

1 **Land Use and Transit Ridership Connections: Implications for State-level**
2 **Planning Agencies**

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1 ABSTRACT

2 Land use and neighborhood characteristics have long been linked to transit ridership. Large-scale
3 agencies, such as state departments of transportations, often make decisions that affect land use
4 pattern and transit services. However, the interdependencies between them are seldom harnessed
5 in decision-making. In this article, we develop and apply a transit ridership model based on land
6 use and other neighborhood characteristics for an entire state. We then discuss its implications
7 for regional and state-level decision-making. We chose the state of Maryland as our study area.
8 Using a number of criteria, we subdivided the state into 1151 statewide modeling zones (SMZs)
9 and, for each zone in the base year (2000), developed a set of variables, including developed land
10 under different uses, population and employment densities, free-flow and congested speeds,
11 current transport capacities, and accessibility to different transport modes. We estimated two sets
12 of OLS-regression models for the base year data: one on the statewide SMZs dataset and other
13 on subsets of urban, suburban and rural typologies. We find that characteristics of land use,
14 transit accessibility, income, and density are strongly significant and robust for the statewide and
15 urban areas datasets. We also find that determinants and their coefficients vary across urban,
16 suburban and rural areas suggesting the need for finely tuned policy. Next we used a suite of
17 econometric and land use models to generate two scenarios for the horizon year (2030) –
18 business as usual and high-energy price – and estimated ridership changes between them. We use
19 the resulting scenarios to show how demand could vary by parts of the state and demonstrate the
20 framework's value in large-scale decision-making.

21

22 **Keywords:** transit ridership, land use, model, Maryland, statewide, scenarios, transportation
23 planning

24

25 INTRODUCTION

26 While it is no surprise that land use and transit are closely connected, planning for them often
27 happens separately. The auto-oriented development landscapes and underused transit systems in
28 most US regions is a testament to this disconnect. From a land use planning perspective, transit
29 has been argued to be a catalyst to refocus developments in dense, mixed-use, and mixed-income
30 communities (1-6). Accordingly, this literature has attempted to identify factors that encourage
31 and sustain transit use, such as design principles for new subdivisions and regional urban form
32 metrics (7-10). Advocates have promoted these ideas in local and regional plans and ordinances.
33 Such arguments are complementary to findings that show that greater transit accessibility make
34 denser urban form and higher ridership more viable (11-16).

35 On the other hand, transit planners include land use characteristics in modeling demand,
36 as do broader transportation system planners. Their analysis often involves the Four-Step Travel
37 Demand Model. Used for decades to determine both highway and transit demand, developing
38 them can be costly and require extensive computational effort. Modeling the transit ridership
39 component is particularly complex, as it requires creating a virtual transit network, conducting
40 ridership surveys, and incorporating routes, stops, headways, and fare-box returns. As a result,
41 only the transit planning agencies that have considerable resources use these practices.

1 While the above approaches serve specific purposes, they have several limitations.
2 Driven by narrowly defined agency objectives, they consider land use as given, thereby limiting
3 the potential value of integrated planning. Further, land use patterns and transit provisions have
4 spatial, financial and other implications beyond their specific geographic areas that are not often
5 considered. For example, a municipality may be interested in more urban development within its
6 boundaries and a transit agency may be interested in more funds for system expansion. Each will
7 advocate in its own interest for state support. However, a state agency with influence over both
8 land use and transit may be interested in evaluating collective outcomes over its broader
9 jurisdiction. The higher-level agency can harness possible interdependencies in making its own
10 decisions by looking for trade-offs without regard to local interests and biases. Such analysis,
11 however, needs proper analytical frameworks.

12 In this article, we develop such a framework. We chose the state of Maryland as our
13 study area. Using a number of criteria, we subdivided the state into 1151 statewide modeling
14 zones (SMZs) and, for each SMZ for the base year (2000), estimated a range of variables,
15 including developed land under different uses, population and employment densities, free-flow
16 and congested speeds, current transport capacities, and accessibility to different transport modes.
17 We estimated two sets of OLS regression models for the base year data: one on the statewide
18 SMZ dataset and the other on subsets of urban, suburban and rural typologies. Our model results
19 are robust and vary across typologies.

20 We then used a suite of econometric and land use models to generate two sets of growth
21 outcomes for the horizon year – one under business as usual and the other under high-energy
22 prices. We use these conditions and our ridership model to generate two distinct scenarios.
23 Drawing upon their differences, we discuss how such analysis can inform decision-making.

24 We proceed as follows. In the next section, we establish the connections between transit
25 ridership and land use through a review of modeling practices to derive and frame integrated
26 planning questions at a larger scale. In the following section, we discuss the datasets, the
27 rationale behind the choice of our study area, and the modeling framework for our empirical
28 analysis; and in the next two sections, we present findings of this analysis and apply our model to
29 develop scenarios for the horizon year and discuss implication for state level decisions,
30 respectively. We offer some concluding thoughts in the final section.

