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Development & Application of the Transportation Index for Sustainable Places (TISP)

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Development & Application of the Transportation Index for Sustainable Places (TISP)

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CHAPTER 1: INTRODUCTION

Background & Motivation

In recent years, society has begun to recognize and place greater emphasis on understanding the broader impacts of transportation systems. Attention to these broader impacts is evident at both the grassroots community level and the federal level. For example, several community-based non-profit organizations (e.g. Congress for the New Urbanism, 1000 Friends, National Complete Streets Coalition, etc.) advocate the need for transportation to provide accessibility for all street users while promoting the economic well-being of society and individuals. At the federal level, one of the most publicly visible policy actions relating to transportation in recent years is the formation of the HUD-DOT-EPA Interagency Partnership. This change in policy is evidence that the federal government now recognizes that transportation policy cannot operate independently and in isolation from housing, urban development, and environmental policies.

Applying the ideas of sustainability broaden our understanding of the role and purpose of transportation. The recent civic and policy developments discussed above contrast the more contemporary understanding of transportation. Transportation systems are typically envisioned only as a means to mobility, and the end product of transportation is to provide mobility. However, the concept of sustainability helps to explain the connection that transportation has with environmental, social, and economic issues. Some critics argue that the idea of sustainability is too vague or too broad, and its application or relevance to transportation policy is unclear or impractical. To counteract this perception, it is important to rigorously define transportation sustainability and develop metrics that identify the measurable objectives of transportation sustainability.

The motivation behind this thesis is the idea that "what gets measured gets managed," because metrics and indices represent more than just mere accounting tools. Transportation metrics embody the interpretation of the role of transportation and the priorities of policymakers. Current assessments of transportation performance focus on congestion or the level of service of a transportation facility. These metrics clearly define the role of transportation as a method of strictly providing vehicular mobility. The result of this thesis is a metric for assessing transportation sustainability. This broadens the scope of the role of transportation to include considerations for issues such as environmental quality, social equity, and economic vitality.

The Transportation Index for Sustainable Places (TISP)

This thesis covers the ongoing development of the Transportation Index for Sustainable Places (TISP), a performance metric that assesses transportation systems with respect to the environment, society, and economy. The TISP is the product of a research initiative at the Center for Transportation and Livable Systems (CTLS) at the University of Connecticut. The initial work for this project established the contextual background and builds the structural framework of the TISP. This thesis further develops the framework, demonstrates the application of the TISP, and discusses the significance of the results. The main body of this thesis is composed of two papers, each a separate chapter. Chapter 2 is titled *Selecting Peer States Based on Degree of Urbanism for Comparison of Transportation Systems* and Chapter 3 is called *Quantifying the Economic Domain of Transportation Sustainability.*

This thesis builds upon the initial work of this project, which consists of two methodology papers: *A Framework for Developing Indicators of Sustainability for Transportation Planning* (Nichols 2008) and *Developing a Sustainable Transportation Composite Index for Performance-Based Ranking* (Nichols 2009). These methodology papers define the concept of transportation sustainability, identify the measurable components of transportation sustainability, and examine existing metrics to help model a framework for the TISP. The result of this initial work was an awareness of the relationship between transportation and sustainability, and a methodology for the computational structure for the TISP framework.

In this thesis, the second chapter is an unpublished paper titled *Selecting Peer States Based on Degree of Urbanism for Comparison of Transportation Systems*. This paper refines the methodological framework of the TISP by establishing a basis of comparing states. The distribution and density of state populations was used to distinguish between rural states and urban states. This is important because transportation infrastructure and performance depend on the local character of development within each state. In other words, rural states and urban states have different settings which may affect the outcomes of the various performance measures of the TISP. The analysis based on this characterization is designed to offer more insight into understanding and interpreting the results from the TISP.

The third chapter, a paper titled *Quantifying the Economic Domain of Transportation Sustainability*, demonstrates the application of the TISP by using the methodological framework that was established earlier. This paper explains how the definition of transportation sustainability is used to guide the development of our framework and how the TISP is used to assess the performance of statewide transportation systems with respect to the environmental, social, and economic aspects of transportation sustainability. In this paper, the focus is on the economic aspect of sustainability because there is no existing literature that explores the relationship between economic growth, transportation activity, and the implication for sustainability. This paper was presented at the Transportation Research Board's 90th Annual Meeting in January 2011 and has been accepted for publication in the Transportation Research Record – the Journal of the Transportation Research Board.

The goal of this research is to develop a tool that identifies and measures the performance of transportation systems with respect to sustainability. By implementing a tool that measures the broader impacts of transportation, the intent is to shift the focus of transportation from primarily a mobility perspective to one that pays equal attention to environmental, social, and economic considerations. Tools such as the TISP can be valuable for planners and policymakers, by bringing attention to impacts that may not have been as visible before. This thesis focuses on the performance of statewide transportation systems with respect to the economic aspect of transportation sustainability. In addition to a basic state-to-state comparison, the analysis also considers the difference in performance when differences between rural and urban states are included.

CHAPTER 2: SELECTING PEER STATES BASED ON DEGREE OF URBANISM FOR COMPARISON OF STATEWIDE TRANSPORTATION SYSTEMS

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ABSTRACT:

Transportation and land use policies are intricately related. This work seeks to understand how transportation patterns are related to the underlying population and land use patterns for each state. To do so, it is important to first establish a means of comparing the states. This paper describes the methodology used to classify states by degree of urbanization, which is a representation of the underlying population and land use patterns. Data for the distribution and density of population for each state are analyzed using two statistical procedures, principal component analysis and hierarchical clustering. The result of this methodology are four distinct groups that represent the range of states from the most rural to most urban and are labeled: Low Density Rural-Suburb, Low Density Balanced, Medium Density Suburb, and High Density Suburb-Urban. The states in these four groups are then assessed based on transportation measures such as vehicle miles traveled, mode shares, and vehicle ownership. The results of our work show that these transportation measures are significantly different between states in different urbanity groups.

1.0 INTRODUCTION

Transportation systems are vital components of modern society, but the character of these transportation systems is not uniform throughout the United States. The aim of this work is to understand if certain geographic differences are related to this difference in transportation systems. More specifically, this analysis looks at the difference in population settlement patterns on a statewide scale.

When analyzing between states, it is important to establish a means of comparison. This is especially true for transportation, as the Federal Highway Administration (FHWA) explicitly stresses the need to identify peer states when comparing transportation characteristics of the states. Policies for the planning and governance of transportation systems must take into consideration local characteristics such as geographic differences (e.g. coastline, winter climate), socio-economic patterns (e.g. population density, economic activity), existing transportation infrastructure (e.g. interstates, railroads, airports), and existing transportation policy (e.g. gas tax, transit). Due to these differences, a general blanket transportation policy may not be suitable for the whole nation without addressing the distinguishing characteristics that set places apart. Therefore, it is helpful to identify peer states for assessing and comparing policy outcomes.

Initially used in the social sciences, methodologies to create peer groups has expanded into many fields such as hard sciences, biomedical research, and is applicable for urban and transportation policy. This work seeks to classify the states based on underlying patterns of population and development. Data for the distribution and density of state populations are used to classify states from the most rural to the most urban. With these classifications, we then seek to determine if various statewide transportation characteristics are related to these underlying land use patterns.

This paper describes the methodological approach and reviews existing strategies for identifying peer groups when making geographic comparisons of places. Principal component analysis (PCA) is used to analyze the population parameters and create a set of uncorrelated variables (or components). Then, hierarchical clustering (HC) is used on the resulting components from the principal component analysis to classify the states into groups of the most similar states or, in other words, identify peer states. After classifying the states based on population characteristics, specific transportation features (such as vehicle miles traveled, mode share, and car ownership) are compared across the states and peer groups to test the validity of the groups.

2.0 LITERATURE REVIEW

Classifying subjects into peer groups to establish a level of comparison is a commonly used procedure in many fields to help identify similarities and differences between the subjects. (*3*) Methodologies for these classification schemes can employ either or both hierarchical clustering and principal component analysis and techniques. (*3, 4*) Identifying peer groups for transportation and urban development is important because the characteristics that differentiate places directly influence decisions on policy, planning, and funding. (*1, 2, 5*)

Since 1945, the Federal Highway Administration's (FHWA) annual publication, *Highway Statistics*, reports a variety of transportation measures for each state but began recognizing the need for establishing a means to compare states in 1995. (*1, 2*) This addendum alerts users of the *Highway Statistics* data to bear in mind the differences between the states, "when making state level comparisons, it is inappropriate to use these statistics without recognizing those differences that impact comparability." (*1*) The example given is that it is inappropriate to equally compare highway maintenance costs for every state. (*1*) Due to climate differences, more northern states incur additional costs for snow removal and salting. (*1*) This example shows one reason why it is necessary to select peer states for transportation comparisons.

