Current Urban Studies, 2018, 6, 517-531
http://www.scirp.org/journal/cus
ISSN Online: 2328-4919
ISSN Print: 2328-4900

Promoting Transportation Sustainability by Utilizing Available Roadway Capacity

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How to cite this paper: Khan, T., Anderson, M., & Kassu, A. (2018). Promoting Transportation Sustainability by Utilizing Available Roadway Capacity. *Current Urban Studies, 6,* 517-531.
https://doi.org/10.4236/cus.2018.64028

Received: August 27, 2018
Accepted: December 11, 2018
Published: December 14, 2018

Abstract

Land use changes affect travel demand, resulting in the need to expand transportation infrastructure. Unfortunately, an inevitable consequence of urban sprawl, the spreading of a city to suburbs and outskirts, is the creation of auto-dependent development. Land use models forecast without considering underutilized roadways leading to urban sprawl. Any change in travel cost or detrimental growth pattern does not have any significant influence on future land use or location choice of future household and employment. This study addresses urban sprawl and available capacity utilization and combines those features with land use change model for planning more compact cities. This research conducted a rigorous step by step analysis to determine a better solution that results in more trips inside a case study community. Based on minimizing vehicle mileage traveled (VMT) and the number of congested links, a preferred scenario was identified that is one of the major contributions of this exploration. Hence, it is a preliminary initiative to promote transportation sustainability and build compact cities using current resources instead of the planning of future road network solely depending on the land use forecast model.

Keywords

Sustainability, Land-Use Change Model, Urban Sprawl Indices, Traffic Analysis Zone, Planning Scenarios, Compact City

1. Introduction

Travel demand forecasting models use the four step process, trip generation, trip distribution, mode split, and traffic assignment, to estimate expected traffic volume on a roadway network to support transportation planning. Adding land use model feedback to travel demand models facilitates the interaction between them based on different proposed scenarios. However, even an integrated land use/transportation model, can overlook underutilized roadways in a community and lead to urban sprawl. Therefore, any change in travel cost or detrimental growth pattern does not have a significant influence on future land use or location choice of future household and employment. Driven Apart, a new report from CEOs for Cities unveils that urban sprawl is the real cause of traffic congestion and the solution to this problem has much more to do with how we build our cities than how we build our roads (Cortright, 2011). Finding ways to outline a simplified methodology that can combine land use change, spatial growth and utilization of the available capacity of existing network, would be beneficial to all communities where urban sprawl needs to be addressed and resolved by promoting a sustainable land use planning and transport system.

Literature related to the simplified land use change model was reviewed to formulate a model that can detect the probability of future development of an area. A study on urban sprawl utilized an elaborate methodology to develop new measures of compactness that have more face validity and were used in our study. An Origin-Destination Matrix Estimation tool was used to find an efficient way to incorporate capacity utilization along with the products from the urban sprawl scoring scheme and land use change model. An appropriate methodology was chosen to consider this issue and analyze transportation networks and travel behavior. The conclusion was a methodology that can be used to limit sprawl conditions using available capacity in a community.

2. Background/Literature Review

2.1. Travel Demand Model

The travel forecasting process is used to estimate the number of trips at some future date as a means to do highway planning and involves a series of mathematical models that attempt to simulate human behavior in response to a given system of highways, transit and policies (Beimborn, 1995).

This study focuses on the relationship between land use and transportation system. The following section provides background on integrated land use and transportation planning.

2.2. Land Use and Transportation Planning

Previous land use models (such as Lowry model, Projective Optimization Land Use System (POLIS) model, MEPLAN model, Kim's Chicago Model, Micro-Analytical Simulation of Transport, Employment and Residence (MASTER) model and Dortmund Model) used travel cost/accessibilities along with population, housing, employment, and spatial interaction into residential and employment allocation models to optimize an objective function (Southworth, 1995). The recent studies or models reviewed and summarized can be presented as follows:

1) Land Use-Transportation Interaction (LUTI) model represented the impact of expenditures on attractiveness and efficiency describes the allocation of money to activities, goods, and the residence, for the time neglecting longer-term decisions (Ettema et al., 2009).

