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Impact of Transit-oriented Development Policy Scenarios on Travel Demand Measures of Mode Share, Trip Distance and Highway Usage in Maryland

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Abstract

This paper aims to evaluate and compare impacts of two alternative Transit-Oriented Development (TOD) policies, concentrating growth of population or employment opportunities in transit service area, on travel demand measures of mode share, trip distance and highway usage. A validated Maryland Statewide Transportation Model (MSTM) is employed to forecast changes in travel demand measures under various TOD policy scenarios in a future year of 2030. The model simulation results show either concentrating population or employment policy has similar impacts on raising transit mode share and reducing auto mode share. However, concentrating population policy decreases average trip distance while concentrating employment policy increases it. Consequently, concentrating population policy reduces highway usage, measured by Vehicle Miles Traveled (VMT), more effectively than concentrating employment policy in this specific region given the existing land use pattern. The findings in this paper have important implications to urban planners, transportation planners and decision makers in Maryland of US. The paper also provides a good example for applying a travel demand model to evaluate and compare alternative TOD policies based on travel demand measures.

Keywords: *transit-oriented development, travel demand measure, land use, transit mode share, average trip distance, vehicle miles traveled*

1. Introduction

With growth in traffic congestion, alternative solutions have been proposed to reduce travel by car. Redesigning cities and expanding alternative transportation modes offer the best long-term means for reducing traffic congestion (Tayor, 2002). Land use patterns which support the use of transit and transit systems are increasingly seen as an essential element in policy packages which aim to reduce congestion. One of the important approaches is Transit-oriented Development (TOD) which focuses the development of housing and employment around the transit stations (Cervero, 1998). Although there are many different definitions of TOD, TOD actually is a term which encapsulates the process of focusing the development of housing, employment, activity sites and public services around existing or new railway stations served by frequent, high-quality and efficient intra-urban rail services (Cervero, 1998; Knowles, 2012; Hesse, 2009). TODs are increasingly being developed across the United States to boost the transit ridership and reduce traffic congestion (Cervero *et al*., 2002), and all levels of U.S. government put in more efforts to promote TOD (Cervero, 2004; Filion and Mcspurren, 2007).

The concept of TOD was first codified by an American architect and planner, Peter Calthorpe (1993), in late 1980's, and it became a fixture of modern planning in 1993 (Calthorpe, 1993; Sung and Oh, 2011). TOD itself is not just a recent phenomenon, and it originated in the late 19th and early 20th centuries in a period which predated private car ownership (Knowles, 2012). Until now, many examples of TOD policies are developed in European and Asian cities such as Tokyo, Copenhagen, and Hongkong (Cervero, 1998; Dittmar and Ohland, 2003; Cervero, 2009; Yang *et al*., 2013). Meanwhile, in United States, some cities such as San Francisco and Atlanta have incorporated TOD concepts, and some others such as Baltimore and Washington metropolitan regions are experiencing an explosion of interest in expanding existing rail transit system to encourage TOD (Ratner and Goetz, 2013). Maryland has placed Legislation since 1998 to

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facilitate TOD as a way of concentrating development at transit stations to boost transit ridership. Most existing studies on TOD focus on the TOD areas where the transit system and urban development took place hand in hand, and not much attention has been put on TOD in large metropolitan cities that already have well-developed transit systems (Loo *et al*., 2010).

With well-developed transit system, there are three broad categories of policies to realize TOD: (1) development of new residential areas in transit service area; (2) development of new employment centers in transit service area; (3) simultaneous development of residential areas and employment centers in transit service area. Qualitatively speaking, all the three categories of policies are likely to increase the market share of transit and reduce car use, thereby reducing traffic congestion. The first category of policies may attract more people to live transit service area and increase the likelihood of using transit for home-based trips. The second category of policies may encourage more commuters to use transit for commuting, which is a major contributor to traffic congestion in peak periods. In addition, employment centers are usually also commercial centers that may attract a large number of non-work trips. Development of employment centers in transit service area may further enhance market share of transit for non-work trips. The third category of policies is a combination of the former two, it can therefore not only bring the benefits of the former two but also promote a mixed pattern of land use, which may shorten trip distance and further mitigate traffic congestion.

However, the future development is inevitably affected by the status quo. From the perspective of travel demand analysis, the first category of policies shift trip production into transit service area while keeping trip attraction unchanged. On the contrary, the second category of policies shift trip attraction into transit service area while keeping trip production unchanged. It can be questioned whether a single-side shift of either production or attraction will lead to a separation of job and home locations and contribute an increase in commuting distance, which may offset the benefit from transit share increment. For example, Giuliano and Small (1993) show that concentration of employment in centers caused workers living in primary residential areas to travel greater distances. The third category of policies intends to shift both production and attraction into the same transit service area which may shorten trip distance. However, new employees do not necessarily choose to live in the same area, which may still cause potential job-home separation problems.

Therefore, it is necessary to quantify the impacts of alternative TOD policies on transportation prior to policy development and implementation. In the previous studies, the impacts were usually evaluated by transit ridership without consideration of the whole trip distance and highway usage. Besides, little research has examined impacts and effectiveness of alternative TOD policies (Mishra *et al*., 2013). While it is evident that TOD is a way to encourage the use of transit, policy and decision makers need to know the scale of impact from a different type of development on travel demand measures.

In this paper, the impacts of alternative TOD policy scenarios in Maryland were investigated with differing levels of residential and/or employment development on travel demand measures including transit mode share, trip distance and highway usage. Efforts are made to address the following questions: (1) Do alternative TOD policies increase transit ridership for all trip purpose? (2) How do alternative TOD policies affect trip distance in the entire region? (3) How do alternative TOD policies affect vehicle miles traveled in the entire region?

The Maryland Statewide Transportation Model (MSTM), which is designed as a functional integrated land use-transportation model for analyzing transportation impacts in the Maryland-Washington DC Region (Mishra *et al*., 2011; Mishra *et al*., 2013a), is employed to conduct travel demand forecasting under different TOD scenarios. In next section, the study area and the transit system are first introduced and then the study area is divided into three geographic areas according to the level of transit service. Section 3 describes the data sources and MSTM. Section 4 shows the methodology for developing the TOD scenarios. The model simulation results are compared in Section 5. The conclusions and discussions are provided in Section 6.