Highway Statistics provides numerous data for making state comparisons such as land area, population, road infrastructure, economic measures, and travel measures. However, FHWA does not provide a specific methodology on how to use the data to classify states. (*2*) The only guidance provided is that the variables selected for identifying peer states is dependent on the specific comparison being made and the goals of the analyst. (*1*)

To develop our classification scheme, we follow the methodology of Mikelbank's work, *A Typology of Suburban Places,* and Hendren and Niemeier's work, *Identifying Peer States for Transportation System Evaluation & Policy Analyses*. (*2, 5*) These researchers employ hierarchical clustering to develop the potential grouping combinations, and they analyze the merits of the potential grouping solutions.

2.1 Hierarchical Clustering

Hierarchical clustering (HC) creates groups of the most similar and dissimilar subjects (or observations) within a dataset. (*3, 5*) This is accomplished by grouping together observations in a manner that minimizes the variance of the observations within a group and maximizes the variance of the observations between the groups. (*2, 3, 5*) The final outcome of the HC process is an informative data analysis that proposes a number of potential solutions of group configurations, also known as clusters. For example, a possible solution could split our original dataset into 2 clusters, 3 clusters, or any number of clusters.

This procedure is attractive for classification and grouping because neither the number of beginning variables nor resulting groupings needs to be specified. (*5*) HC will determine the appropriate number of resulting classification groups based on the variance within the variables and observations of the dataset. (*2, 3, 5*)

At the beginning stage of HC, every observation starts in its own group (or cluster) and there is zero within group variance (because nothing has been grouped together). As a result of the process, variance increases as observations are combined. The HC process chooses which observations to combine based on which combination creates the least amount of within group variance. With each step, the total number of observations/combined-clusters decreases by 1. The end result is 2 clusters, but there are numerous "#-cluster" solutions throughout the HC process.

The #-cluster notation used in this paper represents the potential number of clusters. For example, the notation 2-cluster suggests a solution involving 2 clusters.

There are numerous methods to determine which #-cluster solution works best. (*2, 3, 5*) One method is to look at the agglomeration schedule. (*3, 5*) The agglomeration schedule records the increase in total variance as observations are grouped together. This agglomeration schedule is analyzed for the percentage change of variance (first percentage change) and the rate of that percentage change (second percentage change) to determine the most suitable number of clusters. The first percentage change tracks the increase in variance when observations are combined. (*5*) The second percentage change measures the growth or decline of the first percent change, which is a representation of the growth of change in variance. (*5*) Large increases in the second percent change represent natural break points in the analysis. (*5*) One way to select a specific #-cluster solution is to identify the number of solutions right before a large increase in the second percentage change as a result of clusters being combined together. When this occurs, it signifies that the two clusters being combined are relatively different from one another, thus the large increase in overall variance.

Figure 1, for illustrative purposes, describes how the #-clusters are organized with respect to each other, using the resulting classifications of Mikelbank's work. (*5*) Mikelbank categorized 3,567 suburban places using 45 variables that describe local demographic, place, economic, and government characteristics. (*5*) Using the agglomeration schedule, distinct typologies were determined at the 2-cluster, 4-cluster, and 10-cluster levels. (*5*) The initial set of observations (labeled Group) includes all 3,567 suburban places and is divided into two sub-groups at the 2-group level. These subgroups are then broken down further into the 4-group and 10-group levels.

The 2-group level describes the broadest characteristic that differentiates the suburbs, while the 4-group and 10-group level include specific details. Mikelbank examined these subgroups and labeled them according to their common characteristics. For example, *subgroup 1* in the 2-group level is described as "Middle America" (common traits: lower-than-average income and house value levels), *subgroup i* is described as "Manufacturing" (common traits: high manufacturing employment), and *subgroup a* is described as "Struggling" (common traits: low incomes and house values, low percentage of college educated). (*5*) Thus, all places that were clustered together in *subgroup a* at the 10-group classification level, could be described as a "Middle American Suburb with a Struggling Manufacturing Economy."

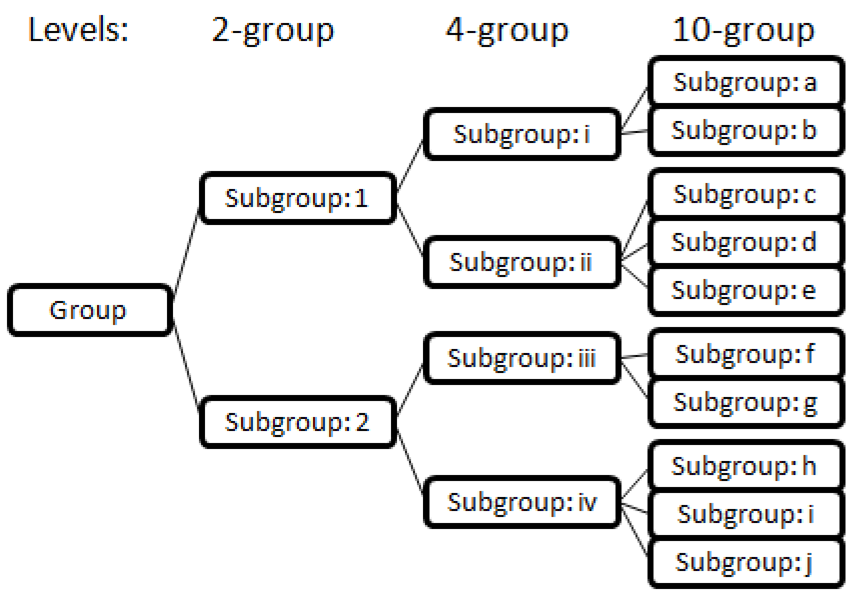


FIGURE 1 Example of How Hierarchical Clustering (HC) Results are Organized

2.2 Principal Component Analysis

Hendren and Niemeier also employ hierachical clustering (HC) in their work, *Identifying Peer States for Transportation System Evaluation & Policy Analyses*. Hendren and Niemeier seek to classify the states based on existing conditions and use 42 variables that describe the population, infrastructure, system usage, government attributes, economic indicators, developed land, and snowfall. These variables were chosen because the analysts seek to create clusters of the most similar states in terms of overall current characteristics. However, the methodology used is a two step process that includes principal component analysis (PCA) prior to HC. (*4*)

PCA can be described as a data reduction process which creates a smaller set of themed variables (also called components or factors) from the original dataset. (*2, 4*) This process is useful for applying to large multivariable datasets because these datasets have the potential for correlations among the variables. (*4*) The smaller set of themed components is constructed from the original data points in a way that accounts for the most variance and correlation between the variables. (*4*)

The resulting components are uncorrelated and statistically independent from one another and should be used in the HC procedure. These uncorrelated components should be used to avoid the occurrence of double counting the same measure using correlated variables. (*2*) For example, in Hendren and Niemeier's work, PCA determined that the two variables "Gas Tax" and "Gas Tax Rate" were correlated so these two variables were ultimately represented by one component.

The resulting components in Hendren and Niemeier's work were then used in hierarchical clustering. The 7-cluster, 8-cluster, 9-cluster, and 10-cluster levels were identified as the best grouping combinations. Like Mikelbank, the authors then examined these groups and labeled them based on their dominant characteristics. Hendren and Niemeier focus on the 9-cluster solution and described the state groups as: (1) Average, (2) Rural, (3) Demand Growth, (4) Urban, (5) Urban VMT Growth, (6) State Control, (7) Transit, (8) Interstate Growth, and (9) Urban System Growth. These descriptions were determined by looking at which PCA components contributed the most to each of the clusters. (*2*)

Although it is possible to identify an optimal #-cluster solution, the chosen #-cluster solution ultimately depends on the motivation of the analyst. (*2*) For example, if a state agency wants to contact a small group of peer states, they may look at the 10-group level (more groups mean there are less states in each group). (*2*) Therefore, Hendren and Niemeier do not state that any one #-cluster solution is the optimal solution. For their work, Hendren and Niemeier chose to focus on the 9-cluster solution because they required that groups contained at least two states because the purpose of the clustering was to identify peer states.

2.3 Discussion

Hendren and Niemeier's work is comparable to our work because it is specific to transportation and also seeks to classify the states, but what sets our work apart is the objective of our clustering and the types of variables chosen. Hendren and Niemeier choose to use both transportation and socio-economic variables because they seek to classify the current characteristics of each state. Unlike Hendren and Niemeier's work, we exclude transportation variables in our work because we do not want their inclusion to have an impact on our clusterings. As our variables, we use the distribution and density of population that represent the degree of urbanization in each state. This is essentially a proxy measure to assess the intensity of urban development for each state. Our goal is to determine if the underlying population characteristics and urban intensities have an impact on statewide transportation characteristics.

These researchers (Mikelbank, Hendren and Niemeier) demonstrate the application, usefulness, and methodological process of HC. Identifying peer groups is valuable for policy and decision makers by establishing a basis of comparing states. (*1, 2, 5*) The chosen variables for developing the groupings and the number of groupings themselves are dependent on the objectives and desired level of analysis of the researchers. (*1, 2, 5*) HC, like other statistical techniques, is valuable to guide researchers in their analysis, but final decisions are still subjective to the goals of the researchers. (*3, 5*) This work uses both PCA and HC to develop the classification groupings. The next section discusses the data for urban population used in this analysis.