2) Predicting Land Use Change (LUC) models found that (perhaps not surprisingly) transportation-related variables exert some influence on changes in land use patterns, though not as much as variables representing existing and neighboring land uses. New Urban Land Use model indicates that the increased travel costs may not alter location choices, though the road pricing scenario does have a significant impact on travel behavior predictions (Iacono & Levinson, 2009; Zhou & Kockelman, 2009).

3) Equity Analysis of Land Use and Transportation Plans utilized the Production, Exchange, and Consumption Allocation System (PECAS) Model shows that Preferred Blueprint can reduce travel costs, wages, and housing costs by increasing accessibility (Rodier et al., 2010).

4) Spatial Dynamics and Temporal Dependency in Land Use Change Model suggested that major transportation roadways can act not only as physical separators of land areas but also as a barrier to peer interactions and influences (Sidharthan & Bhat, 2012).

2.3. Integrated Land Use/Transportation Model

The integrated models reviewed can be presented as follows:

1) California Integrated Land Use/Transportation Model, a Spatial Decision Support System (SDSS) Xplorah integrated Land Use and TDM model or an Integrated Model System with Dynamic Time-Dependent Activity-Travel Microsimulation where the transportation model outputs (distance/time) feedback into the cellular automata local land use model/ Activity Allocation module/the land use microsimulation model to simulate the location choices for a future year including the land use development patterns, household, and business location choices (Rivera, 2009; Gao et al., 2010; Pendyala et al., 2012).

2) Integrated Transport and Gravity-Based Land Use study concluded that a similar pattern in household and employment distribution between two different scenarios implies a lack of responsiveness from two important sources: too low additional travel costs and insensitivity of the gravity model formulation (Zhou et al., 2009).

3) An Integrated Approach to Sustainable Transportation proposed a land use plan that concentrated higher densities and employment along the main arterials and BRT routes and placed all residential areas within walking distance of transit and retail that established a nominal jobs-housing balance. While testing different scenario, diversion 40% of peak hour traffic to other arterial moves bottlenecks to other locations, and without adding car lanes as a solution, giving priority to transit, walking and biking were considered from a sustainable development perspective (Duduta et al., 2010).

4) An Integrated Bi-Level Model presented the methodology and application of a proposed bi-level model on a case study of a factitious urban area shows that relying solely on optimization by the proposed bi-level model is insufficient to meet the increasing land use and transportation demand. Expansion of transportation network is an alternative solution (Zhao & Peng, 2010).

5) In a Data Development Study for Implementing an Integrated Land Use And Transportation (ILUT) Forecasting Model, one of the primary reasons for not implementing such tools was mentioned as concern over the schedule and cost requirements of obtaining the data typically needed to support such models that depend on complexity, geographic size and the availability and quality of existing data (Clay et al., 2011).

6) Integrated LandSys-FSUTMS Model show that in the integrated model the values of number of links with higher saturation, number of households and employments in congested area, pollutant emissions, fuel usage, VMT, and VHT are lower than those predicted by standalone FSUTMS or LandSys models, indicating the importance of LandSys-FSUTMS models in improving transportation environment (Zhao et al., 2012).

The above literature does not have any direct connection to urban sprawl that mentions how to limit the dispersion by utilizing current networks. The following section gives a brief literature review on urban sprawl, its causes, remedies and recent studies.

2.4. Urban Sprawl

Sprawl means low density, sometimes dispersed, sometimes decentralized, sometimes polycentric, sometimes suburban development (strip, scattered, and leapfrog developments), caused by the consumer preference to live in suburbs, low-cost auto travel, technological innovations, subsidies and public and quasi-public goods (Ewing, 1997). Ewing definition of sprawl is shown graphically in **Figure 1(a)** where few significant centers, low average density, and noticeable development gaps exist due to leapfrogging, which all impose high and avoidable infrastructure, travel, energy, and environmental costs (Zhang, 2010).

Figure 1(b) shows a potentially efficient urban form a polycentric pattern with moderate densities and continuous land use except for permanent open spaces. **Figure 1(c)** illustrates a compact monocentric pattern, which will be referred to as a centralized pattern. Any land use change causing employment or housing density distributions to differ from this centralized pattern will be referred to as decentralization. Apparently, Decentralization does not necessarily imply sprawl (Zhang, 2010). In contrast to sprawl, compactness can preserve agricultural land, promote high capacity transit systems and helps to lower automobile dependency for households, reduce environmental destruction and prevent moral minimalism (Gordon & Richardson, 1997).

