WHAT TO EXPECT IN 2030: THE IMPACTS OF FUEL PRICE AND FUEL ECONOMY ON LAND USE AND TRANSPORTATION

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Abstract

The significant role of the transportation sector on land use, socioeconomic development and environment has led to new policies and regulations in the United States (US) that require planning agencies to integrate these additional aspects to be included in their transportation planning processes. This led to integration of macroeconomic, land use and environmental development models with long range transportation planning models. Integrating land use and transportation models in particular receive increased attention due to the significant relation between land use patterns and transportation. The cost of travel, which depends highly on fuel prices, can have a significant impact on the allocation of land uses, the amount of travel, the modes chosen for travel and the routes drivers select in a region. With the volatility of energy prices over the past several decades, the growing instability of energy supply both domestic and foreign, and ever growing demand, it is difficult to predict what fuel prices will be in the future. Reducing demand for fuel through advanced vehicle and fuel technologies by increasing energy efficiency and fuel economy have been one of the strategies to tackle with this problem. However, the market penetration of such advanced technologies in the future remains uncertain. To begin to grapple with such uncertainty, planners must understand the potential future impacts of energy prices. With knowledge of these impacts, better planning can be achieved to accommodate the likely outcomes. This paper investigates the impacts of increased fuel prices on future transportation system performance as well as travel behavior utilizing an integrated land use and transportation model. The developed scenarios build on national macro-economic forecasts of changes in household and employment allocations with future transportation network improvements and modeled in a multi-state integrated land use and transportation model for year 2030 in the Capital Megaregion area. The scenarios are conducted to measure the impacts of different fuel price levels on land use and travel patterns. As past research

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suggests, high fuel prices yield increases in fuel economy. Therefore, the scenarios are designed such that both the impacts of fuel prices and resulting vehicle fuel economy (or vehicle mileage) on land use and travel behavior are captured. These scenarios can aid in understanding the issues regarding the rebound effect of increased fuel economy on travel. The analysis is conducted utilizing a modeling system that couples a four-step travel demand model exogenously with a land use model. The model results are analyzed compared to a baseline scenario considering various systemwide measures such as vehicle miles traveled, congested lane miles and emissions. The results show that increased fuel prices and fuel economy have a significant impact on land use and travel patterns. Increased fuel prices lead to a denser land use pattern and a reduction in automobile mode share and vehicle miles traveled even though fuel economy increases. However, the reduction is less pronounced if fuel economy increases significantly.

1. Introduction

Fossil fuel continues to be the main source of transportation energy in the US. In fact, 97% of US transportation energy comes from petroleum-based fuels (US DOT, 2010). Policies and regulations are in place in the US and elsewhere to reduce dependency on fossil fuels for various reasons such as volatile prices, dependency on foreign oil and related security issues and environmental concerns (e.g. Clean Air Act (CAA), 1970; the Energy Policy Act (EPAct), 1992, 2005; Executive Order (EO) 13423 and the Energy Independence and Security Act (EISA), 2007). Despite all efforts, fossil fuel is likely to remain the major energy source for the transportation sector for years to come. Research and development on alternative fuel and vehicle technology still requires much more time to develop and adopt. These technologies in practice will have many challenges as they become available. Thus, the unpredictable price of increasingly scarce fossil fuels will continue to impact the transportation sector and in turn land use patterns.

Early studies regarding the impact of energy prices on transportation and land use in the US primarily stem from the energy crisis of the 1970s and 1980s. Most of these studies focused on the impacts of fuel prices on either the transportation sector or on land use. Few studies considered the interrelation between transport and land use. Many of these early studies employed econometric methods to explain changes in travel demand with respect to various factors, including fuel prices (the primary concern of this paper). The relationship found between fuel price and travel demand was analyzed with an economics framework; using the term elasticity to describe the relation between the two phenomena. Many of these studies found that transportation demand is highly inelastic with respect to fuel prices in short-term, varying from -0.10 to -0.3 (Goodwin, 1992; Dahl, 1995; Espey, 1998). On the other hand, long-term price elasticity tends to be higher, varying from -0.3 to -1.06 (e.g. Dahl and Sterner, 1991a and 1991b; Graham and Glaister, 2002, 2004; Goodwin, 1992; Goodwin et al., 2004; Brand, 2009).

An increase in fuel price corresponds with an increase in transportation cost, which in turn leads to a series of travel behavior changes. A shift in travel mode, travel time or route is a short-to-medium term change. The common short-term response to increased prices is less personal vehicle travel. Eltony (1993) found that 75% of households' response to higher prices was driving fewer miles. Similarly, Bomberg and Kockelman (2011) analyzed the change in travel behavior in response to a gas price spike in 2005 and found that the respondents reduced overall driving and tended to chain together their activities. They also found that urban form plays a key role in individual responses, more than demographics. Hughes et al. (2006) compared short-term price elasticity of US gasoline demand between 1975 to 1980 and 2001 to 2006 and found that the elasticity is significantly more inelastic today than in previous decades. The significance of this result is that it reflects a structural change in the US market for transportation fuel which may be explained by changes in land use, socioeconomics or vehicle characteristics.

