooperative forecasts was converted using econometric and land use models into two sets of values under BAU and HEP scenarios for a number of variables such as, income less than $60,000, household and employment densities. The network related data was used from the 2030 network developed at the NCSG and the Maryland State Transportation Model. These are leveraged to generate two sets of conditions for average free flow speed and drive alone density. The land use data such as the square feet under different land uses are estimated by extrapolating the trends in different land use categories from last five years (using MD Property View data) into year 2030. Finally, we assume that other variables such as average free-way distance, school enrollment, and some other land use variables remain same as these data is not available from public and private agencies in the state and it is very difficult to predict for a HEP scenarios. This assumption is reasonable because these variables’ contributions are lower compared to other more significant variables. From the two sets variables representing 2030 conditions – BAU and HEP – we then develop two ridership scenarios using coefficients from Model I in Table 4. We also estimated a summary map of the difference between them as depicted in Fig. 4.

The map compares total ridership under each scenario in 2030. Dark gray-colored SMZs are those that have high ridership irrespective of the changes in external conditions. This is expected as, being urbanized areas, they already had high ridership and high transit services in year 2000. The gray areas are those that have considerably higher ridership in the BAU scenario (than HEP) and hatched areas are those that have considerably higher ridership in the HEP scenario (than BAU). This reflects a key outcome of explicitly considering different sets of external conditions. For example, since high-energy prices make the inner SMZs more attractive to development (due to many reasons, including lower commute times, and proximity to multiple employment scenarios), which is then reflected in higher growth in these areas, leading to greater demand for transit ridership. In the case of BAU-scenarios, where energy prices increase at a lower rate, the trend of higher development in exurban areas lead to more growth away from the urban centers and an increase in transit ridership demands in those areas.

These findings have several implications. For example, our analysis shows that simple assumptions in a future-oriented analysis can lead to significantly different outcomes and, as a result, they should be carefully considered and analyzed. While a large number of SMZs will continue to require transit services under both scenarios, a number of them will require additional services only under HEP or under BAU scenario. How this information is used in decision-making will depend on the agency and the decision in question. For example, a transit agency overseeing a SMZ that may have high ridership demand in one scenario but little in another,
might want to track the likelihood of external conditions (since it cannot directly influence them), and make any new investment decisions only if there is a high likelihood of HEP. A state agency, however, might use the same information for different purposes.

Fig. 5 shows, as expected, statewide transit ridership is higher in the high-energy price scenario. Further, it shows that some counties will receive a higher share of this growth than other. Such differences may play a role in state level decisions, including land use policies and future transit subsidies. For example, promoting new

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**Fig. 4.** Change between HEP and BAU scenarios.

**Fig. 5.** Transit ridership in Maryland counties under BAU and HEP scenarios.
development in Baltimore City or Prince George's County seems to be one way to encourage transit ridership. Also, if steep increase in energy prices becomes a likely scenario, it might be useful to know that it might have a spatially varied impact and can inform state financing of new projects. Furthermore, if a state level agency is interested in (and capable of) coordinating urban development and transit investment it may look at development patterns and ridership across counties, projected trends in development and other factors in making land use and transit related policies.

In an actual planning situation, of course, more future scenarios would have to be formulated and tested, and the final decision will be the outcome of a political process. This framework, nevertheless, is important as it lends itself to both collaborative and independent decision-making process. In a collaborative process, a larger set of conditions will be “internal” to the planning agencies whereas in case of independent decision-making, agencies will need to identify their internal choices and external givens or uncertainties.

Conclusions and discussion

Frequent under-utilization of transit networks combined with lack of transit services in many areas points to a mismatch in development preferences and limitation of public transportation modes. Such disconnect raises economic and equity concerns that are further heightened under steep increases in energy prices and housing costs. The challenges are exacerbated by fragmented nature of planning agencies across sectors and scales.

Research has long shown that efficiencies of public transit and high-density land use developments are interdependent. Increasing sprawl, residential segregation, and income inequality, decreasing share of transit use and uncertainties in gasoline prices make it imperative that planning agencies take advantage of these interdependencies. However, the literature provides limited guidance on modeling transit use at a large scale, thereby limiting the potential for coordinated land use and transit planning. As we have discussed, this may be due to several reasons including, institutional barriers to agency functions, models that take limited advantage of the notion of uncertainty, or simply a lack of data and frameworks for analyzing the future.

In this paper, we show that a higher-level agency can harness possible interdependencies in making its own decisions without regard to local interests and biases. To do this, we developed a transit ridership model for the whole State of Maryland that joined land use and other neighborhood level variables. We found that characteristics of land use, transit accessibility, income, and density are strongly significant and robust for the statewide and urban areas datasets. We also find that determinants and their coefficients vary across urban, suburban and rural areas suggesting the need for finely tuned policy.

Development of travel demand models can be expensive, requiring extensive data collection, and many states does not have statewide travel demand models. In the absence of functional four-step travel demand model to predict transit ridership, planning agencies often need to have an alternate measure of determining strategies for investment in transit. This framework could be useful as a way to inform service provision decisions in such places and to enhance the use of transit in rural regions by incorporating changes in land use characteristics.

DOTs seldom succeed at conducting planning for the statewide multimodal network; typically transit is missing, added separately at key stages based on planning by transit agencies or sometimes MPOs, but seldom with the ability to reflect transit's statewide contribution and potential. This paper takes an important step toward filling that void. Further, in using a stylized case of two scenarios - business as usual and high energy prices - we demonstrated how such analysis could lead to multiple choices that a state level agency can consider in making its decisions. Estimating transit ridership under multiple scenarios shows how demand could vary by parts of the state and demonstrates the model's value in assessing transit and land use planning decisions. Given the State Plan and strong count for planning in Maryland, this paper describes a useful supportive analysis and modeling effort that can likely be incorporated in Maryland statewide planning activities and project analyses (and elsewhere).

We, however, acknowledge that there are several limitations to this study. While our statewide and subarea models are robust they are based on several estimated variables, many of which could be fine-tuned with additional resources. The treatment of different transit modes separately may also affect our results. Finally, as we noted earlier, the scenario analysis is highly stylized and is meant for the purpose of demonstrating the framework and is not intended to recommend policy. That being said, we believe that there are unique opportunities in considering state level questions as we not only consider interdependencies but also non-urban regions in the analysis and decision-making choices for higher levels of governments.

References