Economists believe that three underlying forces—population growth, rising

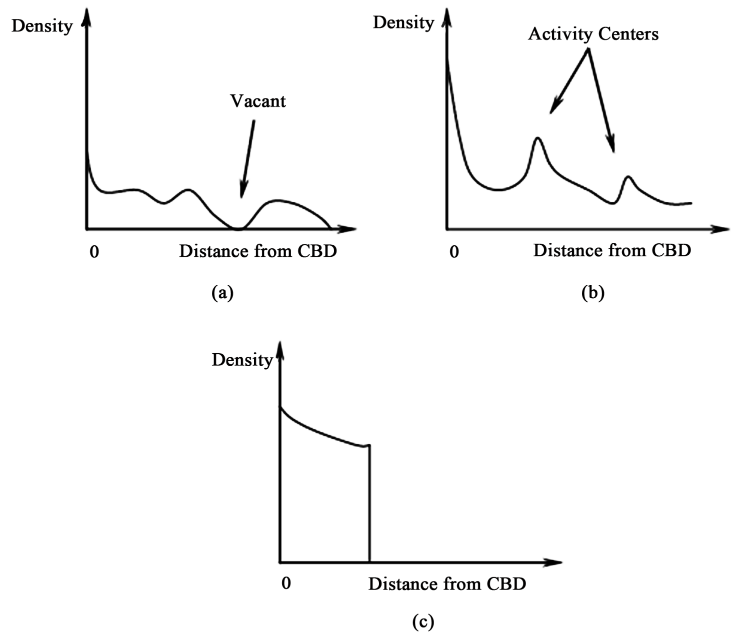

Figure 1. Definition of sprawl and decentralization (Zhang, 2010). (a) Sprawl; (b) Polycentric efficient pattern; (c) Monocentric pattern.

household incomes (demand more living space), and transportation improvements—are responsible for this spatial growth and urban sprawl. Moreover, three market failures such as failure to take into account the social value of open space, failure to recognize the social costs of congestion, and failure of real estate developers to take into account all of the new development costs are the main causes of urban sprawl (Brueckner, 2000).

Refined versions of sprawl indices defined/shown in "Measuring Sprawl 2014" capture four distinct dimensions of sprawl for instance development density, land use mix, population and employment centering, and street accessibility. Compactness indices/sprawl-like metrics within metropolitan areas were derived through the use of variables applied in larger area analyses (metropolitan area, urbanized area, and county sprawl metrics) (Ewing & Hamidi, 2014; National Cancer Institute, n.d.; Jessup, 2014).

3. Summary of Literature Review and Problem Statement

After reviewing old and recent literature that deals with land use and TDM, the following points have been noted:

1) Land use forecast model used travel cost (travel time/travel distance/accessibility) from previous year TDM and outputs from the land use model are fed into TDM to determine the updated travel cost that again used as one of the inputs for land use model by a feedback loop.

2) One of the studies has stated that transportation does not have a major impact on land use forecast model. Other studies have found no difference in land use pattern for different scenarios.

3) A factitious study found a significant difference in land use allocation for optimal and worst case scenario, observed relatively smooth traffic in the case of optimal land use allocation. However, most of the links were close to or over the capacity and concluded that relying solely on optimization by the proposed bi-level model is insufficient to meet the increasing land use and transportation demand, and expansion of transportation network is an alternative solution.

4) Land use model provides future transportation demand using accessibility/ travel cost term from base year TDM, existing/dynamic land use change which entirely determines the future expansion and building of the new network, considering an optimal way of land use allocation to minimize the system cost of transportation.

5) The Integrated LandSys and FSUTMS model comprises of combined CA and agents models and transportation model, feeding back new travel cost and accessibility into the land use model. It shows that the values of the number of links with higher saturation, the number of households and employments in a congested area, pollutant emissions, fuel usage, VMT, and VHT are lower than those predicted by standalone FSUTMS or LandSys models.