31 **EXISTING RESEARCH ON TRANSIT RIDERSHIP MODELING AND DECISION** 32 **MAKING**

33 Ridership estimation models are frequently studied in public transit and have been reviewed
34 multiple times (17-22). Not surprisingly, these studies are framed for transit agency related
35 questions and purposes. Taylor et al. (2005) group ridership determination factors into two
36 categories from a transit agency perspective: external and internal. External factors include
37 population, economic conditions, auto ownership levels, and urban density; all factors over
38 which agency managers have no control. Internal factors, in contrast, allow transit agency
39 managers exercise some control. They include the amount of service the agency provides, the
40 reliability of service, service amenities, and fare. Taylor et al. (2009) show that understanding the
41 influence of these factors is important to transportation system investments, pricing, timing, and
42 deployment of transit services.

1 Studies on the influence of external factors on ridership have employed a variety of
2 methodological approaches, including case studies, interviews and surveys, statistical analyses of
3 characteristics of a transit district or region, and cross-sectional statistical analyses. These studies
4 find that transit ridership varies depending upon a number of factors, such as (i) regional
5 geography (e.g. total population, population density, total employment, employment density,
6 geographic land area, and regional location) (23-29)., (ii) metropolitan economy (e.g. median
7 household income) (30-38), (iii) population characteristics (e.g. percent of captive and choice
8 riders, or household with zero cars) (39-42), and (iv) auto/highway system characteristics
9 (specifically non-transit/non-single occupancy vehicle trips, including commuting via carpools)
10 (43-47). They also confirm that availability of public transit is strongly correlated with the
11 urbanization of the area. Overall, the relative importance of external factors, the interaction
12 between them, and their impact on the transit ridership continues to be debated in the literature.
13 To address this, a number of studies focus on testing the relative causal influences of internal and
14 external factors on ridership. They generally find external factors more important in explaining
15 ridership change (46, 48).

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

26 To address transit ridership questions from the perspective of higher-level agencies, we
27 should: 1) consider transit interdependencies with a broader range of transportation services and
28 regional urban form characteristics; and 2) reframe internal/external factors for the specific
29 decision-making agency.

30 Firstly, the regional land use and transportation system interactions have been studied
31 extensively in the regional planning and urban modeling literature. It cites commuting costs,
32 housing and employment locations, housing prices, institutional considerations, and history of
33 investment in transportation systems among factors that have reinforcing effects on transit
34 accessibility and ridership (49-52). Lacking institutional frameworks for regional planning in
35 US, the policy efficacy studies are fewer in US (e.g. Portland, OR) and draw heavily upon
36 European experiences in integrated spatial planning (1,6,16,17,53). This literature has also
37 illuminated the benefits of transit in providing energy use and air quality benefits, and in
38 promoting more equitable urban form in the future under higher energy price fluctuations. This is
39 an important motivation for our work and study region, which includes high variation in transit
40 services and densities. As we discuss later in more detail, such considerations can help fine tune
41 policies to specific spatial typologies.

42 Secondly, internal/external framing of factors is important and apply to state level
43 analysis as well, albeit in an adjusted format. Internal/external frame has been used often in the