2. Study Area

The state of Maryland is located in the heart of the Mid-Atlantic region of the United States, neighboring Washington DC, Virginia, Delaware, Pennsylvania and West Virginia. It consists of 23 counties and Baltimore City, and has a robust dedicated right-of-way transit network. The Baltimore and Washington metropolitan region including the “Washington area” (the light purple area in Fig. 1) and “Baltimore area” (the dark purple area in Fig. 1) is the study area. There are 96 rail transit stations in the study area. According to the Maryland TOD legislation in 2008 (Maryland Department of Transportation, 2015), the metropolitan region is divided into three distinct geographic areas (see Fig. 1): (a) Priority Transit Areas (PTA) - TOD areas

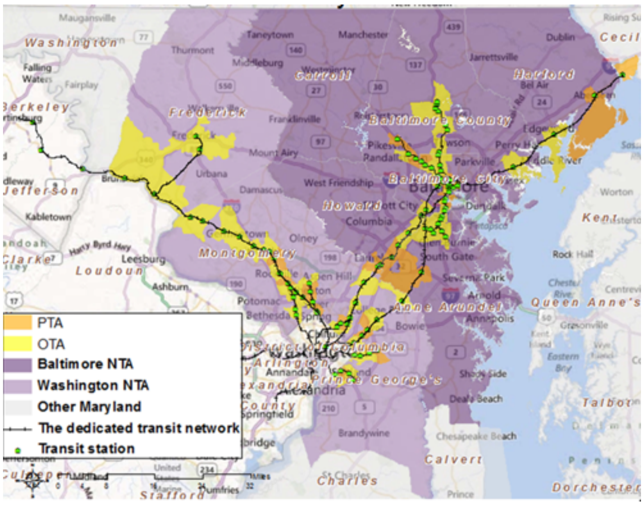


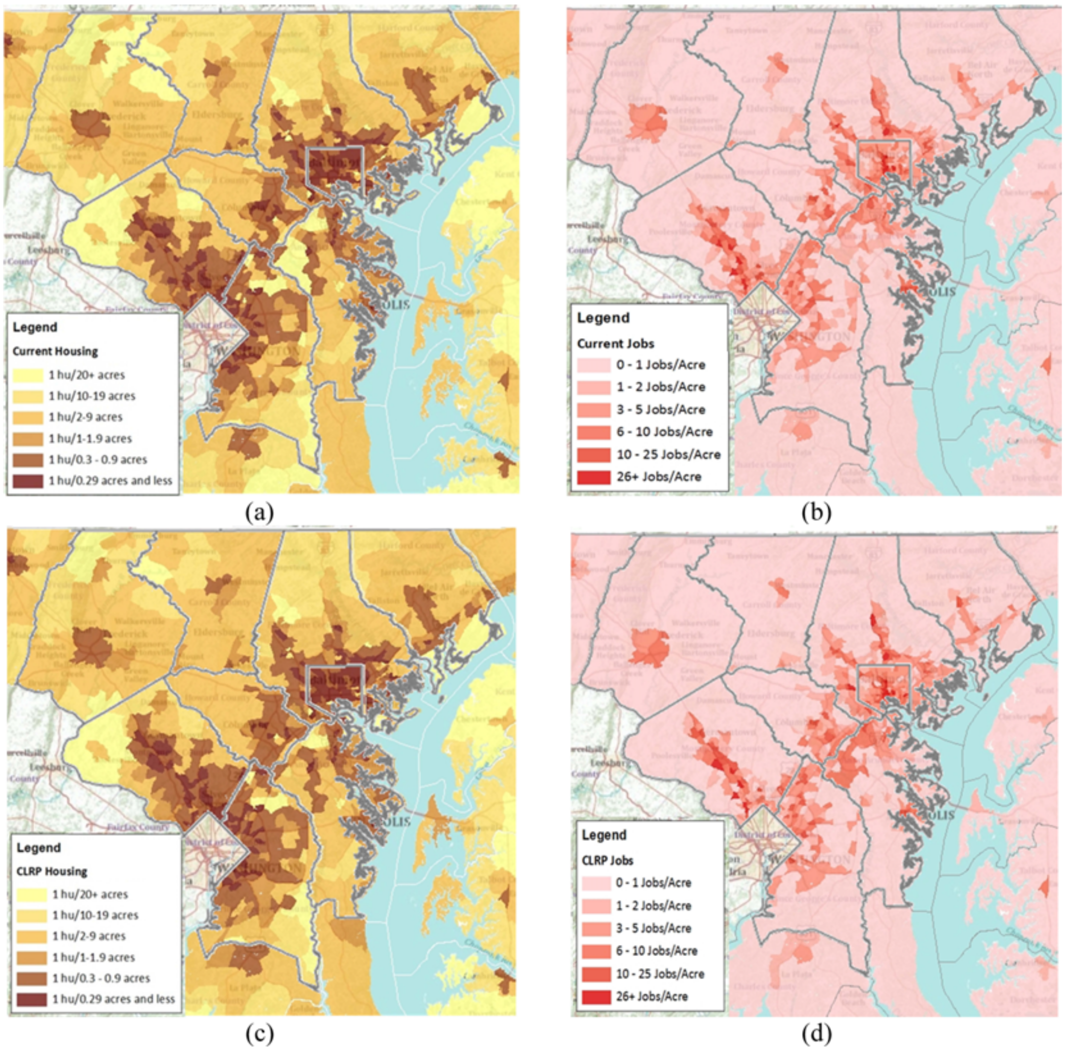
Fig. 1. Study Area and Its Distinct Geographic Areas

served by designated rail transit stations; (b) Other Transit Areas (OTA): non-priority areas served by a rail transit station; (c) Non-Transit Areas (NTA): the areas not served by a rail transit in the study area.