As the higher elasticity suggests, the response to a price increase in the long-term is more significant. Long term-responses include changing vehicle type (e.g. to energy efficient or alternative fuel powered vehicles), shifting to energy efficient modes (e.g. transit, ridesharing, non-motorized), reducing number of trips, lowering car ownership, and altering destination and location choices (e.g., Lutsey and Sperling, 2005; Litman, 2009, 2012). Another response found to be significant in the literature is a move towards increasing fuel economy (see for example Small and Van Dender, 2007; Johansson and Schipper, 1997; Brons et al., 2008). Similarly, residential and employment location choice can be influenced by increased fuel prices due to the change in travel cost. However, the literature suggests that the choice of employment location is not significantly impacted by changes in fuel cost for various reasons. Such explanations include the complexity and the transaction costs associated with a move which typically outweigh the small proportion of fuel prices in the total expenditures of many companies (Fisher and Mitchelson, 1981). Although the literature is limited in regard to the impacts of high fuel prices on land use, studies suggest that higher travel costs could lead to more compact and multi-centered (or decentralized) development (e.g. Romanos, 1978; Waymire and Waymire, 1980; Fisher and Mitchelson, 1981). Most past work has focused on fuel consumption in relation to city structure rather than looking into changes in travel patterns and land use (e.g. Mogridge, 1985; Newman and Kenworthy, 1989).

The interrelation between transportation and land use has been studied widely in the literature (e.g. Abraham et al., 1998; Rodier et al., 2002; Handy, 2005; Johnston et al., 2005; Pendalaya et al., 2012; Zhao et al., 2012,). This interest partially stems from largely accepted propositions about land use-transportation interaction including e.g. building highways will increase sprawl, building more roads will increase driving, transit oriented development will increase density and reduce automobile use and the like. Despite a large volume of research, it is not clear how this interaction works due to the complex endogenous relationship between the two and the numerous exogenous factors such as socioeconomic characteristics and political forces. Finding empirical data presents another difficulty in establishing this relationship due to the long-term nature of land use changes. Therefore, coupling travel forecasting models with various land use models (e.g. Lowry (Lowry, 1964); MEPLAN, (Hunt and Echenique, 1993); UrbanSim, (Waddell, 2002)) has been the typical approach in the research arena.

Adding the influence of energy prices into an already complex interrelated system of transportation and land use has not received much attention. A limited number of studies have considered the potential impacts of energy prices on land use and transportation simultaneously. Mishra et al., (2011) and Ducca et al. (2012) investigated impacts of high-energy prices on the state of Maryland and the Chesapeake Bay Megaregion respectively. Although these studies reflected an increase in energy price differently (the former considered increases in crude oil price, agricultural commodity prices, federal defense spending, and employment in professional service while the latter considered only sudden increase in auto operating cost (AOC) in the target year of 2030), both utilized a national econometric model to estimate future land use given the change in transportation impedances. This paper builds on their work but investigates the sensitivity of land use changes with respect to different fuel price and fuel economy combinations instead of using the national economic model. This approach is selected to examine propositions inferred from the literature such as (1) an increase in fuel price causes small to moderate location changes, (2) the likely response to high fuel prices is increasing fuel economy rather than location changes, (3) the assumption of high fuel prices leading to more concentrated land use patterns may not hold if improvements in fuel economy and fuel efficiency are significant.

2. Analysis Framework

2.1 Model Framework

The modeling structure involves three main components that are loosely coupled: econometric, land use and transportation (Figure 1). The economic model uses national and regional economic trends for a variety of sectors to project household and employment growth and allocates it throughout the state (details of the economic model can be found in Inforum, 2011). The land use forecast is informed either by local zoning plans, which do not involve modeling, or by employing macro-level economic modelling data which comes from Inforum (2011).