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

11

12 **DEVELOPING A STATEWIDE RIDERSHIP MODEL**

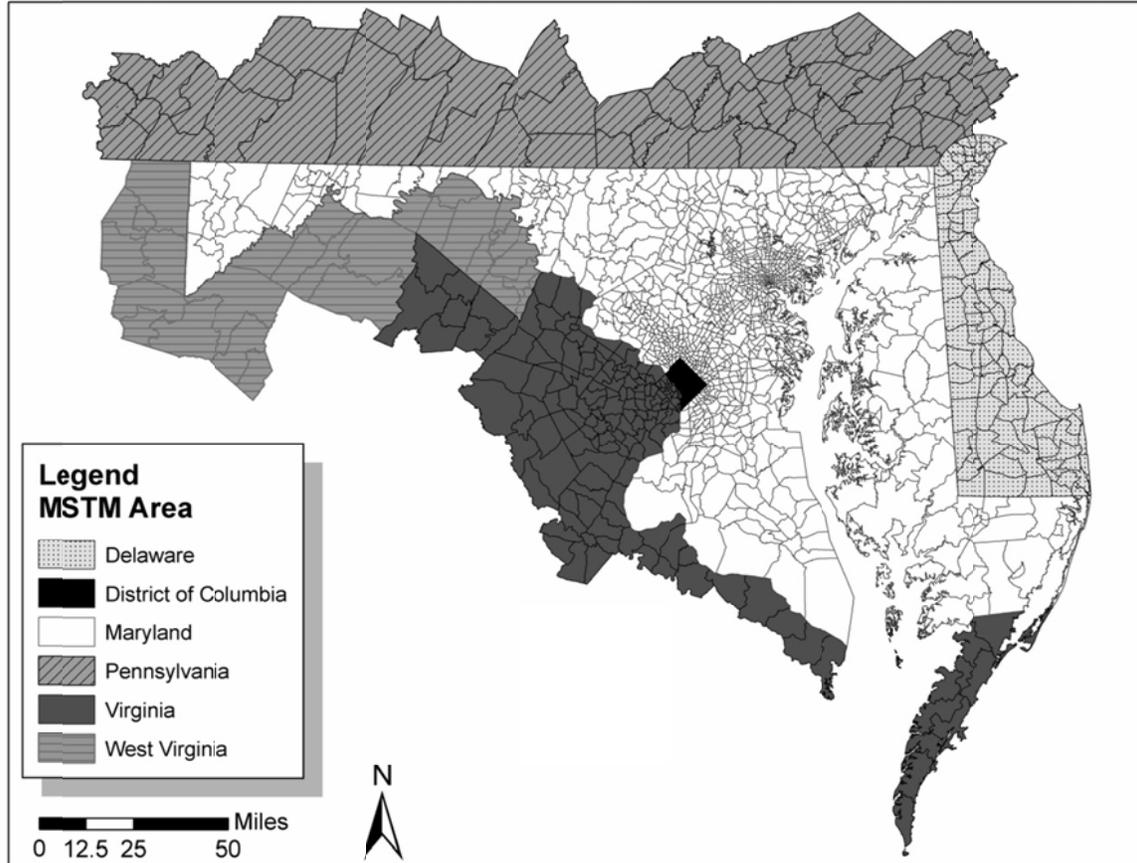
13 **Data**

14 Our objective was to develop a transit ridership model for the entire state of Maryland and
15 demonstrate its usefulness in state-level decision-making, especially in more integrated land use
16 and transit planning. In this section we focus on the first part using datasets for the year 2000¹.
17 The state of Maryland consists of 23 counties and one independent city and had a total
18 population 5.8 million and total employment of 3.4 million in the year 2010 (54, 55). It also has
19 seventeen types of public transportation systems including metro rail, commuter rail, local bus
20 and long distance buses. To develop our dataset, we subdivided the state into 1,151 Statewide
21 Modeling Zones (SMZs). The SMZ development went through an iterative process including
22 several reviews by the State Highway Administration and was part of a larger modeling project.
23 We identified the broader study area using 2000 Census Transportation Planning Package
24 (CTPP) data to encompass the bulk of labor flows in and out of Maryland. Within this larger
25 boundary, six regions were identified for SMZ formation. The outline of the state and the
26 broader region with its sub-regional components are shown in Figure 1. Our model is restricted
27 to the SMZs within Maryland.

28

29

¹ This remains the latest time period for which this data is contiguously 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 would also argue that this does not affect the bigger points in our analysis.



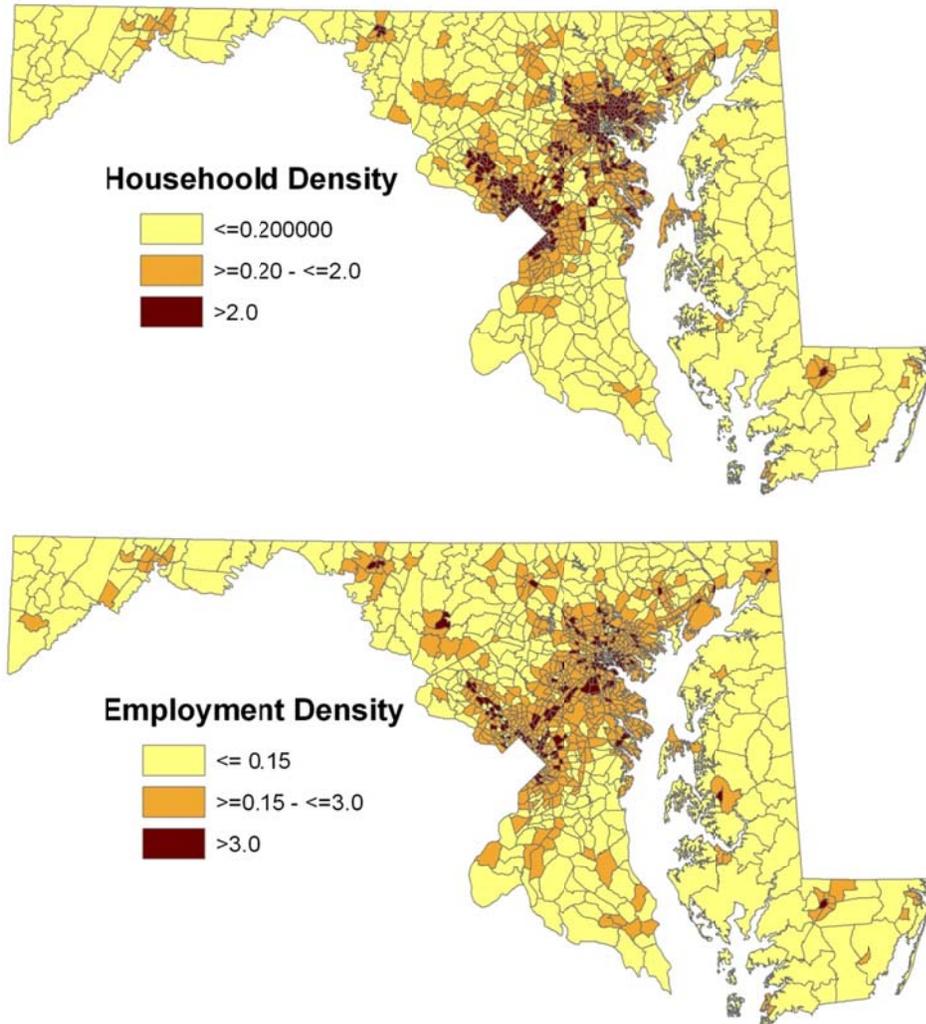
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2 **FIGURE 1 Regions used to develop Statewide Modeling Zones (Source: Maryland**
3 **Statewide Transportation Model, State Highway Administration)**