It can be understood that travel cost and accessibility is a minor part of land use change model while land use model governs the future network and major input for travel demand model. It controls the expansion or building new route without considering underutilized roads or the disperse growth of cities.

Transportation improvements, failure to take into account the social value of open space, and failure to recognize the social costs of congestion that cause to excessive commuting, congestion, spatial growth and urban sprawl (Brueckner, 2000).

To limit the growth of sprawl and utilize the existing capacity of all links, it has been suggested to conduct a study without being totally controlled by the growth of cities. That means a future trip table can be developed by using a land use change model and can be modified to limit sprawl/ spatial growth and can be further adjusted according to the capacity that can be utilized. Thus, it can be a preliminary initiative to build compact cities using current resources instead of the planning of future road network in accordance with the land use forecast model.

This information can be very beneficial for land use planners and policy makers to explore enhanced ideas and implement potential changes in transportation policies and investments.

4. Case Study

4.1. Location

The Huntsville, Alabama Metropolitan Planning Area (MPA) was used for the case study. The area includes all of Madison County and part of Limestone County. The metro area is around 947 square miles and has a population of 363,210 people with 156,649 households (United States Census Bureau, 2010).

4.2. Network Setup

Huntsville TAZs and network data were obtained and TransCAD 4.7 was used to provide the ODME tool. The model network in TransCAD contained 3097 bidirectional links in the network and 1264 one-way links. Also, there are 525 Traffic Analysis Zones in the network of which 508 are internal zones, and 17 are external zones.

5. Methods to Estimate O/D Matrix

Most of the studies focused on optimization techniques where an old/target origin/destination matrix was updated by analyzing traffic counts using maximum likelihood, generalized least squares, or Bayesian inference techniques (Abrahamsson, 1998). The estimation method implemented in TransCAD 4.7 was chosen to determine an origin/destination matrix from traffic counts by following user equilibrium (UE) assignment. Many computer models have been proposed and applied for O-D matrix estimation to investigate the relationship between traffic counts and O-D matrix, and TransCAD Model is one of the most widely-used models (Almasri & Al-Jazzar, 2013). The O/D Matrix Estimation (ODME) procedure in TransCAD is based on the work of Nielsen, which is an iterative (or bi-level) process that switches back and forth between a traffic assignment stage and a matrix estimation stage, until convergence is reached (Corporation, 2002; Iyer, 2010).

6. Estimation of O/D Matrices

This section begins with illustrating the ODME procedure and its application. It continues by combining the above findings, adding different hypothetical planning scenarios and demonstrating how OD estimation tool in TransCAD can be used to compare different options.

6.1. ODME Tool Description

The following data was prepared/created to use the OD Matrix Estimation procedure in TransCAD (Corporation, 2002):

1) Base/initial/prior OD matrix

2) Geographic file with required link data: both a node and a line layer

3) Network file from the line layer with attributes such as link flow (count), capacity, time, speed, etc.

The O-D Matrix Estimation procedure/tool can be promptly used, once necessary input files are ready to run. The existing OD was fed into TransCAD as seed/initial matrix and OD estimation was carried out by choosing User Equilibrium assignment method. After completing this procedure successfully, the estimated OD flows can be stored to do a further assessment (Corporation, 2002).

Traffic can be assigned by TransCAD to the roadway network, and the assigned flows can be regarded as counts to estimate the OD. In this study, since our interest is on available capacity, it is necessary to subtract assigned flows from road capacity that can provide the values of available capacity on each link. In similar fashion, these values can be treated as counts to determine the expected OD with or without any change in the existing OD matrix. This process may alter the pattern of seed matrix significantly in order to fit the counts although they are dependent on the pattern of the seed matrix (Nielsen, 1998). In our study network, present volume and capacity ratio of 230 links is more than 1. Utilization of the available capacity of uncongested links can make current, and other links overly congested. To prevent the number of congested roadways, an average of 90% of available capacity was treated as count. To do so, random numbers were generated between 0.85 and 0.95, and the count was computed as the product of this value and available capacity.