3.0 URBAN POPULATION DATASETS & VARIABLE SELECTION

This work uses data related to the distribution and density of population in rural and urban areas across each state. The source of this data is the US Census Bureau's 2000 Decennial Census. (*6*) It is important to understand the numerous methods that the US Census Bureau uses to report and organizes population data. One method of organizing the population data is to use the urban and rural classifications, as defined by the US Census Bureau (*6*). Another method makes use of the metropolitan and micropolitan statistical area (MSA and μSA respectively) definitions, which are geographic entities defined by the US Office of Management and Budget (OMB). (*6*) The US Census also uses the MSA and μSA geographic definitions in conjunction with the urban/rural classifications to organize and present population data.

3.1 U.S. Census Terminology

The urban/rural classifications are based on population density and are measured at the census block level. The census block is the smallest geographic unit used by the US Census Bureau. Urban areas have a core census block of at least 1,000 people per square mile and include surrounding census blocks that have at least 500 people per square mile. Rural areas are defined as all areas that are not urban. While this provides data for urban and rural populations, we expand upon the data by including MSA and μSA information to help explain the varying degrees of urban areas.

The MSA and μSA definitions are based on the presence of urban areas (based on the urban/rural classification) and are measured at the county level. The county level is the largest census defined geographic entity for each state. The MSA and μSA use the minimum density definitions of urban areas at the census block level, as previously described, but also includes the immediate and adjacent counties. A metropolitan statistical area (MSA) consists of a core urban area (collection of census blocks) that contains at least 50,000 people, includes the county(s) of the core urban area, and includes any adjacent counties with economic ties (commuters) to the urban core. A micropolitan statistical area (μSA) is similar to a MSA, but has a core area (collection of census blocks) that contains between 10,000 and 50,000 people. Incorporating these definitions, urban areas inside MSA's are termed urbanized areas (UA) and urban areas inside μSA are termed urbanized clusters (UC).

Note that these geographic entities can go by different names and have different roles in each state. States such as Louisiana and Alaska do not have counties, but instead use the terms parish and borough, respectively. In addition, the US Census also identifies certain distinct places using various other terminologies. For example, there are autonomous regions (also known as independent cities) which are mostly prevalent in Virgina. These parishes, boroughs, and independent cities are treated as county-equivalents.

Further complicating the understanding of these geographic entities, most cities are typically a separate jurisdiction from the greater county level of government but some areas are known as a consolidated city-county where there is not separate distinction. For example, the same governing body exists for the city of San Francisco and the county of San Francisco. In other cases, a large county can consist of multiple cities. The role of counties can also vary from region to region. For example, New England counties only serve as geographic entities while individual cities and towns have the responsibility of governance. For this reason, the US Census also uses the New England City and Town Areas (NECTA), similar to the MSA, to organize states in the New England region. We make no special consideration for these cases, and use the data as it is reported in the existing UA, UC, MSA, and µSA terminology. We choose to do this so that we consistently treat the data the same way throughout the whole country.

3.2 Describing Urbanized Areas (UA), Urbanized Clusters (UC), Metropolitan Statistical Areas (MSA), and Micropolitan Statistical Areas (µSA)

The relationship between the urban/rural classification and MSA/µSA classification is summarized in Table 1. The MSA is defined at the county level and consists of multiple counties joined together. At the core of each MSA is an urbanized area (UA) with a total population of at least 50,000 and minimum density of 1,000 people per square mile. The µSA's are also defined at the county level and consist of multiple counties combined together. At the core of each µSA is an urbanized cluster (UC) with a total population between 10,000 and 50,000 and a minimum density of 1,000 people per square mile. UC's also exist outside of MSA's and μSA's because the census blocks meet the density criteria but have less than 10,000 total people. Note that, these places are not always present in each geographic entity. For example, all MSA's have a central city, but may not always have small towns. Figure 2 provides a visual interpretation of these differences using the states of Kansas and Missouri as an example.

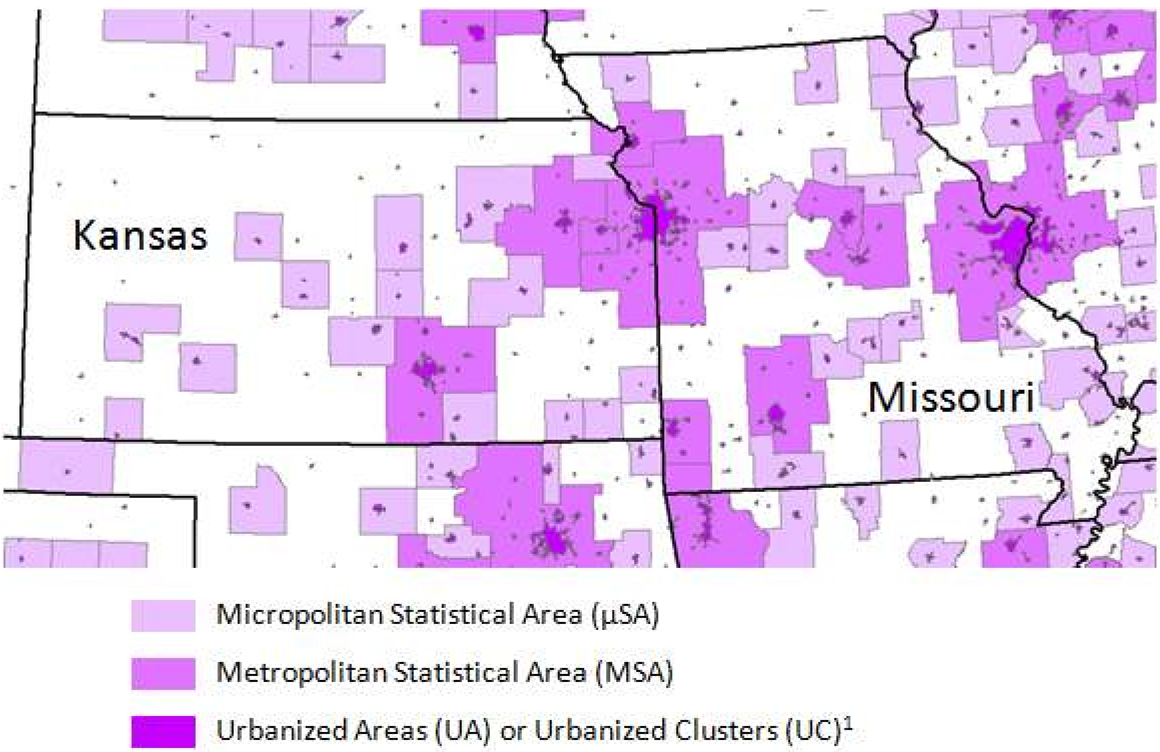
The US Census Bureau and US Office of Budget and Management also use additional names for the urbanized blocks and statistical areas that are more descriptive. The core UA of MSA's is referred to as the central city, while the remaining areas within the MSA but outside the UA are considered suburbs. Following this theme, we chose to label UC's as small towns and the remaining areas as rural areas, as shown in Table 2. This table includes the average density of these places that we calculated for comparison purposes. Based on these results, central city(s) and suburb(s) are unique to the MSA given their respective average density of 3,000 and 300 people per square mile. Small towns appear similar among the MSA, μSA, and Neither-MSA/μSA with an average density of 1,000 people per square mile. The remaining area, rural, is similar for the μSA and Neither-MSA/μSA with an average density of 50 people per square mile.

Using this combination of urban/rural and MSA/μSA classification provides a better understanding of the data. Using just the US Census's urban/rural classification does not fully account for the range of differences between the places. The urban/rural classification would aggregate together all the central city and small town data, and it would aggregate together the suburbs and rural data. However, as shown in Table 2, these types of places are distinctly different.

TABLE 1 MSA, µSA, UA, and UC Requirements

Geographic Entity (composed of counties)	Presence of Urbanized Census Blocks	Population Criteria for UA/UC (sum of census blocks)	Density Criteria[1] (individual blocks)
Metropolitan Statistical Area (MSA)	Contains at least 1 Core Urbanized Area (UA)	Greater than 50,000	1,000 people per square mile
	Can Contain Additional UA's	Greater than 50,000	1,000 people per square mile
	Can Contain Urbanized Cluster(s) (UC)	Less than 50,000	1,000 people per square mile
Micropolitan Statistical Area (µSA's)	Contains at least 1 Core UC	Between 10,000 and 50,000	1,000 people per square mile
	Can Contain Additional UC(s)	Less than 50,000	1,000 people per square mile
Neither MSA/µSA's	Can Contain UC(s)	Less than 10,000	1,000 people per square mile

[1]At least one census block must contain a minimum 1,000 ppl/mi^2. Adjacent census blocks may contain 500 ppl/mi^2. Under certain conditions, some census blocks with less than 500 ppl/mi^2 can also be part of a UA or UC. (*2*)



[1]The agglomeration of census blocks with a total population over 50,000 located within a metropolitan statistical area is known as an urbanized area. The agglomeration of census blocks with a total population between 10,000 and 50,000 located within a micropolitan statistical area is known as an urbanized cluster.