4

5 The main criteria for SMZ delineation included conforming to census geographies and nesting
6 within Counties, separating traffic sheds of major roads, and employment activity centers, and a
7 frequent grouping of adjacent TAZs, where they existed. SMZs also delineate areas with good
8 accessibility to Metro rail stations and, to the extent possible, distinguish rural from
9 urban/suburban development zoning boundaries. The variations in land use patterns across the
10 state are characterized in Figure 2. Both household and employment density maps show the
11 concentrated growth in the central portion of the state, while there is relatively less dense
12 development on the eastern shore and western Maryland.

1



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

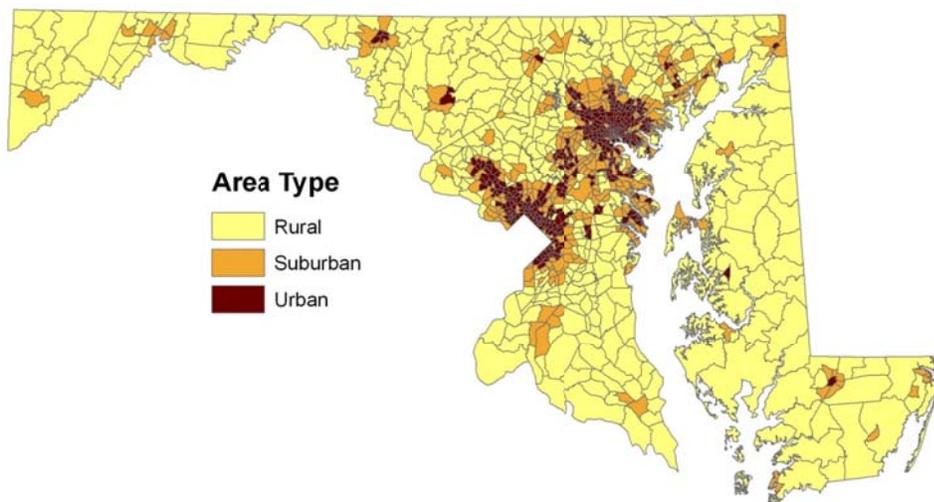
3 To account for variations in relationship between land use patterns and ridership across the state,
4 we used combination of household and employment densities to classify SMZs under three
5 spatial typologies – Urban, Suburban, and Rural. The defined values under each category are
6 presented in Table 1.

7

1 **TABLE 1 Distribution of densities (in households/acre) by spatial typology**

	Employment Density <=0.20	Employment Density >0.20 and <=3.0	Employment Density >3.0
Household Density <=0.15	Rural	Rural	Suburban
Household Density >0.15 and <=2.0	Rural	Suburban	Urban
Household Density >2.0 ²	Suburban	Urban	Urban

2 The classification ranges were based on composite measure of household and employment
 3 densities. The proposed classification system of regions is consistent with the Maryland State
 4 Highway's long range planning. However, for other areas the ranges may change. For example,
 5 an area is classified Rural when the household density is less than 0.15 Households/Acre and
 6 employment density is less than 0.20 Households/Acre. Table 2 shows the classified map and the
 7 number of SMZ units under each typology.

8 **TABLE 2 Area types and Counts**

Typology	SMZ Count
Rural	414
Suburban	312
Urban	425
Total	1151

9

² 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.

1 Next we built an extensive dataset at the SMZ level for year 2000. Our key dependent variable,
 2 transit ridership, is based on ridership data provided to the State Highway Administration by
 3 MPOs and other local agencies. Though data by individual transit services are available, our
 4 variable combined them to create a total daily transit ridership value for each SMZ that includes
 5 all boarding and alighting. The independent variables are combination of demographic,
 6 socioeconomic, network, and land use characteristics. The MPO region employment data is used
 7 for the MPO regions and Quarterly Census Employment and Wages (QCEW³) data used for
 8 employment in the non-MPO covered areas. The MPO and QCEW data are aggregated to
 9 determine the employment by category such as retail, office, industrial, and other. Household
 10 income data is collected from MPOs and Census for the MPO and non-MPO region respectively.
 11 The transportation network datasets from Census TIGER files, and Maryland Department of
 12 Transportation (MDOT) datasets are used to determine the total freeway distance, average free
 13 flow speed, average congested speed, and presence of a bus stop. The property view data from
 14 Maryland Department of Planning (MDP) is used to determine the square footage of health care,
 15 housing, shopping, industry, office, recreation, dining, and warehouse, and other commercial
 16 establishments. The descriptive statistics are presented in Table 3.