3. Data and Models

The socio-economic and transportation data used in this paper are obtained from Maryland Department of Transportation (MDOT) and two Metropolitan Planning Organizations (MPOs) including Baltimore Metropolitan Council (BMC) and Metropolitan Washington Council of Governments (MWCOG). BMC region covers the “Baltimore area” (the dark purple area in Fig. 1) and MWCOG region covers the “Washington area” (the light purple area in Fig. 1). Each MPO has a current travel demand model and also develops a constrained long-range plan (CLRP) that defines the transportation needs for projected land-use pattern and population/employment growth (The National Capital Region Transportation Planning Board, 2015). All these data of the base year (2007), current year (2010) and future year of CLRP (2030) are provided to develop the Maryland Statewide Transportation Model (MSTM). As part of the MSTM development, the 2030 land use and transportation scenario of CLRP has been developed, and the MSTM has been applied under this scenario (Mishra *et al.,* 2013a). The CLRP scenario is used as baseline in this study. Fig. 2 shows the distributions of housing units and jobs in 2010 and 2030 (CLRP year). It shows that population and employment have already been, to some extent, concentrated in some transit service areas, which is critical for understanding the model simulation results to be discussed later in this paper.

MSTM includes 1588 Statewide Model Zones (SMZs) covering Maryland, Washington DC, Delaware and parts of New Jersey, Pennsylvania, Virginia and West Virginia. The base-year network consists of more than 167,000 links, and contains 18 functional classifications including all highway, transit, walk access, and transfer links, etc. It is a trip-based model that operates at a regional, statewide and urban level. Every level is simulated to study travel behavior with an appropriate amount of detail. Each



(a) (b) (c) (d)

Fig. 2. Housing and Jobs Distributions in 2010 and CLRP (2030): (a) Current Housing Units Density Distribution, (c) CLRP Housing Units Density Distribution, (b) Current Jobs Density Distribution, (d) CLRP Jobs Density Distribution

SMZ specified within the model has a unique set of households and employment. Households are cross-classified by income, household size and number of workers. Employment categories include retail, office, industrial and other. Trip production rates are different for each trip purpose and vary across household categories in each region based on data from a regionally detailed household travel survey. The trip distribution portion of the model employs a destination choice model with a multinomial logit formulation to predict the probability of a traveler choosing any given zone as a destination (Mishra *et al.*, 2013b). The mode choice portion of the model employs a nested logit model (Lin *et al.*, 2014). Destination and mode choices are jointly modeled within a nested structure. At first, the utility U_{ijn} of choosing a trip destination j for a trip n produced in zone i is given as:

$$U_{ijn} = log(\sum exp(\lambda^k) \cdot E_j^k) + \alpha \times L_{ij} + \sum \beta^k \cdot D_{ij}^k + \sum \beta^k \cdot D_{ij}^k \cdot N_n^k + \sum \beta^k \cdot Z_j^k \quad (1)$$

where, E_j^k is employment of type k in zone j; their coefficients are re-parameterized as $exp(\lambda^k)$ to guarantee positive values (Since the scale of the size term is arbitrary, one of λ^k value is always set to 0 for normalization); L_{ij} is the logsum term from mode choices between zone pair '*ij*'; D_{ij}^k represents the various distance terms (linear, log, squared, cubed and square root); N_n^k represent person, household or production zone characteristics for trip 'n' and is used for creating interaction terms with

Table 1. Coefficients of Destination Choice Models by Trip Purpose

	Trip Purpose				
Explanatory Variable	HBW	HBS	HBO	NHBW	OBO
Mode choice logsum	0.5769	0.8000	0.8420	0.9078	0.8000
Distance	-0.4383	-0.3986	-0.5788	0.0978	-0.2241
Distance Squared	0.0137	0.0166	0.0261	-0.0032	0.0106
Distance Cubed	-0.0002	-0.0004	-0.0005		-0.0002
Log of Distance	0.7066	-0.9034	-0.4212	-1.5665	-1.0944
Income X Distance interactions					
Income (<30K)					
Income (30-60K)	0.0176	0.0162	0.0345		
Income (60-100K)	0.0470	0.0255	0.0357		
Income (100-150K)	0.0606	0.0263	0.0357		
Income (150K+)	0.0697	0.0263	0.0357		
Size Term (exponentiated)					
Other Employment	1.0000		0.3052	0.4271	0.1470
Retail Employment	1.0134	1.0000	0.1878	1.0000	1.0000
Office Employment	0.2904		0.0446	0.4992	
Industrial Employment	0.3585				0.0874
Production Region X Distance interactions					
Baltimore CBD (Region 1)	-0.0362				
Washington DC CBD (Region 2)	-0.0882				
Baltimore Semi-Urban (Region 3)	-0.0269				
Wash.DC Semi-Urban (Region 4)	-0.0422				
Baltimore Suburban (Region 5)	-0.0350				
Wash. DC Suburban (Region 6)	-0.0255				
SE Maryland and Halo (Region 7)	-0.0255	-0.0100	-0.0100	-0.0100	-0.0100
SW Maryland and Halo (Region 8)	-0.0350	-0.0100	-0.0100	-0.0100	-0.0100
Intrazonal indicator variable	1.2038		0.6633	0.7228	0.6311
Bridge Crossing indicator	-0.3013	-1.2928	-0.8054	-0.5280	-0.9768
Households			1.0000	0.2825	0.3243
Distance Cap	25	30	30	30	30
Distance Constants					
0-1mile	0.7729	1.7660	1.4007	0.2417	2.2193
1-2 miles	0.0000	1.9110	0.5347	0.0140	1.1874
2-3miles	-0.1059	1.2765	0.1937	-0.0396	0.6676
3-4 miles	-0.3221	0.8224	0.1937	-0.0396	0.6676
4-5 miles	-0.1424	0.7539	0.1937	-0.0396	0.6676
5-6 miles	-0.1424	0.2023	0.0000	0.0000	0.0000
6-7 miles	-0.1000	0.0721	0.0000	0.0000	0.0000

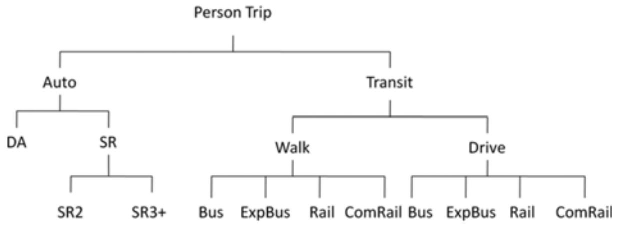


Fig. 3. Structure of Nested Logit Model for Mode Choice

distance terms; Z_j^k represents attraction zone's characteristics other than the size term.