FIGURE 2 Location of MSA's, µSA's, UA's, and UC's with Respect to Each Other

TABLE 2 Location of MSA's, µSA's, UA's, and UC's with Respect to Each Other

Geographic Entity (composed of counties)	Presence of Urbanized & Non-Urbanized Census Blocks	Alternative Name	Average Density (approximately)
Metropolitan Statistical Area (MSA)	Core Urbanized Area (UA)	Central City	3,000 people per square mile
	Urbanized Cluster(s) (UC)	Small Towns	1,000 people per square mile
	Non-UA, Non-UC Areas	Suburbs	300 people per square mile
Micropolitan Statistical Area (µSA's)	UC(s)	Small Towns	1,000 people per square mile
	Non-UC Areas	Rural Areas	50 people per square mile
Neither MSA/µSA's	UC(s)	Small Towns	1,000 people per square mile
	Non-UC Areas	Rural Areas	50 people per square mile

3.3 Determining Variables for the Distribution and Density of Population

Variables were selected for the analysis after determining underlying geographic structure of the population data. Given the scope of the project, the most reasonable choices for variables were the amount of land, amount of people, and density of people for each type of place within each state. The types of places are shown in Table 2 and are central city(s) in MSA's, small towns in MSA's, suburbs in MSA's, small towns in µSA's, rural areas in µSA's, small towns in Neither-MSA/µSA's, and rural areas in Neither-MSA/µSA's.

The analysis also uses the percentages, rather than raw numbers, because we want to understand the patterns and distribution of settlement, rather than total size. Looking at the percentage allows us to understand to what extent is the state's total population living in an urban or rural environment.

To understand the degree of development, we consider using percentage of total land and population density. Ultimately, we chose to exclude % of land from the analysis in favor of density. The purpose of looking at land and density is to understand the extent and nature of land use. However, we are more interested in how settled lands are utilized. Density gives an idea of how much land is being utilized and to what extent is land being developed. Given need for choice, we believe density better represents the characteristics of land use that we are looking for.

As a caveat, in calculating our densities, we use gross land area as opposed to net land area. This can skew some of the density results in some places because gross land area includes uninhabitable land such as mountains and wetlands. Net land area is preferred, but data was only available for gross land.

3.4 Chosen Variables and Data for Analysis

This section explains how the nine variables, as shown in Table 3, were determined for the analysis. The variables used in this analysis are the percentage of state population living in the following entities and the density of each entity: central cities, small towns, suburbs, and remaining rural areas. A binary variable is included for the states that do not have µSA's or rural areas (based on our labeling scheme as shown in Table 2).

When looking at the data for the geographic entities that cross state lines it was necessary to split the data into their respective states. For example, as shown in Figure 2 with Kansas and Missouri, there is one MSA that spans the border between the two states. The data for the MSA and UA as a whole must be split into their respective states.

Data for certain geographic entities were combined together. For example, small towns from MSA, µSA, and Neither-MSA/µSA geographic entities were aggregated together. This was done because small towns across all these entities are similar in terms of density. It would have been repetitive to have a variable for small towns from MSA, small towns from µSA, and small towns from Neither-MSA/µSA regions. This aggregation was also done for rural areas from µSA and Neither-MSA/µSA regions. Central city data, as shown in Table 3, for percentage of population living in and density is the aggregate sum and average, respectively, of all central cities within the state. The same is true for the suburb data.

TABLE 3 Population (%) and Density (people/mile^2) for Geographic Entities per State

State	Central City(s)		Small Town(s)		Suburb(s)		Rural Area(s)		Binary*
	% Pop. Living in	Density	% Pop. Living in	Density	% Pop. Living in	Density	% Pop. Living in	Density	
Alabama	26%	1,173	11%	535	37%	122	25%	32	0
Alaska	36%	2,863	56%	74	6%	21	3%	0	0
Arizona	53%	2,267	24%	681	15%	17	9%	7	0
Arkansas	25%	1,272	20%	825	18%	67	36%	22	0
California	39%	4,752	5%	1,173	54%	207	2%	11	0
Colorado	34%	2,618	8%	1,168	48%	112	10%	5	0
Connecticut	27%	3,299	3%	499	67%	665	7%	171	0
Delaware	17%	3,163	4%	1,158	61%	498	18%	149	0
D.C.	100%	9,317	0%	n/a	0%	n/a	0%	n/a	1
Florida	22%	1,800	3%	693	69%	387	6%	42	0
Georgia	15%	1,262	8%	828	53%	372	25%	45	0
Hawaii	31%	4,337	16%	631	40%	972	13%	29	0
Idaho	22%	2,712	17%	2,019	16%	81	44%	7	0
Illinois	35%	5,874	8%	1,681	48%	389	9%	30	0
Indiana	30%	2,338	12%	1,798	36%	199	21%	54	0
Iowa	27%	1,812	22%	1,252	17%	83	34%	20	0
Kansas	31%	1,949	25%	1,704	22%	113	23%	8	0
Kentucky	16%	1,570	13%	1,143	28%	202	42%	52	0
Louisiana	29%	2,296	11%	1,193	46%	141	14%	22	0
Maine	12%	1,034	12%	336	21%	216	54%	24	0
Maryland	15%	6,201	3%	1,522	76%	671	6%	93	0
Massachusetts	32%	3,457	2%	834	63%	835	4%	103	0
Michigan	21%	4,452	6%	826	57%	439	17%	39	0
Minnesota	19%	3,649	14%	750	47%	143	20%	16	0
Mississippi	13%	1,427	22%	812	22%	117	44%	30	0
Missouri	22%	2,018	12%	1,116	43%	212	23%	23	0
Montana	23%	2,644	22%	253	11%	12	45%	3	0
Nebraska	36%	3,234	22%	2,058	16%	110	27%	6	0
Nevada	33%	3,612	8%	181	50%	74	9%	2	0
New Hampshire	20%	1,948	14%	477	36%	379	30%	51	0
New Jersey	12%	4,240	1%	462	87%	1,057	0%	n/a	1
New Mexico	32%	2,166	22%	1,066	22%	35	24%	4	0
New York	49%	14,890	4%	1,038	40%	405	7%	51	0
North Carolina	29%	1,900	9%	1,163	33%	177	29%	74	0
North Dakota	30%	2,325	19%	1,663	14%	13	37%	4	0
Ohio	27%	3,410	10%	1,672	48%	363	14%	68	0
Oklahoma	32%	1,044	22%	788	22%	85	24%	15	0
Oregon	29%	3,573	15%	1,928	39%	95	17%	7	0
Pennsylvania	22%	7,563	5%	674	60%	381	13%	67	0
Rhode island	36%	5,334	2%	484	62%	702	0%	n/a	1
South Carolina	14%	1,298	8%	1,000	53%	188	24%	54	0
South Dakota	24%	1,819	25%	1,469	8%	16	42%	4	0
Tennessee	34%	1,444	10%	737	31%	167	26%	51	0
Texas	46%	2,249	11%	1,005	34%	155	9%	9	0
Utah	21%	2,354	8%	849	54%	163	17%	5	0
Vermont	6%	3,683	16%	691	21%	237	56%	40	0
Virginia	26%	1,643	5%	529	51%	269	17%	51	0
Washington	28%	3,502	7%	1,256	52%	169	13%	17	0
West Virginia	10%	2,061	10%	1,440	31%	149	49%	44	0
Wisconsin	30%	3,362	12%	617	34%	152	23%	31	0
Wyoming	21%	2,278	37%	1,270	9%	6	33%	2	0

*Binary variable equal to 1 if entire state is categorized within MSA's (ie: state has no rural areas based on our definition)

A binary variable was necessary because some states did not have any rural areas based on our labeling. The counties (or county-equivalents) that make up the District of Columbia, New Jersey, and Rhode Island are all included in MSA's. Therefore, we describe these states as having no rural areas, and the density for rural areas is undefined, but a zero is necessary as a placeholder for the hierarchical clustering process. Based on the clustering process, these states with "zero" rural density would be grouped with states that have low rural density. To counter this, we introduce a binary factor for the three states that have no rural areas.

The US Census provides a broad depth of data. While there are many ways to interpret and organize the available data, we chose to focus on the definitions for urbanized areas, urbanized clusters, metropolitan statistical areas, and micropolitan statistical areas. The next section, methodology, explains how we use this data in the principal component analysis and hierarchical clustering processes.

4.0 METHODOLOGY

After gathering the data representing our geographic divisions, we refine the nine variables using principal component analysis (PCA) and classify the states into peer groups using hierarchical clustering (HC). The PCA process results in three components. These components were then used in the HC and ultimately result in four clusters.

Prior to PCA and HC, a normalization process is necessary to rescale the values of the dataset from 0 to 100 to account for the difference in scale between the variables. (*2*) For example, the density of central cities is in the range of 1000's while the density of rural places is in the range of 10's.

4.1 Deriving Components from Principal Component Analysis

The mathematical procedure for PCA uses a series of orthogonal matrix transformations, also known as rotations, to transform a multivariable dataset into a small set of theme variables, also known as components. In our work, nine variables are transformed into three components. These rotations also represent a reduction in dimensionality of the dataset, which makes the dataset easier to visualize. (*4*) For example, the nine variable dimension of our dataset is reduced to three dimensions. The resulting three components account for as much variance as possible from the original nine variable dataset.