6.2. Formulation of Planning Scenarios

Before outlining the scenarios, the following aspects can be presented briefly:

6.2.1. Probability of Land Use Change

One study stated that that past counts of households and jobs are strong predictors of current counts of all household types, as well as basic and retail employment (Zhou et al., 2009). Thus, an existing trip matrix can be modified with the predicted probability of land use change by using the proposed binary logistic model with 2010 dataset. Through the use of constraint matrix balancing existing OD matrix of Huntsville area was iterated until the expected ratio is close to one (Khan, 2016).

6.2.2. Urban Sprawl Index

Compactness indices/sprawl-like metrics for TAZs were derived using principal component analysis and transformed the first three principal components to an index with the mean of 100 and a standard deviation of 25. The more compact counties have index values above 100 while, the more sprawling counties have index values below 100 (Ewing & Hamidi, 2014). Number of TAZs (<100) is 214 which is very high comparing to the total number of TAZs. A threshold depending on the quartiles was considered to lower the number of sprawling TAZs. **Table 1** provides the number of sprawling TAZs and its threshold (Khan, 2016).

Because of a higher proportion of sprawling TAZs for both 75 and 50 Percentiles, TAZs below 25 percentile were scrutinized in a later section. It can be observed in **Figure 2** most TAZs under the value of 75 Percentile of sprawling indices are at fringes and very few TAZs are located in the center.

Table 1. Number of sprawling TAZs and its threshold.

Threshold	Value of Quartile	Number of Sprawling TAZs
75 Percentile	92	147
50 Percentile	85	78
25 Percentile	79	31

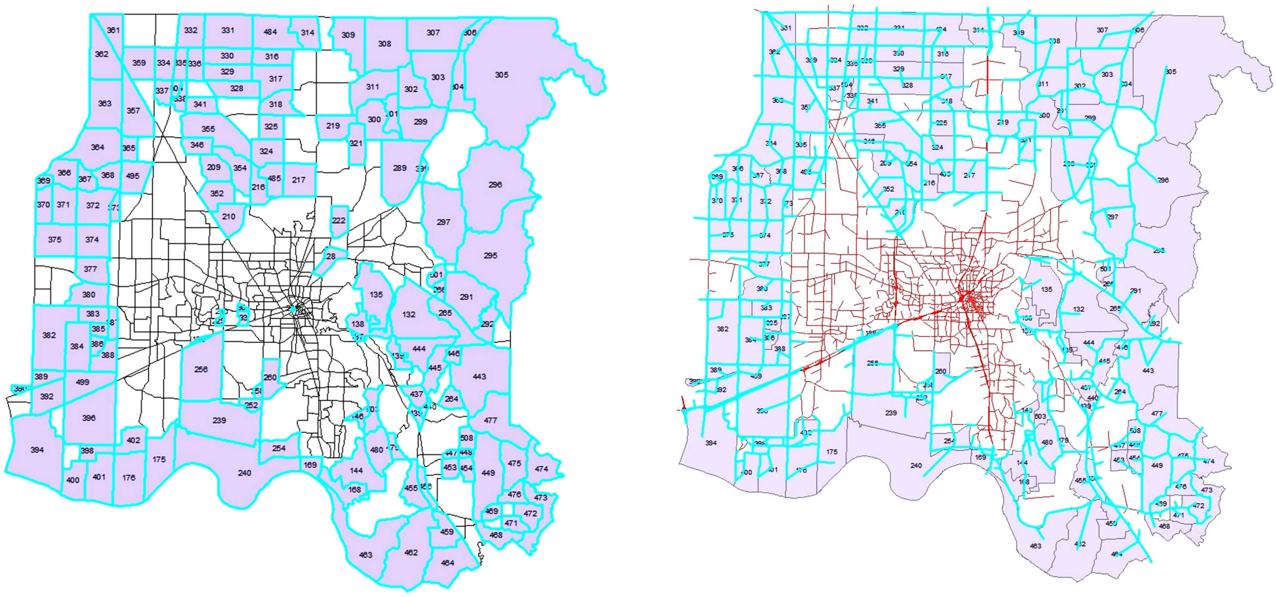

Figure 2. Sprawling TAZs (75 percentile) with/without associated roadways.