A combination of distance terms is used in the utility such that the composite distance utility function is monotonically decreasing. These distance terms are used to closely approximate the shape of trip length distribution. The distance-related disutility is capped at a chosen maximum value, to maintain a reasonable probability of selecting destinations far away. The distance cap was established during model estimation and adjusted during model calibration to ensure that the model reproduces a tail of the trip length distribution. All the model coefficients of destination choice models are listed in Table 1 for different trip purposes.

Travel mode choice model is an adaptation of the most recent BMC nested logit mode choice model. The model involves 11 travel modes, including "DA" (drive alone), "SR2" (shared auto ride with 2 passengers), "SR3+" (shared auto ride with more than 2 passengers); Walk-access Bus, "ExpBus" (express bus), Rail, "ComRail" (commuter rail); Drive-access Bus, "ExpBus" (express bus), Rail and "ComRail" (commuter rail). All those modes are aggregated into three levels of nests, as shown in Fig. 3.

Mode choice is based on generalized utility functions for alternative auto or transit modes. The auto utilities include driving time and cost, terminal time and parking costs at the attraction end, and tolls. Transit utilities include walk or drive-access times, initial wait time, in-vehicle time, number of transfers, transfer time and transit fare. Utility specification is

Table 3. Coefficients in Mode Choice Models

Attribute	HBW, NHBW	HBO, HBS, SCH	OBO
In-Vehicle Time (min)	-0.025	-0.008	-0.02
Terminal Time (min)	-0.05	-0.02	-0.05
Auto Operating Cost (cents)	-0.0042	-0.0018	-0.0044
Auto Parking Cost and Tolls (cents)	-0.0084	-0.0036	-0.0088
Walk Time (min)	-0.05	-0.02	-0.05
Initial Wait Time (under 7.5 min.)	-0.05	-0.02	-0.05
Initial Wait Time (over 7.5 min.)	-0.025	-0.01	-0.025
Transfer Time (min)	-0.05	-0.02	-0.05
Number of Transfers	-0.125	-0.06	-0.15
Transit Fare (cents)	-0.0042	-0.0018	-0.0044
Drive Access Time (min)	-0.05	-0.02	-0.05

Table 4. Mode-specific Constants in Mode Choice Models by 5 Income Categories

Purpose	DA	SR	SR2	SR3	Drive to Transit	Walk to Transit
HBW1	0	0	-0.329	-1.285	-0.856	3.996
HBW2	0	0	-0.351	-1.266	-0.539	2.464
HBW3	0	0	-0.409	-1.586	-1.072	0.771
HBW4	0	0	-0.447	-1.664	-2.503	-1.947
HBW5	0	0	-0.463	-1.695	-3.166	-3.231
HBS1	0	0	-0.094	0.035	-3.127	-1.631
HBS2	0	0	-0.194	0.104	-3.176	-2.417
HBS3	0	0	-0.116	0.090	-4.688	-3.552
HBS4	0	0	-0.043	-0.022	-5.072	-3.585
HBS5	0	0	-0.040	-0.040	-5.428	-3.806
HBO1	0	0	-0.014	0.170	-0.848	0.666
HBO2	0	0	-0.095	0.152	-2.665	-0.616
HBO3	0	0	-0.029	0.190	-3.218	-2.041
HBO4	0	0	0.008	0.197	-4.084	-2.961
HBO5	0	0	-0.001	0.18	-4.188	-3.536
HBSc	0	-0.838	0	-0.132	-0.516	-1.229
NHBW	0	-1.098	0	-0.305	-3.076	-2.419
OBO	0	0.351	0	-0.073	-2.712	-1.784

Table 2. Variables Included in Utility Expressions

	Mode								
Variable	DA/SR	Wbus	WEBus	WRail	WCRail	Dbus	Debus	DRail	DCRail
In-Vehicle Time	X	X	X	X	X	X	X	X	X
Terminal Time	X								
Auto Operating Cost	X								
Auto Tolls	X								
Auto Parking Cost	X								
Walk Time		X	X	X	X	X	X	X	X
Initial Wait Time (under 7.5 min.)		X	X	X	X	X	X	X	X
Initial Wait Time (over 7.5 min.)		X	X	X	X	X	X	X	X
Transfer Time		X	X	X	X	X	X	X	X
Number of Transfers		X	X	X	X	X	X	X	X
Transit Fare		X	X	X	X	X	X	X	X
Drive Access Time						X	X	X	X

Table 5. Mode-specific Constants at the 3rd Level

Purpose	Drive to Bus	Walk to Bus	Drive to Express Bus	Walk to Express Bus	Drive to Rail	Walk to Rail	Drive to Commuter Rail	Walk to Commuter Rail
HBW	0	0	-0.437	-5.442	0.378	-0.436	1.107	-3.516
HBS	0	0	0	0	-0.444	1.310	-5.717	0.877
HBO	0	0	0	0	1.398	2.028	3.018	0.272
HBSc	0	0	0	0	-0.126	9.085	41.63	37.091
NHBW	0	0	0	0	-0.330	1.154	2.887	0.792
OBO	0	0	0	0	0.799	2.393	4.360	4.892

Table 6. Nesting Coefficient

Nest	Value
Walk Transit Route (Bus, Express Bus, Rail, Commute Rail)	0.30
Drive Transit Route (Bus, Express Bus, Rail, Commute Rail)	0.30
Transit Access (Walk vs. Drive)	0.65
Shared Ride Occupancy (2 vs. 3+)	0.30
Auto Mode (Drive Alone vs. Shared Ride)	0.65

detailed in Table 2, while model coefficients are provided in Table 3. Mode-specific constants at different levels are included in Table 4 and 5 below, which have been calibrated to match the mode shares observed in Baltimore and Washington areas. Some income-specific constants have also been calibrated to match observed shares for the second level of nests. The nesting coefficients for different levels are provided in Table 6.