17 **TABLE 3 Descriptive statistics**

Variables	mean	s.d.	min.	max.
Daily Transit Ridership	5612.48	9032.29	0	62012.50
Household density	1246.44	2698.96	0	36331.25
Population density	3289.24	7009.19	0	98837.50
Household workers density	1498.58	3025.23	0	39700.00
Total employment density	1398.50	3594.03	0	46770.00
Retail employment density	246.55	1567.29	0	50340.00
Office employment density	759.27	2009.43	0	24980.30
Industrial employment density	133.93	412.72	0	6792.00
Other employment density	618.59	1756.10	0	35680.00
Drive alone density	6542.70	5108.36	0	57233.51
Household with 0 cars ⁴	193.35	360.70	0	3027.00
Income less than 20,000	268.52	377.32	0	3550.00
Income between 20,000-40,000	362.36	384.75	0	2813.00
Income between 40,000-60,000	336.82	313.93	0	2975.00
Income between 60,000-100,000	441.22	394.25	0	3680.00
Income over 100,000	312.06	336.81	0	2587.00

³ QCEW (formerly known as ES202) is an employment data source prepared by the Department of Labor, Licensing and Regulations (DLLR).

⁴ We deliberately chose this over normalized values. One factor in transit service area determination is households within 15 minutes of walking distance in an urban area or driving distance in a suburban/rural area. Given that and the fact more distance can be covered in suburban areas than urban in 15 minutes, areas-based normalization is problematic.

Total school enrollment	706.08	988.00	0	7132.00
Total free way distance	7.05	10.90	0	91.80
Average free flow speed	42.92	8.86	10	70.00
Accessibility to transit	0.19	0.40	0	1.00
Dinning square feet	2431.37	10305.17	0	197750.00
Healthcare square feet	8521.98	71774.91	0	1990004.00
Housing square feet	26719.70	146540.25	0	2758645.00
Industry square feet	2637.49	28409.03	0	706565.00
Office square feet	20086.47	112786.73	0	2279896.00
Recreation square feet	2866.03	14314.23	0	246000.00
Shopping square feet	20237.54	83697.81	0	1157052.00
Warehouse square feet	9833.56	55494.20	0	862137.00

1

2 Empirical Analysis

3 We regressed daily transit ridership in an SMZ with a number of explanatory variables using the
 4 Ordinary Least Squares method. We ran two sets of models, one set for a number of alternative
 5 specifications for the whole state (Models I, I-A, I-B and I-C) and the other set where one model
 6 is tested for each typology subset (Models II, III and IV, for SMZs classified as Urban, Suburban
 7 and Rural, respectively). The results are presented in Table 4 and 5.

8 TABLE 4 Regression Results

Independent Variables	Model I	Model I-A	Model I-B	Model I-C
Constant	631.4** (2.73)	3585*** (4.208)	8902.250*** (11.571)	981.9994*** (4.201)
Household density	1.480*** (4.40)	1.570*** (4.629)	1.2263*** (3.423)	0.7731* (2.038)
Employment density	0.7892*** (9.68)	0.822*** (9.961)	0.8441*** (9.648)	0.7903*** (8.525)
Drive alone density	-1.835*** (-10.53)	-1.906*** (-10.824)	-2.0047*** (-10.755)	-1.976*** (-9.971)
Household without Cars	14.62*** (19.01)	15.230*** (19.793)	15.8629*** (19.495)	16.13*** (18.713)
Household Workers Density	3.4188*** (8.14)	3.548*** (8.374)	4.0447*** (9.049)	4.316*** (9.153)
Income less than 60,000	1.793*** (7.21)	1.493*** (6.046)	1.5879*** (6.071)	1.549*** (5.234)
Number of school enrollment				0.2832 (1.568)
Total freeway distance	-73.07*** (-5.57)			
Average free flow speed		-77.02***	-181.86***	

		(-4.192)	(-10.639)	
Accessibility to transit stop (0, 1)	5325*** (14.58)	4884*** (11.913)		
Health care square feet	-0.0046* (-2.38)	-0.005** (-2.584)	-0.0041* (-2.003)	
Housing square feet	0.0042*** (4.35)	0.003*** (3.49)	0.0037*** (3.588)	
Industry square feet		-0.008* (-1.706)	-0.0092* (-1.773)	-0.010* (-1.944)
Recreation square feet	-0.0362*** (-3.66)			
Dinning square feet				0.0304* (1.972)
R²	0.7383	0.7334	0.7002	0.6641
Adjusted R²	0.7358	0.7308	0.6975	0.6614
Dependent Variable: Total Daily Ridership; T-statistics are in parenthesis,				
*** Significant at 99%; ** Significant at 95%; * Significant at 90%				

1

2 Table 4 presents the results for a number of alternative specifications for the statewide dataset.
3 Overall, the results follow *a priori* expectations and are robust across specifications. Model I,
4 based on SMZs for the whole state, shows that transit ridership increases with household and
5 employment density, is higher in areas with lower income and lower car ownership. This is
6 consistent with urban economic theory and confirms findings from past studies that were
7 previously limited to metro areas.