To minimize the number of trips along the roadways which fall under the area within 75 Percentile Value, links were selected (shown in **Figure 2**) and were marked as sprawling links. The sprawling TAZs (31 TAZs) based on 25 Percentile and the sprawling links presented below were included to constrain the spatial growth of land use while comparing different planning scenarios. For instance, the available capacity of those roadways was considered zero as the congested links that had no additional capacity for new trips.

6.2.3. Land Availability

The zones based on "Developed" land use type by National Land Cover Database (NLCD) (Multi-Resolution Land Characteristics (MRLC) Consortium, n.d.) were identified where the land is fully occupied or has moderate space to accommodate any new development. It has been found that the number of saturated and moderately saturated TAZs at the core of our study area is large (about 98) when all types of development were included to identify the available land. The estimation was narrowed down by considering only medium and high development to determine TAZs with minimal or no space for expansion that is about 36 inside the core. Only saturated TAZs were included in relevant scenarios, and additional scenarios were analyzed without considering the effect of land availability in our existing/expected OD seed matrix (Khan, 2016).

6.2.4. Development of Hypothetical Scenarios

The features need to be incorporated while constructing hypothetical scenarios are:

1) Modifying existing OD matrix to reflect future probability of land use change that followed the proposed binary logistic model

- Assumption on the probability of land use change for external zones (probability of 0 or 1)

2) Restricting TAZs to generate or attract any trips where there is a scarcity of land and it is contributing to potential sprawl

In each case, OD matrix estimation was performed in TransCAD where 90% of available capacity was regarded as count and existing OD matrix was varied depending on the aspects that were illustrated in formulating hypothetical scenarios (presented in Table 2).

The existing matrix was adjusted according to the Options 1 through 9 to reflect above aspects. To incorporate the characteristic of future land use change, rows and columns of existing matrix were multiplied by the specific factors respectively until resulted factors approach a certain limit. To include characteristic other than the value of land use change probability, row, and column of the corresponding TAZ were replaced by zero that is for sprawling and saturated TAZs.

7. Results

The measures summarized to compare the scenarios are average Volume-Capacity (V/C) ratio, Total OD trips, Total VMT and the number of links with V/C more than 1.5 (given in Table 3).

It can be observed that "F Ava US EX 1" is comparatively more sustainable not only based on the level of congestion it exerts but also considering the least amount of vehicle mileage traveled it produces. To enhance the sustainability and reduce the congestion, this option was assessed by varying the utilization of available capacity from 80% through 40%. Table 4 provides the respective measures along with percent utilization of available capacity.

Table 2. Planning scenarios.

No	Scenario Abbreviation	Aspect of Land Availability	Aspect of Land Use Change for Internal Zones	Aspect of restricting Sprawling TAZs	Aspect of Land Use Change for External Zones	
					Value of probability of 1	Value of probability of 0
Option 1	P Ava	X				
Option 2	P US			X		
Option 3	P Ava US	X		X		
Option 4	F Ava EX 0	X	X			X
Option 5	F Ava EX 1	X	X		X	
Option 6	F US EX 0		X	X		X
Option 7	F US EX 1		X	X	X	
Option 8	F Ava US EX 0	X	X	X		X
Option 9	F Ava US EX 1	X	X	X	X	

X-means the presence of the corresponding factor, P-Present and F-Future.

Table 3. Comparison of hypothetical scenarios.

Scenarios	Total OD Trips	Mean V/C	Total VMT	Number of Links with V/C > 1.5	
				Direction AB	Direction BA
P Ava	1,916,602.21	0.94	50,751,623.64	202	108
P US	1,388,971.29	0.84	38,486,713.86	218	129
P Ava US	1,320,994.33	0.84	39,780,347.19	217	144
F Ava EX 0	1,886,715.22	0.97	53,549,358.49	244	160
F Ava EX 1	1,898,853.58	0.99	55,285,094.85	298	176
F US EX 0	1,268,190.23	0.84	37,680,562.33	230	134
F US EX 1	1,338,484.54	0.83	37,764,523.20	209	122
F Ava US EX 0	1,241,769.09	0.82	36,897,460.20	220	136
F Ava US EX 1	1,247,404.12	0.82	36,256,321.00	190	103

Table 4. Respective measures by varying the percent utilization.