There are 957 SMZs within the study area, of which 84 are located in the PTA and 167 are located in the OTA. Table 7 shows the growth in housing units (HU) and employment opportunities expected in the study area between 2010 and 2030, and also illustrates how the CLRP scenario allocates growth between the "Baltimore area" and "Washington area". Fig. 2 has shown the specific distribution of housing units and jobs at present (2010) and in the forecast year (2030).

4. Methodology

The TOD scenarios in this study were developed by relocating the growth of households and/or employment, based on the CLRP forecast. Each scenario was designed to shift expected growth and development into areas served by transit. By relocating the growth, one can assess the impacts on the travel demand measures and draw conclusions on the relationship between land use and transportation.

To this end, a certain percentage of the total growth is relocated and concentrated into PTAs and OTAs respectively while the total regional population and employment keep constant across all the scenarios. The total regional growth comes from 2030-forecasted CLRP scenario. For comparing the impacts of alternative TOD policies on transportation, three types of TOD scenarios are established based on the CLRP. They are (1) relocating household growth from non-transit areas to transit areas while employment location remains unchanged; (2) relocating employment growth while household location remains unchanged; (3) relocating both household and employment growth from non-transit areas to transit areas. These scenarios are named as "Res", "Emp" and "Res & Emp", respectively.

For measuring the potential linear or non-linear effect of population and/or employment changes on travel demand, each of the above mixed land use scenarios is tested with various percentages of household and/or employment growth being relocated. The percentages increase from 15% to 45% with 10% increment. Then, each scenario is named by a combination of the relocation type and percentage. For example, "Res15%" indicates the scenario where 15% of household growth is relocated; "Res&Emp25%" indicates the scenario where 25% of both household and employment growths are relocated.

When the relocation of growth within the study area is calculated, the growth is shifted strictly within each of two major metropolitan regions to ensure consistency of regional growth

Table 7. The Number and Growth of Housing Units (HU) and Jobs Under CLRP

Area		2030 CLRP HU	Growth in HU compare to 2010	Growth% in HU	2030 CLRP Jobs	Growth in Jobs compare to 2010	Growth% in Jobs
Baltimore	Total	1,187,152	160,335	15.61%	1,961,400	276,992	16.44%
	PTA	113,861			456,318		
	OTA	163,374			366,138		
	NTA	909,917			1,138,944		
Washington	Total	931,359	123,654	15.31%	1,330,212	90,211	7.28%
	PTA	125,422			232,442		
	OTA	270,857			525,420		
	NTA	535,080			572,350		
Total		2,118,511	283,989	15.48%	3,291,612	367,023	12.55%

totals. For example, under the “Res15%” scenario, 15% of the total household growth in the Baltimore region (15% × 160,335 = 24,050 households) is shifted to Baltimore PTAs, and the same number of households growth (24,050 households) is shifted to Baltimore OTAs while the corresponding number of households (i.e. 24,050 × 2 = 48100) are taken away from Baltimore NTAs to keep the total household growth unchanged. The amount of employment growth to be relocated is calculated in the same way. The “Res & Emp” scenario is simply a combination of “Res” and “Emp” scenarios. The following formula is used to calculate the number of households or employment opportunities to be relocated in scenarios:

$$N_M^S = p^S \cdot (N_M^C - N_M^B) \tag{2}$$

In the formula, *N* indicates the number of households or employees to be relocated; *M* indicates the metropolitan region of Washington or Baltimore; *S* represents different scenario; *p* is the relocation percentage; *C* means constrained long-range plan in 2030; *B* means the base year of 2010. Once the total household and employment growth are calculated for each metropolitan region, the growths will be allocated to each SMZ. The number of relocated households or employees needs to be calculated by geographic area (PTA, OTA, and NTA) under different TOD scenarios. In general, relocated numbers are calculated in proportion to existing numbers. The following formulae are used to update the household/employee number of each zone i in area A of region M under scenario S:

$$N_{MAi}^S = N_{MAi}^C + N_{MAi}^C \cdot \frac{N_M^S}{\sum_{i \in MA} N_{MAi}^C}$$

(if A = ‘PTA’ or ‘OTA’ for zone i belonging to area A) (3)

$$N_{MAi}^S = N_{MAi}^C - N_{MAi}^C \cdot \frac{2 \cdot N_M^S}{\sum_{i \in MA} N_{MAi}^C}$$

(if A = ‘NTA’ for zone i belonging to area A) (4)

In the formulae, *i* is the zone number; *A* is the geographic area (including PTA, OTA or NTA); *S* means scenario type (including Res15%, Res25%, Res35%, Res45%, Emp15%, Emp25%, Emp35%, Emp45%, Res & Emp15%, Res & Emp25%, Res & Emp35%, Res & Emp45%). N_{MAi}^C is the number of households or jobs in zone *i* belonging to area *A* of region *M* under CLRP scenario; $\sum_{i \in MA} N_{MAi}^{CLRP}$ is the total number of households or jobs in area *A* of region *M* under CLRP scenario. N_M^S is the total number of households or jobs in area *A* of region *M* to be relocated under scenario *S*, which can be calculated from Eq. (2).

At the end of the process, the final household and employment counts are obtained for each zone under all TOD scenarios. Table 2 lists the total number of households and jobs in the three geographic locations of the study area under each TOD scenario, and also shows the percentile change compared to the base CLRP situation.

5. Results

MSTM is used to simulate travelers' behavior under each scenario with a variety of data describing population, land use characteristics and transportation network for the entire region. The results of the CLRP are given as a base, with which all the TOD scenarios are compared to show the impacts of shifting employment, households or both on travel demand measures. For evaluating and comparing the impacts, travel demand is quantified under all the scenarios with three common measures: travel mode share, trip distance, and highway usage (vehicle miles traveled).