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

14 The effect of a number of subcategories of land uses in Model I viz. healthcare, housing,
15 industry, etc. are also significant, though understandably smaller in magnitude. For example,
16 presence of healthcare centers is negatively correlated with transit ridership. While this may
17 reflect greater accessibility by emergency vehicles and personal automobiles, a good thing in the
18 event of an emergency, the lower ridership may also reflect lower service suggesting inequities
19 in service to those without automobile for routine treatments and visiting patients. The other
20 variables show expected signs as ridership increases with increases in housing square footage
21 and decreases with industrial square footage, the latter areas being almost always built for
22 automobile access and in areas with less development intensity (and hence less transit services)
23 in the vicinity.

1 Overall, the results (and R-square) from Model I show that SMZ level transit ridership
 2 model for the entire state is viable and can explain a large amount of variation in ridership across
 3 a number of transit systems.

4
 5 **TABLE 5: Model for Area Type**

Independent Variables	Model II	Model III	Model IV
Constant	6647*** (2.907)	1537.931*** (5.583)	212.198*** (5.045)
Household density	1.073 (1.364)		0.209* (1.899)
Employment density	0.192 (1.375)	0.344*** (5.437)	
Drive alone density	-0.329 (-1.128)	-0.139*** (-3.869)	-0.036 (-1.298)
Household without Cars	11.72*** (9.849)		
Income less than 60,000	2.675*** (5.846)	0.848*** (3.364)	
Number of school enrollment		0.361** (2.129)	0.078* (1.96)
Total freeway distance		-52.893** (-2.496)	
Average free flow speed	-106.8** (-2.215)		-4.124** (-2.121)
Accessibility to transit stop (0, 1)	4824*** (5.255)	3117.371*** (7.094)	828.929*** (6.955)
Health care square feet	-0.007** (-2.526)	-0.027** (-2.019)	
Housing square feet	0.003** (2.445)		
Industry square feet			
Recreation square feet	-0.059*** (-4.117)		
Dinning square feet		-0.037 (-1.188)	-0.03 (-1.595)
R²	0.699	0.267	0.171
Adjusted R²	0.692	0.248	0.158
Dependent Variable: Total Daily Ridership; T-statistics are in parenthesis, *** Significant at 99%; ** Significant at 95%; * Significant at 90%			

1 The Models II, III and IV attempts to look at typology level associations. The
2 directionality and magnitudes of the effects of significant variables in these models are generally
3 consistent with the findings of Model I. To synthesize the results, following can be said: the
4 constant is positive and significant for all the models, but its decreasing magnitude from Model
5 II to IV reflects the commonly known lower overall ridership difference between urban to rural
6 areas. Lower income and higher transit accessibilities are positively correlated and strongly
7 significant across all models. Health care related developments remain negatively correlated with
8 ridership and its effect increases in rural areas – lending credence to the logic that access to such
9 services is even more difficult for households without automobiles in rural areas.

10 There are also some key differences across these models. While household and
11 employment densities are both positively correlated with ridership, household is not a significant
12 determinant of ridership in suburban areas (Model III) and employment is not a significant
13 determinant in rural areas (Model IV). The SMZ with higher school enrollment is expected to
14 produce more transit trips. The square footage for different land use types is differently related to
15 ridership. While beyond the scope of this analysis, this could be studied in greater detail. Also, a
16 number of variables strongly significant in Model I lose their significance in subset-based
17 models. For example, household density, employment density and drive alone density are not
18 significant in Model II. A closer look at the data may explain why. The relationships may not
19 clear due to relative similarity of urban form and transit services among SMZs within a typology,
20 or lower variance among the explanatory variables. This may also explain why the coefficient of
21 determination (R^2) is highest for Model II and least for Model IV. The lower magnitude of
22 ridership might be one of the reasons of lower (R^2) for Model III and Model IV. On the contrary,
23 Model II has the highest (R^2) as the ridership for urban area is the highest among all.