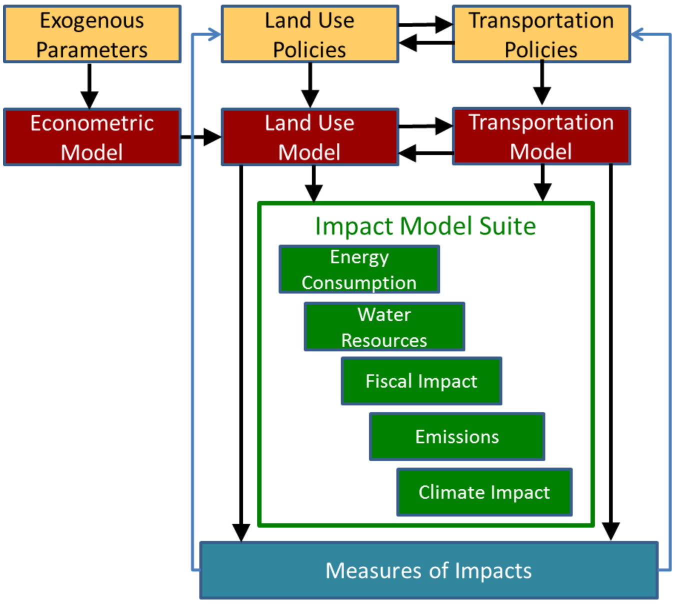

Figure 1. The integrated transportation and land use modelling system

The schematic of land use model that utilizes econometric modelling techniques to forecast future household and employment growth is depicted in Figure 2 (see NCSGRE, 2012 for details).

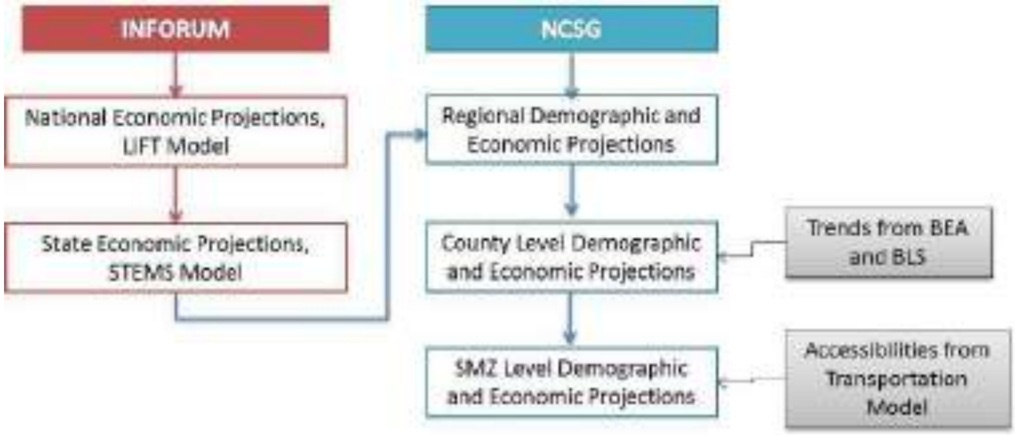

Figure 2. Land use model schematic

The land use model is integrated exogenously with the transportation model. The transportation model takes the socio-economic data from the land use model output and forecasts travel demand and the travel patterns for various future scenarios. The model is a three-level (national, regional and Metropolitan Planning Organization (MPO)) model that covers the entire ‘Capital Mega-region’, an area that encompasses the states of Maryland, Delaware, Virginia, Washington DC and parts of Pennsylvania and West Virginia (see Figure 3). The model also covers the remainder of the United States (primarily for freight, transit and tourism) but at a lower level of fidelity.