5.1 Baseline Results

For better understanding the relative change that occurs under each TOD scenario, it is necessary to capture baseline travel demand measures under the CLRP scenario. Table 9 provides daily trip frequencies and mode shares by trip purposes in the entire study area under CLRP. In MSTM, the total trips are originally classified into six categories according to trip purpose, including Home-Based Work (HBW), Home-Based Shopping (HBS), Home-Based School (HBSc), Home-Base Other (HBO),

Table 8. Household Units (HU) and Jobs in the Three Geographic Areas under TOD Scenarios

scenarios	HU (million)			HU changes			Jobs (million)			Job changes		
	PTA	OTA	NTA	PTA	OTA	NTA	PTA	OTA	NTA	PTA	OTA	NTA
Res15%	0.28	0.48	1.36	18%	10%	-6%	0.69	0.89	1.71	0%	0%	0%
Res25%	0.31	0.51	1.30	30%	16%	-10%	0.69	0.89	1.71	0%	0%	0%
Res35%	0.34	0.53	1.25	39%	21%	-14%	0.69	0.89	1.71	0%	0%	0%
Res45%	0.37	0.56	1.19	53%	29%	-18%	0.69	0.89	1.71	0%	0%	0%
Emp15%	0.24	0.43	1.44	0%	0%	0%	0.74	0.95	1.60	8%	6%	-6%
Emp25%	0.24	0.43	1.44	0%	0%	0%	0.78	0.98	1.53	13%	10%	-11%
Emp35%	0.24	0.43	1.44	0%	0%	0%	0.82	1.02	1.45	18%	14%	-15%
Emp45%	0.24	0.43	1.44	0%	0%	0%	0.85	1.06	1.38	24%	19%	-19%
Res&Emp15%	0.28	0.48	1.36	18%	10%	-6%	0.74	0.95	1.60	8%	6%	-6%
Res&Emp25%	0.31	0.51	1.30	30%	16%	-10%	0.78	0.98	1.53	13%	10%	-11%
Res&Emp35%	0.34	0.53	1.25	39%	21%	-14%	0.82	1.02	1.45	18%	14%	-15%
Res&Emp45%	0.37	0.56	1.19	53%	29%	-18%	0.85	1.06	1.38	24%	19%	-19%

Table 9. CLRP Trip Frequency and Mode Share by Trip Purpose

Purpose	Person trip number (million)			Mode share		
	Auto	Transit	total	Auto	Transit	Total
HBW	2.60	0.54	3.14	82.76%	17.24%	100%
HBS	3.05	0.03	3.08	98.98%	1.02%	100%
HBSc	0.76	0.03	0.79	96.53%	3.47%	100%
HBO	6.27	0.17	6.44	97.38%	2.62%	100%
NHBW	2.91	0.45	3.36	86.58%	13.42%	100%
OBO	6.25	0.25	6.49	96.19%	3.81%	100%
Total	21.83	1.47	23.30	93.70%	6.30%	100%

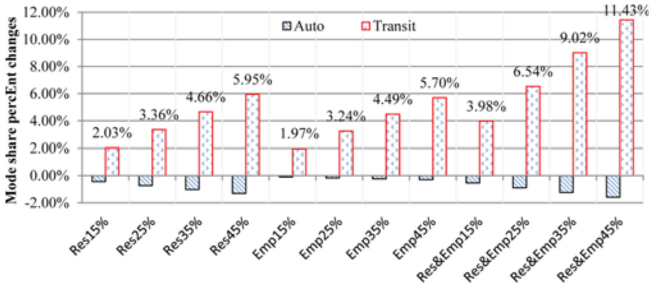


Fig. 4. Entire Region Mode Share Change

Non-Home-Based Work (NHBW) and Other Based Other (OBO), as shown in Table 9.

In the interest of brevity, the comparisons are only focused on four types of trips including HBW, HBS, NHBW trips and the total number of trips, which are of particular interest and quite sensitive to TOD policies. Table 10 shows the daily person trip frequency and average trip distance by area under CLRP. The total daily Vehicle Miles Travelled (VMT) in the whole region under the CLRP scenario is 140,259,440 vehicle miles. This number provides the baseline for the total vehicle travel demand that will be used to analyze changes in highway usage under all the TOD scenarios.

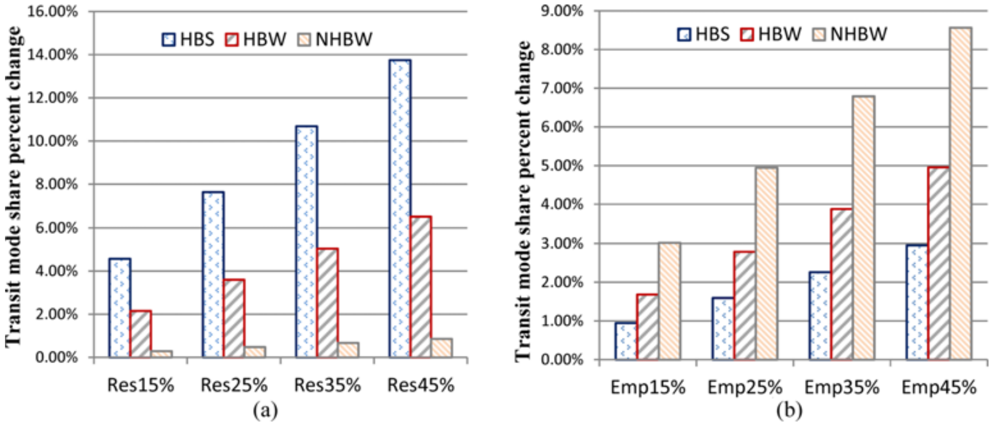
5.2 Impact on Mode Share

Figure 4 shows the percentile increase or decrease of transit share in the study area under each TOD scenario. All the TOD scenarios have decreased auto mode shares and increased transit mode shares. The greater amount of growth is relocated, the greater transit ridership is achieved. The plausible explanation is that people relocated to transit areas have better transit accessibility than those in non-transit areas and are therefore more likely to use transit. The percentile change in auto shares is much lower than that of transit shares due to the higher auto trip frequency. When comparing “Res” and “Emp” scenarios, one may see similar patterns in transit ridership increments. On average, each 1% of household or employment relocation almost equally contributes to 0.13% of transit ridership increment. The effect from relocation is almost linear within the feasible range of relocation rate. The impacts of “Res&Emp” policy scenarios are almost equal to the sum of impacts from individual “Res” and “Emp” scenarios. Those intuitive results show that TOD policies that relocate either population or employment growth into transit areas have almost the same power in boosting transit ridership.