Scenario	Percent Use	Total OD Trips	Mean V/C	Total VMT	Number of Links with V/C > 1.5	
					Direction AB	Direction BA
F Ava US EX 1	45 - 35	697,249.82	0.59	17,467,128.48	27	10
	55 - 45	838,063.78	0.64	21,788,195.38	54	30
	65 - 55	959,361.61	0.69	26,078,868.58	76	35
	75 - 65	1,056,423.07	0.74	29,716,660.61	103	56
	85 - 75	1,164,854.86	0.80	34,564,184.17	161	92
	95 - 85	1,247,404.12	0.82	36,256,321.00	190	103

It can be perceived that about 50% to 40% utilization can yield better results where the number of congested links reduces drastically. To investigate further, base trip table for scenario "F Ava US EX 1" was modified to include 147 sprawling TAZs where the threshold is equivalent to 75 Percentile. The sprawling links were classified as "disable links" while setting up the network file in TransCAD that can block any movement along these roadways. OD matrix estimation was performed in TransCAD where 40% of available capacity was regarded as count. Figure 3 shows the assigned flows of estimated trip table when the base trip table of "F Ava US EX 1" was altered, and sprawling links were disabled in TransCAD.

Table 5 presents the values of similar measures to understand the impact of adding more sprawling TAZs along with blocking related links.

Table 6 summarizes the number of links with V/C ratio more than 1.15 according to the changes considered in the above table. It can be noted that the original existing network contains 200 links in AB direction and 76 links in BA direction with V/C ratio more than 1.

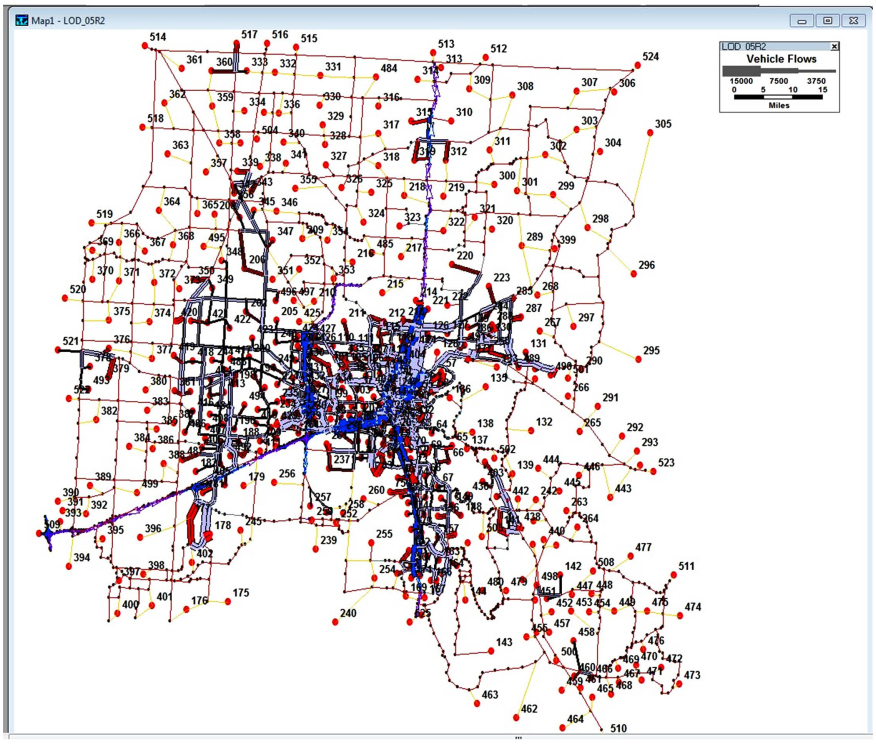

Figure 3. Assigned flows of estimated trip table.

Table 5. Measures depending on type of changes under 40% usage of available capacity.

Scenario	%Use	Total OD Trips	Mean V/C	Tot VMT	Number of Links with V/C > 1.5		Type of Changes to Block Sprawl
					AB	BA	
F Ava US EX 1 (45 - 35)	45 - 35	697,249.82	0.59	17,467,128.48	27	10	31 Sprawling TAZs
	45 - 35	677,572.07	0.59	16,796,127.07	25	12	147 Sprawling TAZs
	45 - 35	700,395.75	0.50	9,078,746.57	24	11	147 Sprawling TAZs plus disabling associated links

Table 6. Number of links with V/C ratio more than 1.15.