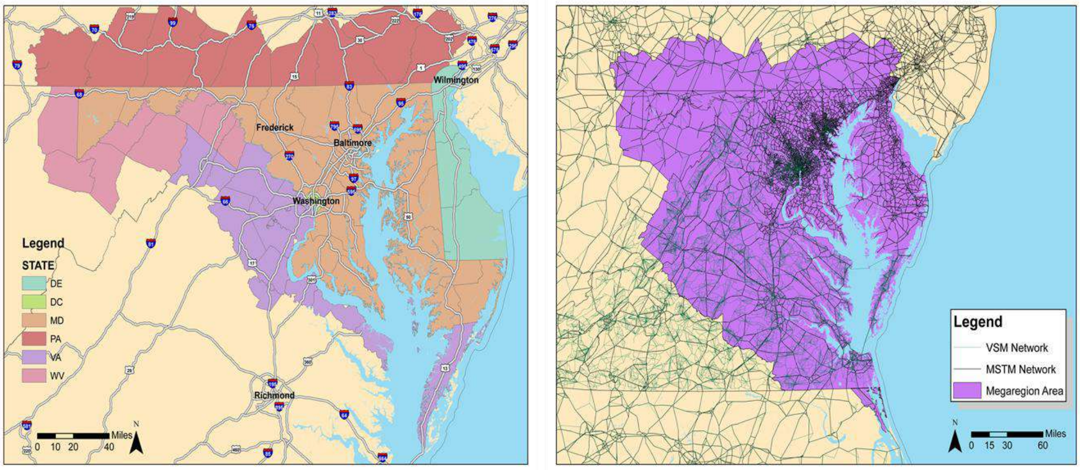

Figure 3. Capital Mega-region study area

2.2 Transportation Demand Model Formulation

The formulation employed in this study is based on the equilibrium analysis of transportation systems where an analyst tries to find traffic flows on a network at an equilibrium state given travel demand (represented by the trip matrix, or matrices) and supply (transportation network and services). The process is also called traffic assignment. The fundamental aim of traffic assignment process is to reproduce on the transportation system, the pattern of vehicular trips/personal trips which would be observed when the travel demand is assigned to the network by employing behavioral models. The traffic assignment model is based on the Wardrop equilibrium conditions (Wardrop, 1952). This principle is based on the fact that individuals choose a route in order to minimize his/her travel time or travel cost and such a behavior on the individual level creates equilibrium at the system (or network) level over a long period of time (Sheffi, 1984). Simply, for each origin-destination (O-D) demand pair, the travel-cost/travel-time on all used routes of the road network should be equal. Equilibrium, called User Equilibrium (UE), is reached when no traveler can decrease travel cost/time by shifting to a new path.

$$Minimize \sum_{a} \int_{0}^{x_a} (t_a(x_a)) \tag{1}$$

Subject to:

$$\sum_{r} f_{ij}^{r} = q_{ij} \quad ,\forall i,j \tag{2}$$

$$x_a = \sum_{i} \sum_{j} \sum_{r} f_{ij}^{r}\, \delta_{a,ij}^{r} \quad ,\forall a \tag{3}$$

$$f_{ij}^{r}, q_{ij}^{r} \geq 0 \quad ,\forall i,j,r \tag{4}$$

Equation (1) represents the objective function which minimizes the sum of the integrals of the link performance functions The term, t_a, is the travel time for link a, which is a function of link flow x_a. Equation (2) is a flow conservation constraint to ensure that sum of flow on all paths *r*, connecting each Origin-Destination (O-D) pair (*i-j*) is equal to the corresponding (O-D) demand. In other words, all O-D trips must be assigned to the network. Equation (3) represents the definitional relationship of link flow from path flows. Equation (4) is a non-negativity constraint for flow and demand. The travel time function $t_a(.)$ is specific to a given link 'a' and the most widely used model is the Bureau of Public Roads (BPR) function given by

$$t_a(x_a) = t_o\left(1 + \alpha_a\left(\frac{x_a}{C_a}\right)\right)^{\beta_a} \tag{5}$$

where $t_o(.)$ is free flow travel time on link 'a', and α_a and β_a are constants (and vary by facility type). C_a is the capacity for link a.

2.3 Model with Fuel Price Change

A change in the price of fuel results in a change in cost for highway travel. The effect of fuel price on user behavior can be represented as follows:

$$u_a\,(x_a, p_a) = t_a(x_a) + \frac{pl_a}{VOT.\vartheta} \tag{6}$$

where, p is the fuel price in miles per gallon, l_a is the link length in miles, VOT is the value of time in dollars per hour, and ϑ is the automobile gasoline efficiency in miles per gallon. Auto Operating Cost (AOC) is another component which is considered in the mode choice model in the next section (please see equation 9). A higher fuel price will result in a higher AOC and therefore will make auto travel more expensive.

2.4 Choice of Destination and Mode

The baseline scenario and all models also work on the choice of destination and mode depending on the respective cost functions. Because of varying cost functions, the destination and mode selected for different scenarios will change. This section explains how destination and mode choice are incorporated in the model, utilizing a random utility approach.

The destination choice model provides O-D demand for all trip purposes. The utility (U_{ijn}) of choosing a trip attraction/destination *j* for a trip *n* produced in zone *i* is given by:

$$U_{ijn} = S_j + \alpha L_{ij} + \sum \beta^k D_{ij}^k + \sum \beta^k D_{ij}^k N_n^k + \sum \beta^k Z_j^k + C_{jn} \tag{7}$$

Where, S_j is the size variable for destination zone j, L_{ij} is the mode choice logsum between zone pair *i-j*, D_{ij}^{k} represents the various distance terms (linear, log, squared, cubed and square root), N_n^k represents person, household or production zone characteristics for trip n and is used for creating interaction variables with distance terms, Z_j^k represents attraction zone characteristics (other than the size term), and C_{jn} is a correction term to compensate for the sampling error in the model estimation (i.e., it represents the difference between the sampling probability and final estimated probability for each alternative). The size variable may consist of several different terms; up to four categories of employment in addition to households were used. Weights (β^k) for each term in the size variable were estimated along with all other model parameters as follows, where E_j^k is employment of type *k* in zone *j*:

$$S_j = log\left(\sum \beta^k E_j^k\right) \tag{8}$$

A nested logit structure is used for the mode choice model, which is based on generalized utility functions for auto and transit travel. Separate utilities were developed to represent mode choice by trip purpose. The mode choice utility function is represented as follows:

$$\begin{aligned} U_m^p = \pi_m^p + \beta_{1}{}_{m}^{p} IVTT_m^p + \beta_{2}{}_{m}^{p} TET_m^p + \beta_{3}{}_{m}^{p} \times AOC_m^p + \beta_{4}{}_{m}^{p} PC_m^p \\ + \beta_{5}{}_{m}^{p} \tau_m^p + \beta_{6}{}_{m}^{p} WT_m^p + \beta_{7}{}_{m}^{p} IWTa1_m^p + \beta_{7}{}_{m}^{p} IWTb_m^p \\ + \beta_{8}{}_{m}^{p} NOT_m^p + \beta_{9}{}_{m}^{p} TF_m^p + \beta_{10}{}_{m}^{p} DA_m^p \end{aligned} \tag{9}$$

Where π_m^p is a mode specific constant for mode m, and purpose p; β in each term is the mode and attribute specific coefficient; $IVTT$ is the in-vehicle travel time, TET is the terminal time, AOC is the auto operating cost, PC is the parking cost; τ is the toll value, WT is the waiting time, $IWTa$ is the initial waiting time less than 7.5 minutes; $IWTb$ initial waiting time greater than 7.5 minutes; NOT is the number of transfers, TF is the transit fare; and DA is the drive access time. The mode choice model results in splitting O-D trip matrices into 11 travel modes (3 auto modes, and 8 transit modes). Three auto modes refer to Single Occupant Vehicles (SOV), High Occupant Vehicles with two occupants (HOV-2), and High Occupant Vehicles with three or more occupants (HOV-3+). Eight transit modes are combinations of walk and drive to bus, express bus, rail, and commuter rail.

3. Scenario Design

In this paper we measure two parallel phenomena related to fuel prices. The first is the elasticity of location decisions in relation to fuel prices. The second is the elasticity of travel decisions that result from fuel prices changes as well as the change in travel that occurs in response to changes in location decisions. The result is a complex series of behavioural responses that affect the nature of travel in the study area. Four scenarios were developed to model the effect of the possible changes in gas prices and technology on land-use and travel behaviour.

In the first scenario, we specify a baseline where gas prices are low but have steadily increased over time. In this case, gas is $3.88 ($US) per gallon before tax, resulting in an auto operating cost of $0.18 per mile. Land use response to this moderate travel cost change is assumed to be steadily growing from 2007 to 2030.

In the second scenario, we envision a case where prices for fuel have remained steady as in the baseline scenario, but due to policy requirements, specifically the ‘Corporate Average Fuel Economy’ (CAFE) standards for 2030 set out by the U.S. Environmental Protection Agency (EPA); average fuel economy has doubled from 27 to 54 MPG (miles per gallon). The result of the increase in fuel economy, with steady fuel prices on the auto operating cost per mile is a reduction to $0.09. This makes travel significantly less expensive. In response to the significant reduction in travel cost, the land use is less constrained and trends towards a slightly more diffuse urban pattern between 2007 and 2030.

The third scenario sets fuel economy back to the 2007 level, as if no improvement in technology was made and no policies were enacted to force increases in fuel economy. At the same time, we predict the price of fuel follows more historic world trends, absent policy intervention, the price of fuel is allowed to rise at the market rate resulting in a price per gallon of $15.52. At this price, the auto operating cost increases to $0.72 per mile. Land use patterns respond to the significant increase in price and future development patterns gradually move to a more concentrated urban form.

In the final scenario, policy intervention is again absent as it relates to fuel prices, allowing the cost per gallon to increase to $15.52. However, policy intervention and technology do adjust to this rise in prices. With the refined CAFE standards, average fuel economy increases to 54 MPG and the cost of operating a vehicle under these conditions reduces to $0.36 per gallon. Land use responds by moving towards a slightly more concentrated urban pattern than in the baseline scenario, where there was no policy intervention or technological improvements in vehicle fuel economy.

4. Results

This section contains the transportation demand model results from the baseline and three scenario models. Figure 4(a) illustrates the density of land use in the baseline (scenario one) for counties in the Baltimore Washington Metropolitan area. In this scenario, the region grows as usual with a standard rise in fuel prices. In the second scenario, where the fuel economy improves while the prices of fuel remains steady, making the relative cost of transport cheaper, the average density in each county decreases compared to the baseline scenario (Figure 4(b)). Figure 4(c) shows the relative change in land use density in the third scenario, when the price of fuel increases substantially and fuel economy does not keep up. In this case, land uses in the central cities and along main transportation corridors become denser. Figure 4(d) shows the land use density change under scenario four, where there is only a moderate change in travel cost, resulting in some densification over the baseline scenario.