The values in Table 4 represent how much variance from each variable is accounted for by each component using Varimax orthogonal rotation. Numerous rotations methods exist, but the Varimax method is most commonly used. (*4*) The Varimax method, for each variable, concentrates the most variance onto one component while contributing near zero variance to the other components. For example, as shown in Table 4, *variables 1 and 2* contribute the most variance to *component 2* while contributing minimally to *component 1 and 3*. Each of the nine variables in Table 4 typically contribute largely to just one of the components. The highlighted cells of Table 4 indicate the largest contributing variable to each component. These three components are labeled according to the contributions from the variables. For example, *component 2*, "Central City Population Characteristics," is mostly made up of variance from the central city variables.

TABLE 4 Component Contributions from PCA using Varimax Method

Variables		Component		
		1	2	3
		Suburb & Rural Population Characteristics	Central City Population Characteristics	Small Town Density & Absence of Rural Areas
1	Central City - % Population	-0.35	0.84	-0.14
2	Central City - Density	0.22	0.79	0.02
3	Small Towns - % Population	-0.75	-0.30	0.06
4	Small Towns - Density	-0.04	0.03	0.86
5	Suburb - % Population	0.93	0.07	-0.10
6	Suburb - Density	0.83	0.09	-0.26
7	Rural - % Population	-0.40	-0.69	0.22
8	Rural - Density	0.72	-0.13	0.25
9	Binary Factor (no rural)	0.08	0.46	-0.69

4.2 Resulting Potential Clusters from Hierarchical Clustering

The three resulting components from PCA are then used in the HC procedure. Many methods are available for HC. This analysis uses Ward's method which aims to minimize the variance between observations within a group while maximizing the variance between groups at the same time. Other methods typically do one or the other, while Ward's method does both.

The process begins with *n* clusters equal to the number of original observations. In our case, *n* is 51. The number of clusters decreases as observations are grouped together. There are numerous #-cluster solutions. For example, a 2-cluster solution indicates the 51 states are divided into two groups. There are multiple methods to determine which #-cluster solution is the most meaningful, and one such method is to analyze the agglomeration schedule, as shown in Table 5. The agglomeration schedule tracks the increase in total variance among the observations as they are combined together. The total number of clusters decreases as the process continues (the stage number increases at each step).

The point where the largest second percentage change occurs, which indicates the change in the rate of the growth of variance, helps determine a reasonable #-cluster solution. Looking at Table 5, the step going from 7 clusters to 8 clusters, at stage 45, shows the variance within the whole system has increased from 36.76 to 46.31 which represent a 26% increase (first percent change, shown in column *1st % Change*). The rate of this percentage change from 17% to 26% is a 52% increase (second percent change, shown in column *2nd % Change*). Looking at the largest second percent changes, the appropriate break points are at the 49-cluster, 11- cluster, 7- cluster, and 3- cluster configurations.

While using the agglomeration schedule provides a basis for determining the optimal #-cluster solution(s), (*5*) the desired cluster configuration is up to the analyst to determine what is most meaningful. (*2*) The 49-cluster solution should be immediately discarded because at 49-clusters and 51 initial observations, this means that the majority of observations are in their own individual clusters. This is meaningless for our purpose of identifying similar peer states.

4.3 Analyzing Potential Clusters using Dendrogram Tree

A useful visualization tool for the clusters is the dendrogram tree, as shown in Figure 4. The dendrogram shows the most similar observations grouped together at the "bottom" of the tree towards the left-side of the figure. This represents the most identifiable peers for each state. For example, the states that are most similar to Minnesota are Tennessee, Utah, Wisconsin, Missouri, North Carolina, and Nevada.

To interpret the #-cluster solutions from the dendrogram, vertical lines can be drawn and intersect the appropriate number of branches. Each branch that is intersected by the vertical line represents a cluster. Figure 4 shows this for the 3-cluster and 7-cluster solutions.

The dendrogram tool provides visual cues to identify which states are most similar or dissimilar. From Figure 4, New Jersey, Rhode Island, and the District of Columbia immediately branch off from the rest of the states, labeled as branch C on the dendrogram. This indicates that these states are drastically different from the other states. This is most likely a direct result of the use of binary factors to represent the states with no rural areas. These states were identified with no rural areas because of the specific definitions that were used in this analysis.

The 3-cluster solution, as previously described, shows three states immediately branching off into one cluster. The major drawback to the 3-cluster solution is that it features more than half of the remaining states in a separate cluster, labeled as branch A.

The 7-cluster solution divides branch A into more manageable clusters, labeled as branches D, E, and F. However, the downside to the 7-cluster solution is that the remaining clusters, branches B and C, are divided up into smaller groups.

Therefore, we propose to use a hybrid solution of the 3-cluster and 7-cluster configurations. It makes reasonable sense to split branch A into branches D, E, and F, but branch B should remain together. Furthermore, branch B and C are combined for our analysis so that New Jersey, Rhode Island, and the District of Columbia have additional peer states for comparison.

TABLE 5 Agglomeration Schedule for Hierarchical Clustering

Stage	Number of Clusters	Cluster Combined		Sum of Variance	Stage Cluster First Appears		Next Stage	1st % Change	2nd % Change
		Cluster 1	Cluster 2		Cluster 1	Cluster 2			
1	51	24	43	0.01	0	0	3		
2	50	17	35	0.04	0	0	19	245%	
3	49	24	45	0.08	1	0	6	90%	-64%
4	48	6	19	0.14	0	0	7	77%	-14%
5	47	4	37	0.21	0	0	28	50%	-36%
6	46	24	50	0.29	3	0	29	35%	-29%
7	45	6	48	0.37	4	0	23	26%	-26%
8	44	42	51	0.44	0	0	22	21%	-19%
9	43	25	46	0.52	0	0	25	18%	-17%
10	42	11	41	0.62	0	0	30	18%	5%
11	41	18	49	0.72	0	0	36	16%	-11%
12	40	26	34	0.83	0	0	29	15%	-7%
13	39	16	32	0.95	0	0	22	14%	-6%
14	38	10	23	1.07	0	0	20	13%	-10%
15	37	1	30	1.21	0	0	30	13%	1%
16	36	15	38	1.39	0	0	26	14%	10%
17	35	7	22	1.57	0	0	32	13%	-11%
18	34	12	47	1.75	0	0	20	12%	-9%
19	33	13	17	1.99	0	2	27	14%	19%
20	32	10	12	2.24	14	18	31	13%	-8%
21	31	5	14	2.57	0	0	34	15%	15%
22	30	16	42	2.94	13	8	40	15%	0%
23	29	6	44	3.32	7	0	39	13%	-12%
24	28	8	21	3.80	0	0	32	14%	11%
25	27	20	25	4.28	0	9	38	13%	-11%
26	26	15	36	4.76	16	0	34	11%	-11%
27	25	13	28	5.26	19	0	40	10%	-8%
28	24	4	27	5.81	5	0	38	10%	0%
29	23	24	26	6.36	6	12	33	9%	-9%
30	22	1	11	7.02	15	10	36	10%	9%
31	21	10	39	7.81	20	0	41	11%	10%
32	20	7	8	8.82	17	24	46	13%	15%
33	19	24	29	9.85	29	0	39	12%	-10%
34	18	5	15	10.92	21	26	43	11%	-6%
35	17	2	3	12.14	0	0	44	11%	2%
36	16	1	18	13.48	30	11	42	11%	-1%
37	15	31	40	14.83	0	0	47	10%	-9%
38	14	4	20	16.31	28	25	42	10%	0%
39	13	6	24	17.98	23	33	41	10%	2%
40	12	13	16	20.23	27	22	44	13%	23%
41	11	6	10	23.45	39	31	45	16%	27%
42	10	1	4	26.73	36	38	45	14%	-12%
43	9	5	33	31.38	34	0	46	17%	24%
44	8	2	13	36.76	35	40	48	17%	-1%
45	7	1	6	46.31	42	41	48	26%	52%
46	6	5	7	57.75	43	32	49	25%	-5%
47	5	9	31	72.19	0	37	50	25%	1%
48	4	1	2	87.86	45	44	49	22%	-13%
49	3	1	5	115.68	48	46	50	32%	46%
50	2	1	9	150.00	49	47	0	30%	-6%