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

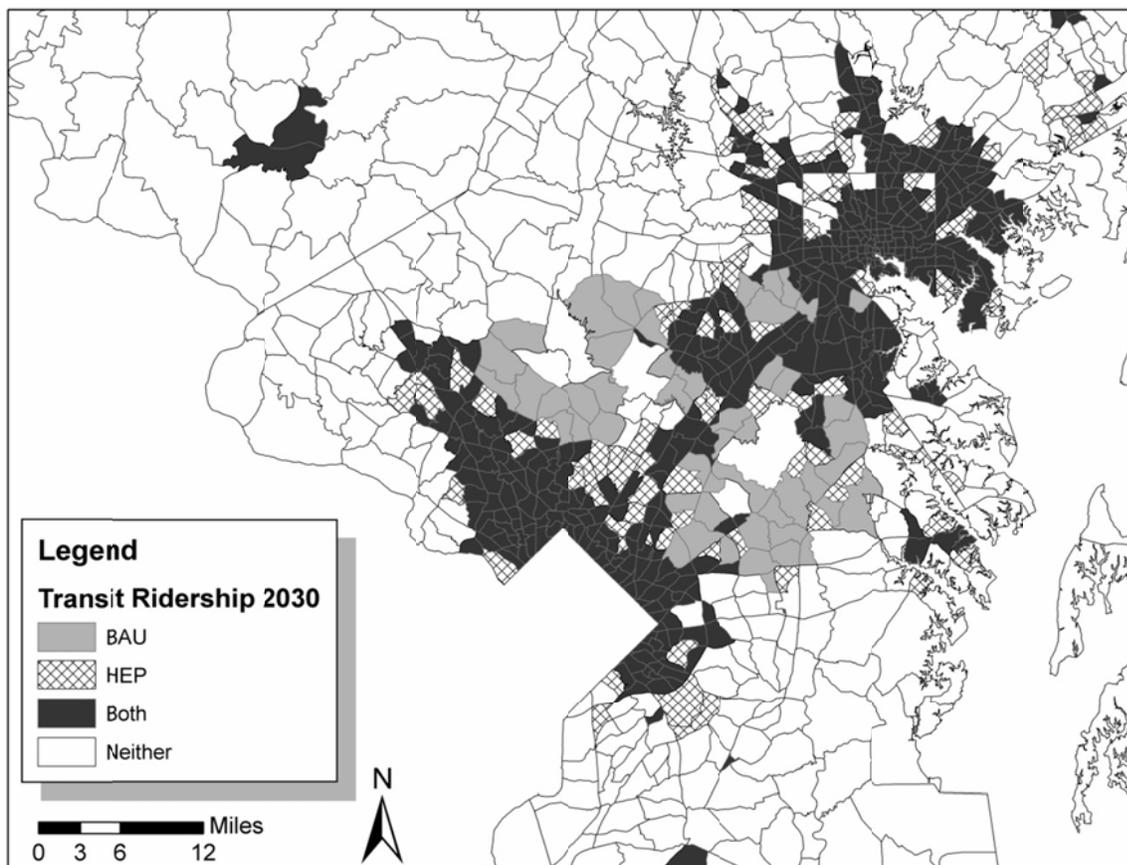
28 **PLANNING APPLICATION: HORIZON YEAR RIDERSHIP SCENARIOS**

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

34 To illustrate our application, we drew upon the work of Maryland Scenario Project
35 (MSP), a large-scale visioning exercise led by the National Center for Smart Growth (NCSG) at
36 the University of Maryland. For more on MSP, please refer to the past publications (56, 57). The
37 principles of scenarios were developed by the Scenario Advisory Group, an MSP-affiliated
38 group of nearly 40 land use and transportation planning professionals. The Group identified a
39 number of important yet uncertain sets of conditions that may affect development of the region.
40 The most relevant among these for our purposes were growth rates of energy prices and federal
41 expenditures. Building on these, we characterized one set of year 2030 conditions as (a) Business
42 as Usual (BAU), where the past relationships between sectors, investment patterns,

1 demographics, etc., continue unimpeded; and the other set of variables as (b) High Energy Prices
 2 (HEP), an alteration of energy prices where some past historical relationships will continue, and
 3 changes in energy prices reverberate throughout the economy and change economic, land use,
 4 and transportation outcomes. Under HEP, real crude oil prices rise faster than BAU at 1 percent
 5 above the projected inflation rate. In BAU, oil prices roughly follow the Energy Information
 6 Administration's short-term projections.

7 Next we leveraged a set of models developed for MSP to operationalize these conditions
 8 into specific variables for each SMZ (Figure XYZ. The national economic model is based on the
 9 Long-term Interindustry Forecasting Tool (LIFT), forecasts outcomes of various macroeconomic
 10 policies and changes such as energy prices. The outcomes of this model, in turn, influence the
 11 regional and local demographic model, which determines households' employment in various
 12 county and SMZ-level sectors. Since this paper is not on the adequacy and accuracy of these
 13 models, we refer the readers to model documentation and published material elsewhere (58,59).
 14



15
 16 **FIGURE 3 Change between HEP and BAU scenarios**

17
 18 Additional datasets were collected from a number of agencies. The socioeconomic data was
 19 obtained from the MPO cooperative forecasts. The network related data was used from the 2030