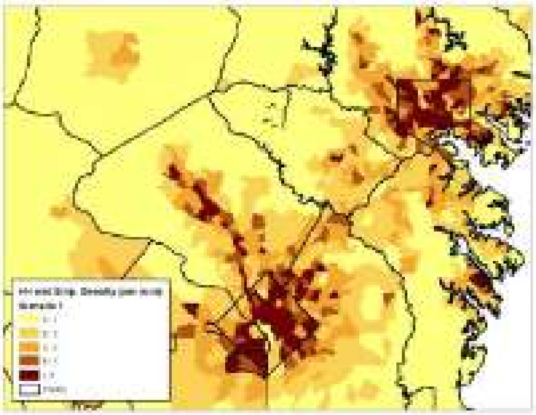

Figure 4(a). Baseline Land Use Density (Scn-1)

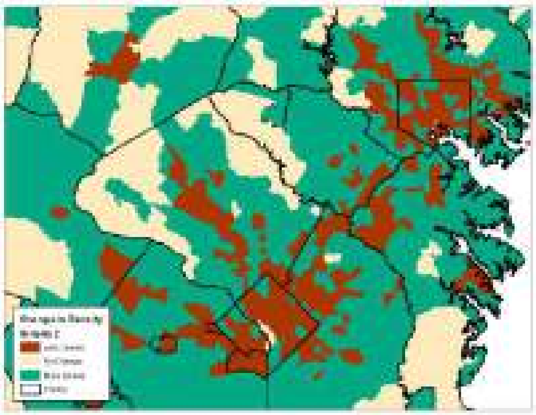

Figure 4(b). Change in Land Use Density (Scn-2)

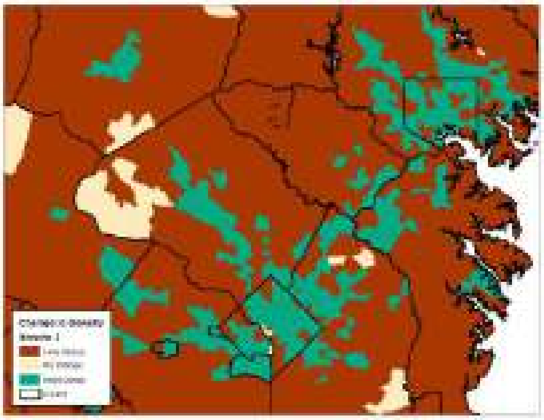

Figure 4(c). Change in Land Use Density (Scn-3)

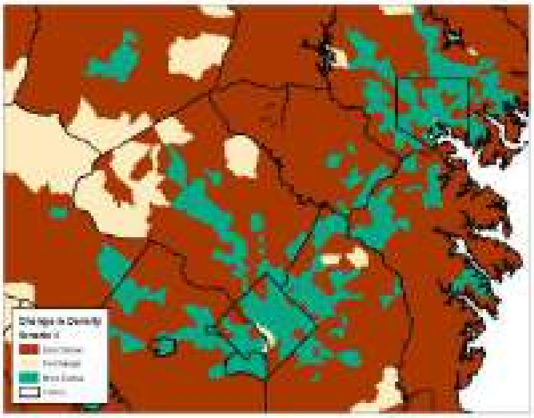

Figure 4(d). Change in Land Use Density (Scn-4)

Table 1 shows the effect each scenario has on mode share in the study area. In the baseline scenario, drive alone trips are over 70% of the person trips. When carpool trips are added, 91.61% of trips are by personal vehicle, the remaining trips are split between bus and rail modes. When the auto operating cost decreases by 50%, there is a 17.5% increase in private auto use over transit.

Table 1. Mode Choice

	Auto Trips		Transit Trips		Auto Share		Transit Share		Percent Change			
	Drive Alone	Car pool	Bus	Rail	Drive Alone	Car pool	Bus	Rail	Auto	Car pool	Bus	Rail
Scenario-1	807,778	240,858	34,363	61,672	70.57%	21.04%	3.00%	5.39%				
Scenario-2	1,002,293	230,510	29,454	53,005	76.20%	17.53%	2.24%	4.03%	24.08%	-4.30%	-14.29%	-14.05%
Scenario-3	601,560	489,526	66,235	104,845	47.66%	38.78%	5.25%	8.31%	-25.53%	103.24%	92.75%	70.01%
Scenario-4	788,537	373,489	46,315	80,232	61.19%	28.98%	3.59%	6.23%	-2.38%	55.07%	34.78%	30.09%

This indicates that there is an elastic of the mode share with auto operating cost of about 0.35. When the price of transport increases over the base case by about 50%, there is a signficant increase in the non-drive alone trips. The share of drive alone trips decreases by over 25%, lending to a 103% increase in carpooling, a 92%

increase in bus and a 70% in rail share. In the final scenario, with a moderate operating cost increase, drive alone auto use declines just 2%, but results in a 55% increase in carpooling and over 30% increase in both rail and bus trips.