In the comparisons by trip purpose in Fig. 5, it is easy to see

Table 10. CLRP Person Trip Frequency and Distance by Trip Purpose and Area

Area	Person trip number (million)				Average trip distance (mile)			
	Total	HBW	HBS	NHBW	Total	HBW	HBS	NHBW
Total	23.3	3.14	3.08	3.36	15.52	24.33	12.14	16.81
PTA	3.78	0.43	0.42	0.86	14.61	22.06	11.80	16.04
OTA	4.96	0.61	0.60	0.91	14.21	21.39	11.53	16.18
NTA	14.59	2.09	2.06	1.59	16.22	25.58	12.37	17.59



(a) (b)

Fig. 5. Entire Region Transit Mode Share Changes of HBS, HBW, and NHBW Trips: (a) Mode Share Changes Under Res Scenarios, (b) Mode Share Changes Under Emp Scenarios

that, in "Res" scenarios, the transit ridership of home-based trips, especially home-based shopping trips, are more sensitive to relocation rate than non-home-based work trips. Meanwhile, in "Emp" scenarios, the transit ridership of work-related trips, especially non-home based work trips, are more sensitive to relocation rate than home-based shopping trips. The reason behind is that the shift of population into transit areas results in more home-related transit ridership while the shift of employment into transit areas leads to more work-related transit ridership.

5.3 Impact on Trip Distance

In this study, the impact on trip distance is viewed from two different perspectives: the average trip distance of the entire region and the average trip distance by three different areas including Non-Transit Areas (NTA), Priority Transit Areas (PTA) and Other Transit Areas (OTA). Trips are assigned into those three different areas for analysis as per their origin locations.

Figure 6 shows the percentile changes in average trip distance of the entire region under each TOD scenario. As shown, the average distance of total trips declines under population relocation scenarios but increases under employment relocation scenarios. By looking into the analysis by trip purpose, one may see the reason behind is that the average distance of home-based work and shopping trips increases while that of non-home-based work trips slightly decreases in all the "Res" scenarios. When residents relocate to transit service areas with better access to job opportunities, shopping and other amenities, their trips tend to be shorter. However, in all the "Emp" scenarios, job opportunities are probably moved further from home locations, which lengthened home-based work trip distance. Further, the relocation of all types of employment, including retail and other local serving employment, makes home-based shopping trips longer but non-home-based work trips shorter. In addition, the effect from relocating both households and employment seems to be a combination of effects from individually relocating households and employment. The combined effect includes reductions in overall trip distance, reductions in distance of home-based work and non-home-based work trips but slight increases in distance of home-based shopping trips.

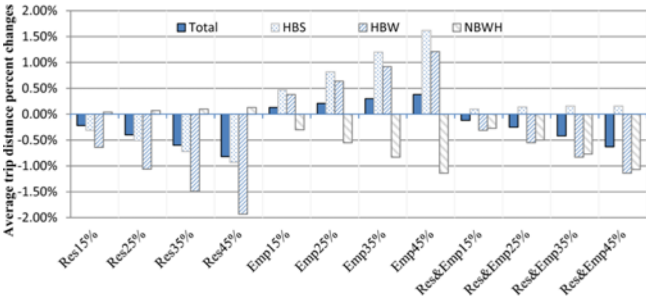


Fig. 6. Entire Region Average Trip Distance Changes

Table 11 shows the changes in average trip distance by PTA, OTA and NTA under each TOD scenario. For PTA and OTA, as more and more residents locate into those areas, the average trip distance declines. This is true for all trip purposes and all scenarios. The greatest decline occurs when both population and employment relocate. For NTA, the average trip distance increases under all scenarios. The increase under the employment scenarios is slightly greater than that under the residential scenarios. The greatest increase by purpose occurs in non-home-based work trips while the greatest increase in total trip distance occurs when both residents and employees relocate.

As shown in Table 11, when relocation rate increases, the trip distance of HBW, NHBW and HBS declines faster in PTA and OTA and increases faster in NTA under "Emp" scenarios than under "Res" scenarios. It is probably because when all kinds of jobs, including those in retail and service sectors, relocate to PTAs from NTAs, people living in PTAs will have better access to those job opportunities or points of interest associated with those jobs but those living in NTAs will be further away from them. The concentrated growth of population and employment through a mixed pattern of land use can explain the reason why "Res & Emp" scenarios have greater impact on trip distance reduction in transit areas and trip distance increase in non-transit areas than individual "Res" or "Emp" scenarios.