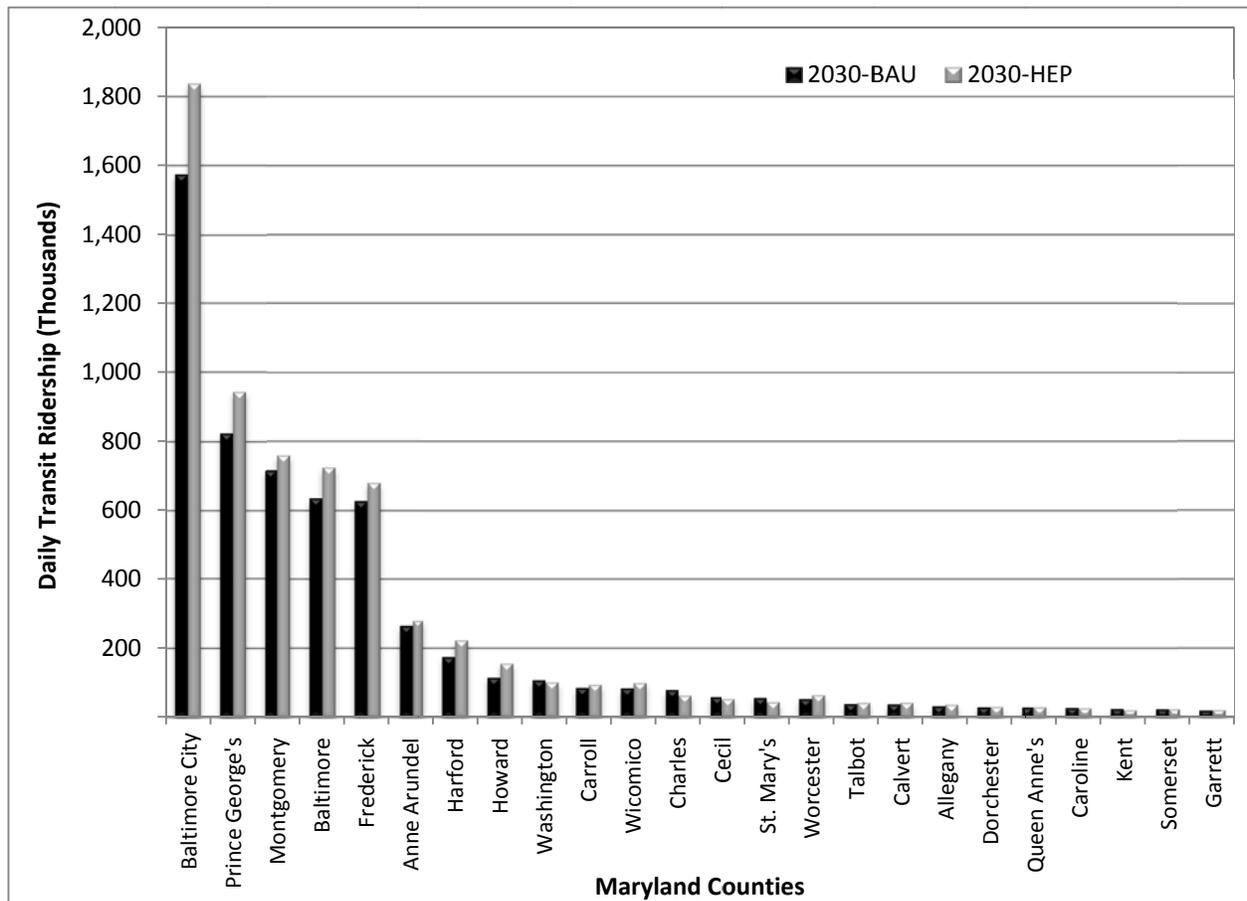
1 network developed at the NCSG. The land use data such as the facility type square feet are used
2 from the property view data to develop the growth from last five years and extrapolated for the
3 year 2030. Two ridership scenarios – BAU and HEP –were obtained using 2030 input datasets
4 and the coefficients from Model I in Table 4. A summary map of the difference between them is
5 depicted in Figure 3.

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

18 These findings have several implications. For example, our analysis shows that different
19 assumptions about the future can have different outcomes. While a large number of SMZs will
20 continue to require transit services under both scenarios, a number of them will require
21 additional services only under HEP or under BAU scenario. How this information is used in
22 decision-making will depend on the agency and the decision in question. For example, a transit
23 agency overseeing an SMZ that may have high ridership demand in one scenario but little in
24 another, might want to track the likelihood of external conditions (since it can't directly
25 influence them), and make any new investment decisions only if there is a high likelihood of
26 HEP. A state agency, however, might use the same information for different purposes.

27 Figure 4 shows, as expected, that statewide transit ridership is higher in the high-energy
28 price scenario. Further, it shows that some counties will receive a higher share of this growth
29 than other. Such differences may play a role in state level decisions, including land use policies
30 and future transit subsidies. For example, promoting new development in Baltimore City or
31 Prince George's County seems to be one way to encourage transit ridership. Also, if steep
32 increase in energy prices becomes a likely scenario, it might be useful to know that it might have
33 a spatially varied impact and can inform state financing of new projects. Furthermore, if a state
34 level agency is interested in (and capable of) coordinating urban development and transit
35 investment it may look at development patterns and ridership across counties, projected trends in
36 development and other factors in making land use and transit related policies.

37



1

2 **FIGURE 4 Transit ridership in Maryland counties under BAU and HEP scenarios**

3

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

10

11 **CONCLUSIONS AND DISCUSSION**

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

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

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

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

22 Further, using a stylized case of two scenarios – business as usual and high energy prices
23 – we demonstrated how such analysis could lead to multiple choices that a state level agency can
24 consider in making its decisions. Estimating transit ridership under multiple scenarios shows
25 how demand could vary by parts of the state and demonstrates the model’s value in assessing
26 transit and land use planning decisions.

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

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