Highway assignment results for the baseline and three scenario models are presented in Table 2. Each model output is further categorized by major highway facility types for detailed analysis. The third column in Table 2 provides the vehicle miles travelled (VMT), followed by congested lane miles (lengths of road with a volume to capacity ratio of over 0.75, an aggregate statistic typically used for measuring the level of congestion), and the average speed on each facility type.

Table 2. Highway Assignment Results

Model (1)	Facility Type (2)	VMT (3)	Emissions (Tonnes) (4)	Congested Lane Miles (5)	Average Speed (MPH) (6)	Percent Change VMT (7)	Percent Change Emissions (8)	Percent Change Congested Lane Miles (9)
Scenario-1	**Freeways**	210,828,019	671,604	3,041	48.16			
	Major Arterials	139,623,717	355,900	2,849	27.86			
	Minor Arterials	89,848,377	158,779	1,295	26.69			
	Other	122,825,001	274,347	1,899	23.73			
	TOTAL	***563,125,115***	***1,460,630***	***9,085***	***32***			
Scenario-2	**Freeways**	227,287,509	356,626	3,761	46.89	7.81%	-46.90%	23.67%
	Major Arterials	162,658,837	202,501	3,894	27.23	16.50%	-43.10%	36.70%
	Minor Arterials	107,473,293	94,202	1,797	26.36	19.62%	-40.67%	38.73%
	Other	148,299,931	162,526	2,565	23.47	20.74%	-40.76%	35.04%
	TOTAL	***645,719,571***	***815,856***	***12,018***	***31***	***14.67%***	***-44.14%***	***32.28%***
Scenario-3	**Freeways**	177,869,296	552,279	1,567	50.79	-15.63%	-17.77%	-48.47%
	Major Arterials	108,366,275	269,661	1,240	28.76	-22.39%	-24.23%	-56.47%
	Minor Arterials	67,265,704	117,178	613	27.09	-25.13%	-26.20%	-52.68%
	Other	101,654,213	225,558	1,099	24.02	-17.24%	-17.78%	-42.12%
	TOTAL	***455,155,488***	***1,164,676***	***4,520***	***33***	***-19.17%***	***-20.26%***	***-50.25%***
Scenario-4	**Freeways**	200,252,866	312,962	2,589	49.16	-5.02%	-53.40%	-14.87%
	Major Arterials	131,214,078	164,297	2,327	28.20	-6.02%	-53.84%	-18.31%
	Minor Arterials	83,712,465	73,359	1,041	26.81	-6.83%	-53.80%	-19.64%
	Other	121,704,833	133,130	1,618	23.82	-0.91%	-51.47%	-14.84%
	TOTAL	***536,884,242***	***683,748***	***7,575***	***32***	***-4.66%***	***-53.19%***	***-16.62%***

The results show the impacts of the change in travel behavior that occur as a result of changes in fuel price and economy on the highway usage measures. In general, the results coincide with intuition. For example, when the price of fuel remains low, and fuel economy standards increase, more travel occurs. While this is in part due to the more scattered nature of land use in the study region, it is also a result of the ability to make longer trips at a lower cost. For example, the 14.67% increase in VMT that occurs in Scenario-2, induced by the decrease in travel cost, leads to a 32% increase in congested lane miles and 2 miles per hour decrease in average speed along freeways. The significant increase in auto operating cost that occurs in Scenario-3 combined with improved fuel economy and the denser land use, results in a 19% decrease in VMT and a 50% reduction in congested lane miles. These results indicate that the fuel price has a significant impact on travel behavior. Despite the improved fuel economy, VMT and CLM decline significantly compared to the baseline.

Scenario-4 has a smaller impact on travel behavior relative to the previous two scenarios, with only a 4% decrease in VMT and a 16% reduction in congested lane miles. This indicates that if significant improvements are achieved in vehicle technology that increases fuel economy considerably (doubled in this study), the impacts of high fuel prices may not be as pronounced.

The combined effect of changes in fuel economy and price has a significant impact on total emissions. In Scenario-2 where fuel economy significantly increases and travel cost decreases, total emissions are reduced by 44%, despite the higher VMT. In Scenario-3 fuel efficiency is reduced and the cost of travel increases. As a result, emissions are only reduced by 22%. Scenario-3 sees the highest emissions reductions with a 53% decrease. This is the result of a combination of higher fuel economy and fuel price.

To test for convergence, the gap between assignment iterations in between the baseline and Scenarios -1 through -4, was measured. Gap is a function of change in assigned link volumes and cost between iterations. Therefore, as gap decreases the assignment gets closer to convergence, which indicates that a change in travel cost for a link does not produce a significant change in the entire network. For this study, the convergence criteria was set at a gap of 0.002 for the iterative assignment and 0.005 for the variable demand iteration. Figure 5 shows the iteration results in terms of the gap for fifty model iterations. In all cases the models reached the convergence criteria in less than 26 iterations.