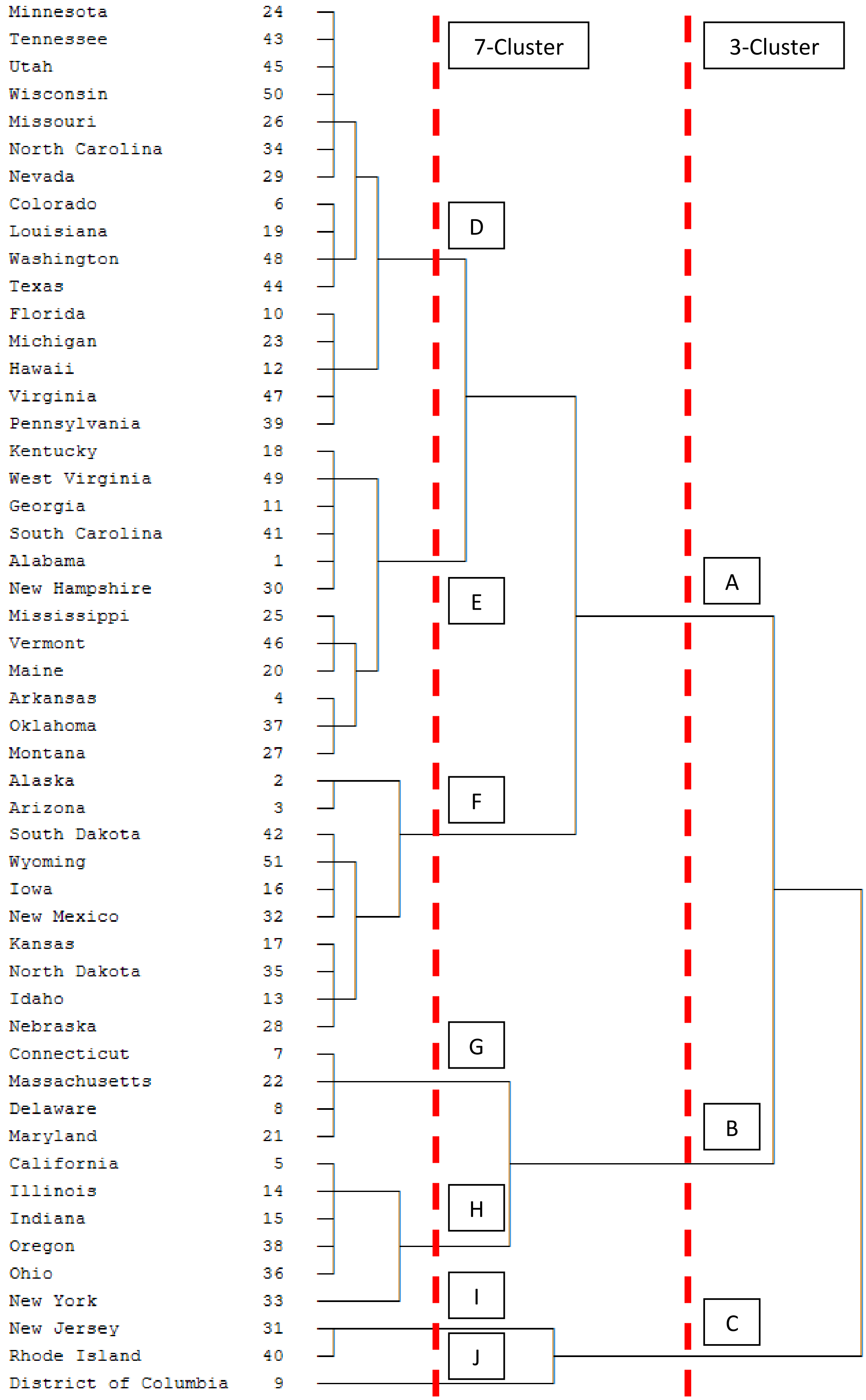


FIGURE 3 Dendrogram Tree with 3-Group and 7-Group Results

5.0 RESULTS & DISCUSSION

5.1 Describing the Four Urbanity Clusters

The final classification scheme consists of four clusters. Each cluster represents the different patterns of density and distribution of population across central cities, small towns, suburbs, and rural areas. Table 6 lists the states and their respective cluster (branches from Figure 3), while Table 7 details the population characteristics of each cluster. Population characteristics are used to label each cluster and both tables are ordered from most rural to most urban, shown in Table 7, as: Low Density Rural-Suburban, Low Density Balanced, Medium Density Suburban, and High Density Suburban-Urban. Figure 4 visually shows the states and their respective clusters.

Looking at the differences between all four clusters of Table 7, the two more rural clusters can be described as the states that have a higher percentage of rural population and the two more urban clusters can be described as the states that have a lower percentage of rural population (or in other words, higher percentage of urban population). Rural states also tend to have a relatively larger portion of the population living in small towns, while urban states tend to have a relatively larger portion of the population living in suburb areas. Three out of the four classifications have approximately a third of the population living in central city locations. In general, the more rural states can be described as having lower population densities than the more urban states.

The two more rural clusters, Low Density Rural-Suburb (LDR-B) and Low Density Balanced (LDB), also exhibit key differences from each other. The LDB cluster has a relatively much larger portion of the population living in central cities and small towns. The density of these cities and towns is also much higher than the LDR-B cluster counterparts. However, the LDR-B cluster has a higher density and higher percentage of population living in suburbs and rural areas. Among all four classification clusters, the rural group has the highest portion of population living in rural areas.

The two more urban clusters, Medium Density Suburbs (MDS) and High Density Suburb-Urban (HDS-U), also exhibit key differences from each other. The MDS cluster has relatively more people living in small towns and rural areas. The overall density of places in MDS is also lower than the HDS-U cluster counterparts. Among all four classification clusters, the HDS-U group has the highest density and portion of population living in central cities.

TABLE 6 Classification Clusters showing the Most Similar States

Cluster	States
Branch E	Alabama, Arkansas, Georgia, Kentucky, Maine, Mississippi, Montana, New Hampshire, Oklahoma, South Carolina, Vermont, West Virginia
Branch F	Alaska, Arizona, Idaho, Iowa, Kansas, Nebraska, New Mexico, North Dakota, South Dakota, Wyoming
Branch D	Colorado, Florida, Hawaii, Louisiana, Michigan, Minnesota, Missouri, Nevada, North Carolina, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, Wisconsin
Branch G, H, I, J	California, D.C., Connecticut, Delaware, Illinois, Indiana, Maryland, Massachusetts, New Jersey, New York, Ohio, Oregon, Rhode Island

TABLE 7 Population and Density by Clusters for Central Cities, Small Towns, Suburbs, and Rural Areas

Descriptive	Central City		Small Towns		Suburbs		Rural	
	% Pop. Living in	Density	% Pop. Living in	Density	% Pop. Living in	Density	% Pop. Living in	Density
Low Density Rural-Suburban (Branch E)	17%	1700	15%	760	29%	180	38%	34
Low Density Balanced (Branch F)	31%	2300	27%	1300	14%	50	27%	6
Medium Density Suburban (Branch D)	28%	3000	9%	840	47%	260	16%	30
High Density Suburban-Urban (Branch G, H, I, J)	34%	5400	5%	1200	52%	510	8%	74

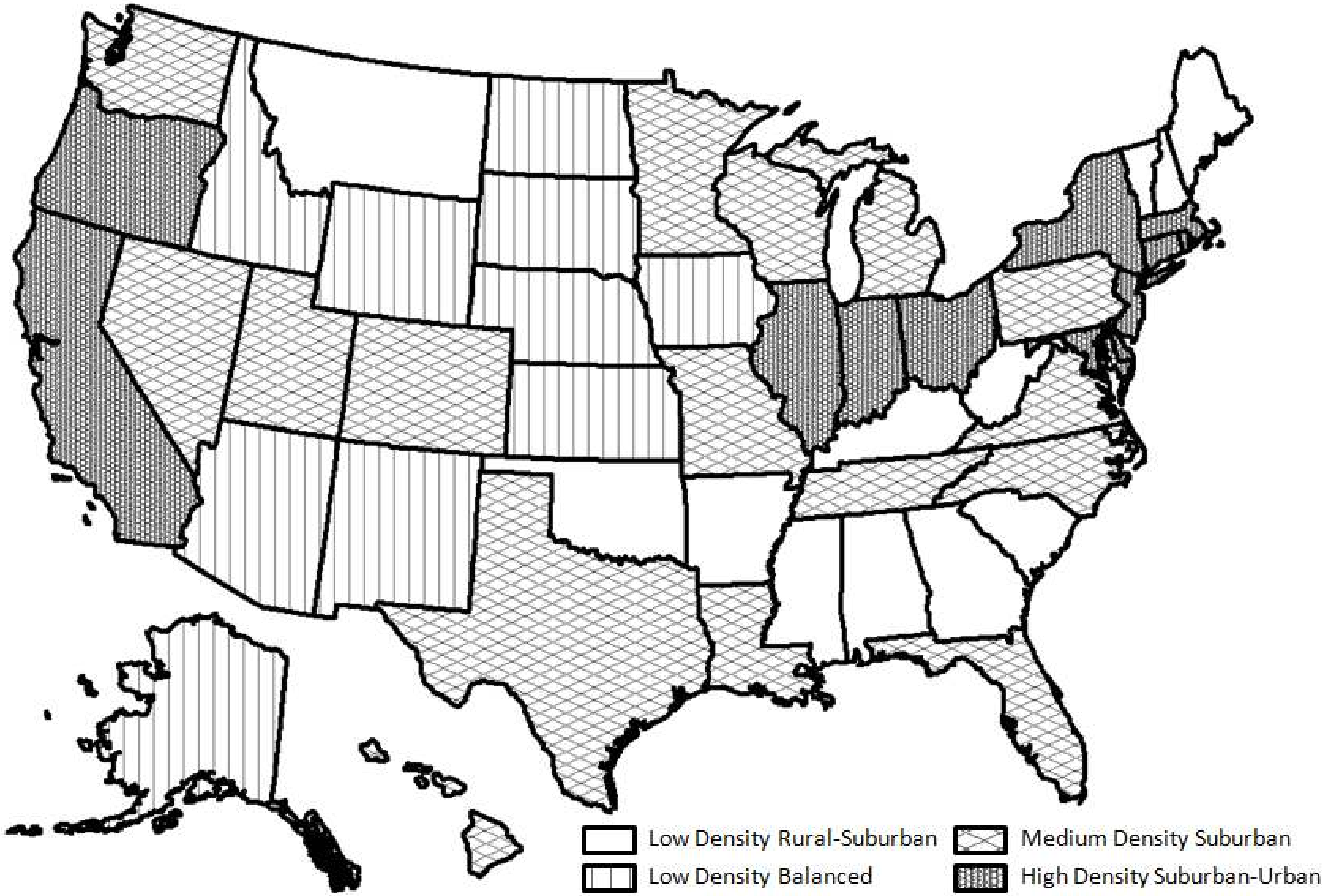


FIGURE 4 Four Classification Clusters Based on Distribution and Density of Population