Scenario	%Use	Type of Changes to block sprawl	Number of Links with V/C > 1.15	
			Direction AB	Direction BA
F Ava US EX 1 (45 - 35)	45 - 35	31 Sprawling TAZs	276	123
	45 - 35	147 Sprawling TAZs	286	133
	45 - 35	147 Sprawling TAZs plus disabling associated links	211	78

This study compares different scenarios by varying percent utilization and blocking sprawling extent to determine the future trip table. This step by step analysis can help readers understand that scenario "F Ava US EX 1 (45 - 35)" with "147 Sprawling TAZs plus disabling associated links" can promote a more sustainable land use, transportation planning, and transport systems in the long run. **Figure 4** presents the additional total trips that can be produced or

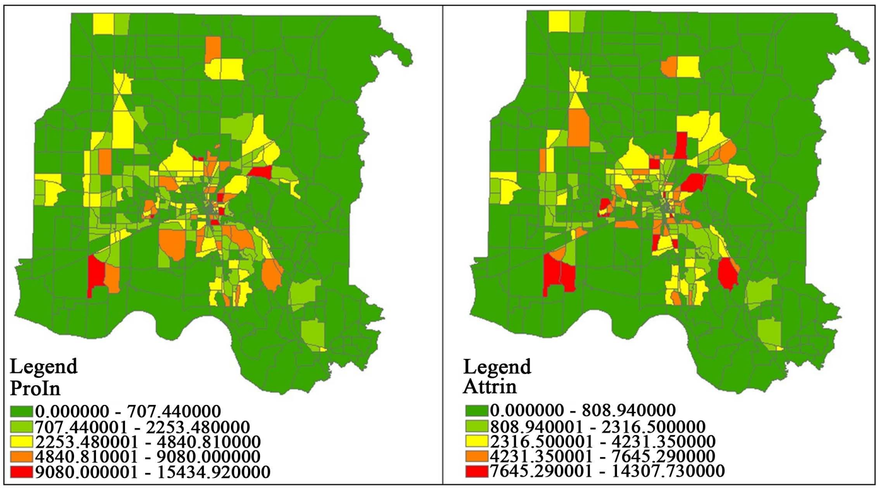

Figure 4. Additional production and attraction by TAZ.

attracted by TAZs respectively, resulted from the scenario "F Ava US EX 1 (45 - 35)" with "147 Sprawling TAZs plus disabling associated links".

8. Conclusion

It has been addressed in our problem statement that travel cost and accessibility is a minor part of land use change model while land use model governs the future network and major input for travel demand model. It controls the expansion or builds new route without looking at the underutilized roads or the disperse growth of cities. Therefore, any change in travel cost does not have any significant influence on land use model or location choice of future household and employment. Furthermore, the real reason Americans spend so much time in traffic is because of sprawl, and the solution to this problem has much more to do with how we build our cities than how we build our roads (Cortright, 2011).

The main motive of this study is to address urban sprawl and available capacity utilization and combine those features with land use change model for having a notion of forming more compact cities.

The study presents the formulation of different planning scenarios and estimation of OD matrices, including the aspects of future land use change, limiting sprawl by utilizing available capacity. This paper conducted a rigorous step by step analysis to determine a better solution or a more compact trip table that results in more trips inside the city of Huntsville if a TAZ can accommodate new trips. Based on the least amount of vehicle mileage traveled and a minimum number of congested links, a preferred scenario was identified that is the important part of this research. Hence, it is a preliminary initiative to build compact cities using current resources instead of the planning of future road network solely depending on the land use forecast model.

These results can provide a better understanding of how communities have developed in the United States and a better realization of the significance of building more compact cities that can promote effective public transit, and improve mobility options for walking and bicycling. This paper can help planners make appropriate changes in future land use planning to minimize growth in sprawling areas that can improve life expectancy, economic mobility, transportation choices, personal health, and safety.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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