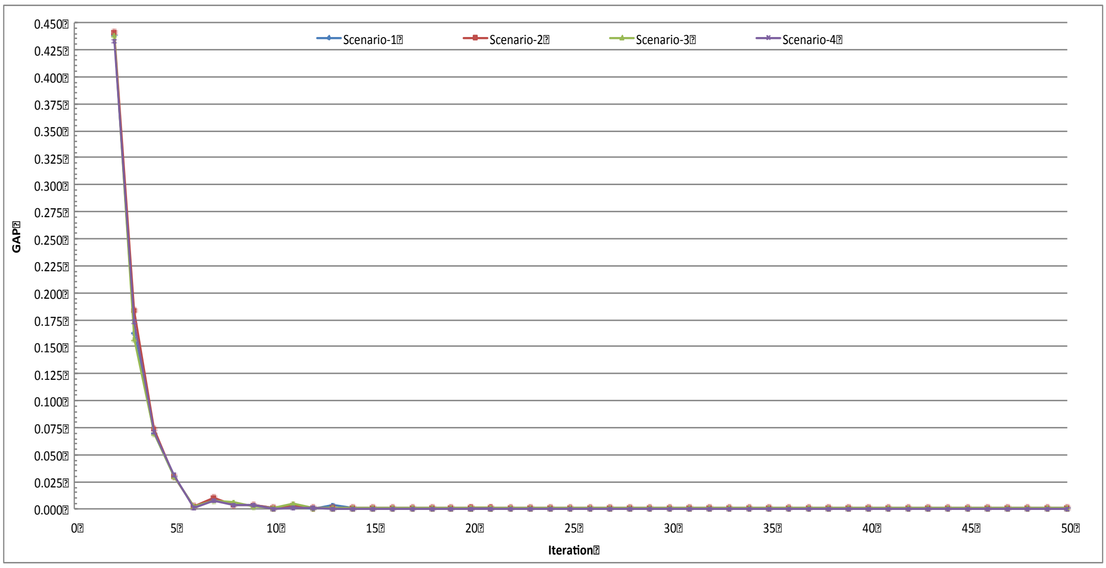

Figure 5. Convergence Results for Scenarios 1 through 4

5. Conclusions

The analysis conducted in this study sheds some new light on probable changes in land use and travel behavior in response to future changes in fuel prices and improvements in vehicle technologies. The analysis focused on two parallel phenomena related to fuel prices: the elasticity of location decisions and the elasticity of travel decisions that result from fuel price changes as well as the change in travel that occurs in response to changes in location decisions. A state-of-the art integrated land use and transportation model system, essential for such analysis, is utilized to analyze these complex series of behavioural responses that affect the nature of travel in the Capital Megaregion study area.

The results show that increased fuel prices and fuel economy have a significant impact on land use and travel patterns. The improved fuel economy causes a scattered land use change when the fuel prices remain steady. A substantial increase in fuel price can reverse this scattered distribution of land use with moderate improvements in fuel economy. However, if fuel economy increases significantly, the concentration of land use towards city centers and main transportation corridors occurs less. The results also indicate that the elasticity of location decisions is highly sensitive to changes in fuel prices and that improved fuel economy reduces this sensitivity. When technological advances lead to very high fuel economy in the future, it may be necessary for policy intervention to increase travel cost to meet planning goals that aim to prevent sprawl.

The impacts of changes in fuel price and economy on travel behavior and traffic measures are also remarkable. The results indicate that the elasticy of the mode share with auto operating cost is about 0.35. When the cost of transport increases, a significant increase in carpool and transit trips are observed. Similar to the land use response, when fuel economy increases significantly, a decline in the share of drive alone trips is not as pronounced. However, the increase in carpool and transit mode share is still significant. Highway usage measures also show similar behavior. For example, increasing fuel prices reduces VMT while increasing fuel economy standards and causes more travel. The results indicate that the fuel price has a significant impact on travel behavior: despite the improved fuel economy, VMT and CLM decline significantly. Emissions are also significantly impacted by gas price and fuel economy. Result show that increased fuel economy leads to higher emission reduction. The highest reduction in emissions is obtained when higher fuel economy and fuel price are applied in combination.

The approach followed in this study can be used to analyze alternative future scenarios and develop strategic policies. Despite the volatile nature of fuel prices and uncertain phase of technological developments, the knowledge of how the land use and transportation system will respond under different scenarios will help develop better informed policies and strategies. The results point to future research on different pricing strategies that would impact cost of travel in addition to fuel prices so that the changes in land use and transportation can be guided towards a more desirable pattern.

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