5.2 Relating the Urbanity Clusters to Transportation Measures

The four urbanity clusters are compared to statewide transportation characteristics to see if these transportation features are related to the underlying population and land patterns. The transportation characteristics compared in this study are vehicle miles traveled (VMT), mode share, and vehicle ownership. VMT is observed as annual vehicle miles travelled per capita, with separate measures for personal automobile and truck travel. Mode share is observed as percentage of work commutes made by automobile. Vehicle ownership is observed as the current number of cars for every thousand people. Table 8 shows the data for these transportation measures and the states with their respective classification clusters. Table 9 shows the mean results for each transportation measure for each cluster.

The transportation features that we choose to look at only represents a small portion of potential transportation issues. However, the purpose of this comparison is to test whether certain aspects of transportation are, as theorized, affected by the states degree of urbanity and whether or not these differences in urbanity are being captured by the clusters developed here. To test this, we employ a statistical test, the analysis of variance (ANOVA), to examine the significance of the means of the transportation measures between the different classification clusters. Table 10 shows our ANOVA results for each of the transportation measures.

ANOVA calculates the resulting F-value, critical F-value (not shown), and the level of significance (p-value). The ANOVA results in Table 10 indicate that our means are statistically significant for all four of our transportation measures between the clusters. This means that the average annual per capita automobile VMT between the LDR-S, LDB, MDS, and HDS-U clusters are statistically different. The same is true for annual per capita truck VMT, automobile mode share, and car ownership.

TABLE 8 Transportation Measures per State by Cluster

Desc.	States	VMT (car) per Capita per Year	VMT (truck) per Capita per Year	Car Mode Share (work commutes)	Cars per 1,000 People
Low Density Rural-Suburb (LDR-S)	Alabama	11,608	1,633	95%	737
	Arkansas	9,735	1,936	93%	694
	Georgia	10,705	1,100	90%	660
	Kentucky	9,736	1,556	92%	699
	Maine	10,353	1,060	89%	751
	Mississippi	12,845	1,987	94%	676
	Montana	10,162	1,650	84%	801
	New Hampshire	9,454	763	90%	742
	Oklahoma	11,165	2,005	92%	718
	South Carolina	10,369	1,183	92%	698
	Vermont	11,287	1,113	85%	752
	West Virginia	10,031	1,323	92%	697
Low Density Balanced (LDB)	Alaska	6,897	656	80%	615
	Arizona	8,778	1,118	88%	616
	Idaho	8,766	1,760	88%	785
	Iowa	8,666	1,826	89%	793
	Kansas	9,401	1,425	91%	766
	Nebraska	9,543	1,440	89%	767
	New Mexico	10,828	2,810	90%	704
	North Dakota	9,794	2,497	88%	849
	South Dakota	9,843	1,455	87%	804
	Wyoming	14,470	3,425	88%	834
Medium Density Suburb (MDS)	Colorado	9,466	594	85%	726
	Florida	10,258	1,019	90%	651
	Hawaii	7,778	324	83%	625
	Louisiana	8,699	1,670	92%	617
	Michigan	9,603	805	92%	686
	Minnesota	10,358	667	87%	745
	Missouri	9,994	1,707	91%	711
	Nevada	7,850	775	89%	657
	North Carolina	10,157	1,273	92%	732
	Pennsylvania	7,783	897	86%	657
	Tennessee	10,241	1,290	93%	729
	Texas	8,903	1,309	91%	612
	Utah	8,137	1,935	88%	651
	Virginia	9,836	796	88%	735
	Washington	7,923	885	85%	743
	Wisconsin	9,473	1,147	89%	737
High Density Suburb-Urban (HDS-U)	California	8,346	717	85%	628
	Connecticut	8,632	555	87%	684
	Delaware	10,011	954	90%	676
	District of Columbia	3,363	65	45%	217
	Illinois	7,375	1,035	83%	631
	Indiana	9,655	1,609	93%	726
	Maryland	9,258	771	85%	670
	Massachusetts	8,072	401	81%	608
	New Jersey	8,130	688	81%	609
	New York	6,494	546	61%	464
	Ohio	8,508	1,095	91%	702
	Oregon	8,249	1,060	85%	728
	Rhode Island	7,805	380	89%	660

TABLE 9 Mean Results for Transportation Measures by Cluster

Descriptive	VMT (car) per Capita per Year	VMT (truck) per Capita per Year	Car Mode Share (work commutes)	Cars per 1,000 People
LDR-S	10,621	1,443	91%	719
LDB	9,698	1,841	88%	753
MDS	9,154	1,068	89%	688
HDS-U	7,992	760	81%	615

TABLE 10 Analysis of Variance Results for Transportation Measures among the Cluster Groups

Transportation Measure		Sum of Squares	df	Mean Square	F-value	Sig. (p-value)
VMT (car) per Capita per Year	Between Groups	45.1E+6	3	15.0E+6	7.58	<0.0004
	Within Groups	93.2E+6	47	1.98E+6		
	Total	138E+6	50			
VMT (truck) per Capita per Year	Between Groups	7.57E+6	3	2.52E+6	9.16	<0.00007
	Within Groups	13.0E+6	47	276E+3		
	Total	20.5E+6	50			
Car Mode Share (work commutes)	Between Groups	65.1E-3	3	21.7E-3	4.09	0.01
	Within Groups	249E-3	47	5.31E-3		
	Total	315E-3	50			
Cars per 1,000 People	Between Groups	122E+3	3	40.7E+3	5.60	<0.003
	Within Groups	342E+3	47	7.27E+3		
	Total	464E+3	50			

6.0 CONCLUSIONS

This work provides a better understanding of how certain transportation characteristics are related to the underlying population and land use patterns. In the initial step, the states are classified by degree of urbanity which is based on the distribution and density of populations. Then, the transportation characteristics of these states are assessed with respect to the classifications by degree of urbanity.

The data analysis uses the US Census Bureau's definitions for various geographic scales to generalize density and population distribution among central cities, small towns, suburbs, and rural areas for each state. Population trends serve as a proxy for the intensity of infrastructure and urban development for each state. The resulting four clusters from our methodological processes describe the degree of urbanity of the states from the highest to lowest percentage of population in rural areas as: Low Density Rural-Suburb, Low Density Balanced, Medium Density Suburb, and High Density Suburb-Urban.

We then test to see if degree of urbanity has an impact on transportation by evaluating how various transportation measures differ between the urbanity classifications. Our analysis shows that the transportation measures we assessed are significantly different among the urbanity classification. States that tend to be more urban and more dense have lower vehicle miles traveled (for both automobiles and freight trucks), lower automobile mode shares for work commutes, and lower automobile ownership rates.

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CHAPTER 2: QUANTIFYING THE ECONOMIC DOMAIN OF TRANSPORTATION SUSTAINABILITY

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ABSTRACT:

The lens of sustainability refocuses our perception of transportation and allows us to look beyond the accustomed role of providing vehicular mobility to the broader impacts that transportation has on the environment, society, and economy. As the understanding of transportation's function evolves beyond throughput and capacity, sustainability can be used as an organizing principle for transportation planning to promote livable communities. To fully understand and integrate the ideas of sustainability with transportation, the proper metrics and performance measures need to be developed and adopted. This paper demonstrates how the theoretical concepts and definitions of transportation sustainability can be transformed into a practical metric for assessing the performance of the United States' transportation system in terms of sustainability. The focus of this paper is on characterizing and measuring the economic aspect of sustainability as it is related to transportation. The analysis is carried out for surface transportation at the state-wide level, and takes into consideration the degree of urbanization of states. The final results describe the relationship between urbanity, mode share, and the economic aspects of transportation sustainability. Based on this assessment, the best performing states in terms of the economic aspects of transportation sustainability are more urban and have lower automobile mode shares.