Table 11. Average Trip Distance Changes in PTA, OTA and NTA

	PTA				OTA				NTA			
	Total	HBS	HBW	NBWH	Total	HBS	HBW	NBWH	Total	HBS	HBW	NBWH
Res15%	-0.83%	-0.30%	-0.25%	-0.24%	-0.58%	-0.01%	-0.09%	-0.17%	0.59%	-0.06%	0.01%	0.29%
Res25%	-1.36%	-0.46%	-0.38%	-0.39%	-0.95%	-0.01%	-0.15%	-0.27%	0.99%	-0.11%	0.02%	0.49%
Res35%	-1.86%	-0.60%	-0.50%	-0.54%	-1.31%	-0.01%	-0.20%	-0.38%	1.40%	-0.16%	0.03%	0.69%
Res45%	-2.35%	-0.72%	-0.60%	-0.69%	-1.64%	-0.02%	-0.24%	-0.49%	1.81%	-0.22%	0.03%	0.89%
Emp15%	-0.61%	-0.32%	-0.50%	-1.09%	-0.43%	-0.50%	-0.39%	-0.87%	0.64%	0.87%	0.70%	1.09%
Emp25%	-1.01%	-0.51%	-0.82%	-1.77%	-0.71%	-0.81%	-0.65%	-1.42%	1.08%	1.50%	1.19%	1.84%
Emp35%	-1.40%	-0.69%	-1.13%	-2.42%	-0.99%	-1.10%	-0.89%	-1.95%	1.53%	2.16%	1.68%	2.60%
Emp45%	-1.78%	-0.85%	-1.43%	-3.04%	-1.26%	-1.37%	-1.12%	-2.47%	1.99%	2.87%	2.20%	3.39%
Res&Emp15%	-1.40%	-0.67%	-0.78%	-1.31%	-0.99%	-0.52%	-0.50%	-1.02%	1.25%	0.81%	0.71%	1.39%
Res&Emp25%	-2.27%	-1.09%	-1.27%	-2.12%	-1.61%	-0.85%	-0.82%	-1.67%	2.12%	1.39%	1.21%	2.35%
Res&Emp35%	-3.08%	-1.50%	-1.75%	-2.90%	-2.20%	-1.17%	-1.13%	-2.29%	3.03%	2.00%	1.72%	3.34%
Res&Emp45%	-3.85%	-1.89%	-2.21%	-3.63%	-2.75%	-1.48%	-1.44%	-2.88%	3.98%	2.66%	2.26%	4.35%

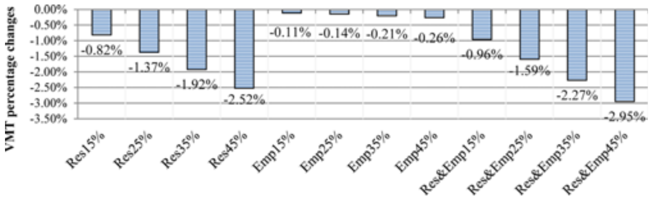


Fig. 7. Vehicle Miles Traveled Changes Compared to CLRP

5.4 Impact on Highway Usage

In the entire region, the daily Vehicle Miles Traveled (VMT) decline under all the TOD scenarios, as shown in Fig. 7. Since both auto mode share and average regional trip distance decrease in “Res” scenarios, VMT decline almost linearly with increase in relocation rate. It can be estimated that each 1% of household relocation contributes to about 0.056% reduction in VMT.

In the “Emp” scenarios, reduction in auto mode share and increase in trip distance eventually result in a slight reduction in VMT. That is because the lengthened trip distance offsets the VMT reduction contributed from lower auto mode shares. Besides, the VMT reduction in “Res & Emp” scenarios is slightly greater than the sum of reductions in relevant individual “Res” and “Emp” scenarios, which reflects a somewhat synergetic effect from simultaneous development of residential area and employment center in transit service area. However, given the existing land use pattern in this study area, the model simulation results show that development of residential area in transit area to relocate population is much more effective in VMT reduction than development of employment center in the same area.

6. Conclusions

In this paper, authors employed Maryland Statewide Transportation Model to analyze the complex impacts from alternative TOD policy scenarios in Maryland of US, where the growths of jobs or/and households are relocated, on travel demand measures of transit mode share, trip length and highway usage. The main objective of this paper is to make an empirical, instead of theoretical, contribution to the transportation literature regarding evaluation of alternative TOD policies based on a comprehensive travel demand model. The main findings of this paper can be summarized as follows:

1. Relocating population or employment opportunities into transit service areas has similar contribution to transit share increment and auto share reduction;
2. Relocating population into transit service areas decreases trip distance while relocating employment opportunities increases trip distance;
3. Either relocating population or employment opportunities contributes to VMT reduction but relocating population is much more effective in VMT reduction than relocating employment opportunities.

These findings have important implication for TOD policy development. Conceptually speaking, either concentrated development of residential area or employment center in transit service area can be a good TOD strategy. However, the current distributions of housing and jobs cannot be overlooked. It is necessary to develop and apply a travel demand model to simulate TOD scenarios with alternative policies. Under the current status of Maryland, the model indicates that relocation of population or employment opportunities in transit service area will bring more transit share but employment relocation will result in longer trip distance. Therefore, in the process of TOD policy development for this region, priority needs to be placed on residential area development, rather than employment center development, in its transit service area. Certainly, this finding cannot be generalized to any other regions because each region has its own characteristics and requires specific and in-depth studies.

The other objective of this paper is to provide a paradigm for TOD policy exploration and evaluation using a travel demand model, which allows urban planners and policy makers to recognize the importance of travel demand models in TOD policy development. Without simulation results from a model, it is hard to imagine based on common sense that employment relocation policy will result in a longer average trip distance in the entire region. Likewise, it is almost impossible to quantify the extent to which alternative TOD policies affect highway usage without a travel demand model. Through this study, it is promising to envision that VMT dramatically drops in the scenario of relocating population into transit area. As per model simulation results, this type of TOD policies can be effective to reduce auto use and possibly mitigate traffic congestion in this region.

Finally, it should be noted that there are still some gaps to be filled through more effort in the future, which can be summarized as below:

1. The analysis is conducted based on the simulation results from MSTM. The mode choice model of MSTM does not incorporate non-motorized travel modes. This disadvantage does not allow for further analyzing potential increase in non-motorized travel after trip distance is found to be shorter in some scenarios. For more comprehensive assessment of TOD policies, one needs to develop a mode choice model incorporating non-motorized travel modes. It is a good lesson to learn from this study.
2. In different TOD policy scenarios, the relocation rate is chosen arbitrarily without consideration of land capacity constraints. Therefore, the scenarios do not correspond to any real policies to be implemented but are just created to explore the feasibility of some alternative policies.
3. Since MSTM model is a trip-based model, it has flaws of traditional trip-based models. For example, the model cannot capture the effects from change in trip chaining behavior on travel mode choice, trip distance, etc. A trip-based model evaluates policies solely from travel demand perspective but ignores potential changes in life style and quality of residents. The more advanced activity-based travel demand model is preferred to evaluate the impact on life quality from perspective of activity agenda and time use change.

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