1.0 INTRODUCTION & MOTIVATION

Transportation plays a pivotal role in some of global society's critical issues including greenhouse-gas emissions, diminishing natural resources, energy security, and the current economic downturn. Transportation is also associated with more domestic policy issues such as pollution and air quality, obesity and health, sprawl and development patterns, and social equity. To address some of these environmental and socio-economic concerns, in 2009, the federal government formed the HUD-DOT-EPA Interagency Partnership, which coordinates housing, transportation, and environmental protection to promote sustainable development and livable communities. While this partnership demonstrates an immediate response, another more longstanding plan is the National Cooperative Highway Research Program's (NCHRP) multi-year study on 'long-range strategic issues facing the transportation industry.'(*1*) One key component of the NCHRP study is to assess how sustainability can be used as an organizing principle for transportation agencies.

Sustainability is a broad and variously defined concept whose principles can be incorporated into a framework that offers a holistic approach for transportation. However, successful integration of sustainability with transportation requires a "paradigm shift," (*2, 3*) which ultimately means expanding the understanding of the complex and recursive interactions between transportation and the environment, society, and the economy. New federal initiatives and the ongoing efforts to develop innovative methods to quantify a broader range of transportation impacts suggest that this paradigm shift is under way. Conventional transportation metrics have primarily focused on vehicular mobility resulting in transportation systems being planned for throughput and capacity without sufficient regard for other impacts. (*3, 4*) New metrics, with sustainability as a theme, will assist policymakers in developing more comprehensive transportation plans that enhance environmental conservation, social livability, and economic vitality. (*4, 5*)

This paper reviews the metric we developed for transportation sustainability, with emphasis on the details of how we defined, characterized, and assessed the economic domain of transportation sustainability. Existing metrics and definitions for transportation sustainability were used to frame the overall metric. We chose to further develop the economic domain because the background of the economic components is not well explored in existing literature on transportation sustainability. The literature review explores pertinent literature on transportation that relates economics with sustainability. This helped to form a set of indicators for the economic domain of transportation sustainability that were then used to assess the performance of individual states. Additional analysis was also conducted to distinguish between rural and urban states to provide relevant comparisons and to assess the role of urbanity in transportation sustainability.

2.0 FRAMEWORK FOR TRANSPORTATION SUSTAINABILITY

Defining transportation sustainability is the first critical step in developing a tool to measure it. (*4*) Definitions of transportation sustainability are rooted in the broader concept of sustainability, which focuses on the interaction between the environmental, social, and economic domains. (*2, 5*) Additional concepts that expand the understanding of sustainability include *Haughton's equity principles* and the *green/brown agendas*. (*4*) Haughton's principles consider how our actions may affect intergenerational, intragenerational, geographical, procedural, and interspecies equity. (*6*) The green agenda is concerned with long-term and indirect global issues such as resource consumption and climate change, while the brown agenda focuses on short-term and direct local issues such as clean air and water. (*7*) These domains and concepts underscore the breadth and richness of sustainability, how it spans numerous academic disciplines, and how it can be considered at various geographic and temporal scales.

Establishing a definition provides the foundation for creating a standardized framework that identifies and organizes indicators. (*4*) Many organizations favor the Canadian Centre for

Sustainable Transport's definition (CST) because it is comprehensive and clearly considers the three major domains. (*4, 5, 8*) This definition states that a sustainable transportation system: (*8*)

- Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.
- Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.
- Limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

This definition outlines the broad goals of transportation sustainability and captures the essence of what we ultimately want to achieve. (*4, 5*) These goals can be used to identify objectives to reach broad outcomes. (*4, 5*) The goals and objectives, derived from the definition, can be organized into performance indices and metrics to provide a starting point for identifying the major components of transportation sustainability. (*4*)

Building on this background, we developed a rating system to assess the performance of the states in terms of transportation sustainability. This rating system, or metric, was built using a hierarchical composite index framework, (*4, 9*) illustrated in Figure 1. Each level of this hierarchical structure demonstrates how the broadest concepts are translated into subsequent components which helps simplify measuring and understanding the multi-dimensional nature of sustainability. (*4, 9*) The domains serve as thematic categories; the elements represent goals and constitute the definition of transportation sustainability; the indicators identify the key ideas of each element; and the variables represent the datasets.

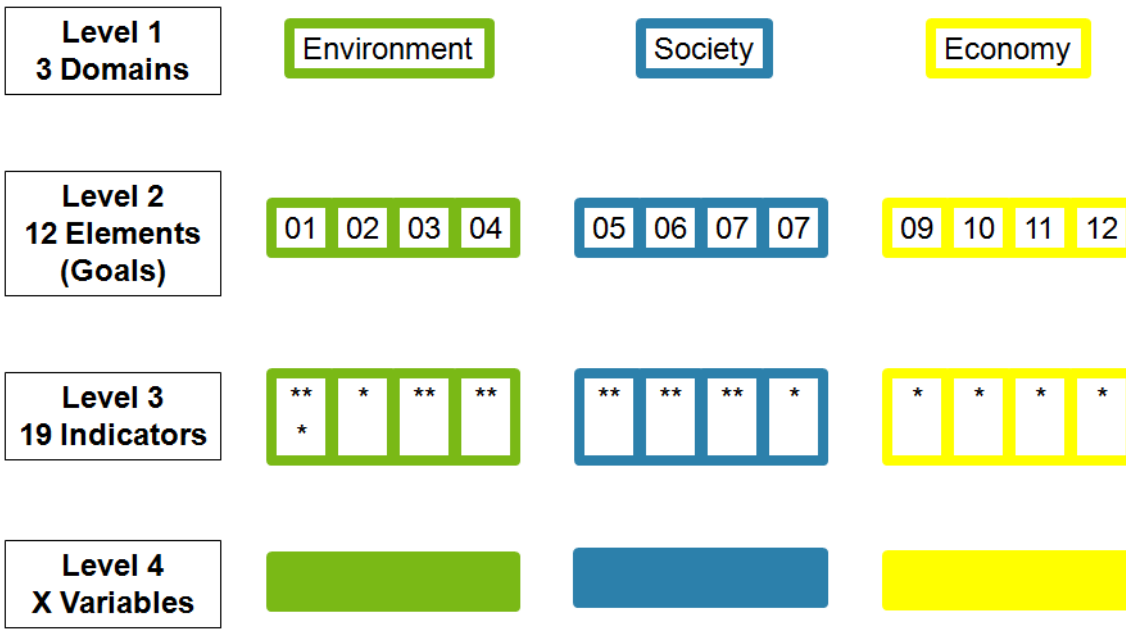


FIGURE 1 Structure of Hierarchical Composite Index for Assessing Transportation Sustainability

The number and types of variables are unspecified because this metric was developed with a flexible framework. (*4, 9*) This flexibility strengthens the overall usability of our metric because it can be adopted by policymakers to measure transportation at various geographic scales. For example, broad measuring variables can be used on a national scale while more narrow specific variables can be used at a local scale. Another advantage of this flexibility is that our framework can be applied to different types of metrics for transportation sustainability. For example, some existing metrics identify broad outcomes and goals; some identify specific objectives and tasks; and some do both.

When used to assess the broad outcomes of sustainability, the variables do not necessarily represent specific objectives or tasks. Furthermore, an exhaustive set of variables is not necessary because it is common to use one or two key variables that best represent the indicators. For example, bird populations are commonly used as an indicator to represent overall wildlife diversity. (*10*) Variables are chosen to best represent the overall goal for each element. Data availability should not limit the determination of variables. (4) Instead, the variables should be chosen with a sound theoretical background, and a lack of data highlights areas where insufficient data exists. (*5*)

The elements, which represent the broad goals of transportation sustainability identified in CST's definition, and indicators for the structure presented in Figure 1 are expanded in Table 1. Some of these elements are directly adopted from CST's definition, such as element 1, "Minimize consumption of renewable and non-renewable resources," and element 9, "Transportation is affordable for individuals." The remaining elements were constructed by referencing existing definitions and literature for transportation sustainability while considering equity issues. This paper focuses on the economic domain, and how the economic elements were developed based on the body of literature pertaining to the economic aspects of transportation sustainability.

TABLE 1 Composite Index for Transportation Sustainability

Domain	*e*	Element	*i*	Indicator
Environmental	1	Minimize consumption of renewable & non-renewable resources for transportation	1	Energy Consumption
			2	Infrastructure Materials Consumption
			3	Vehicle Materials Consumption
	2	Transportation and placemaking system is designed to maximize land use efficiency	4	Land Use
	3	Minimize transportation and place-making system's impact on ecological systems	5	Ecological Systems
			6	Greenhouse Gas Emissions
	4	Limit transportation related wastes & pollution	7	Pollution
			8	Waste Production
Social	5	Transportation system meets access needs in a way that is consistent with human health & safety	9	Health
			10	Traffic Safety
	6	Planning and management of the transportation system incorporates different levels of government & community input	11	Government Interoperability
			12	Community Involvement
	7	Transportation and placemaking system promotes social interaction & social equity	13	Social Interaction
			14	Social Equity
	8	Transportation and placemaking system meets basic access needs of all individuals	15	Accessibility
Economic	9	Transportation is affordable for individuals	16	Affordability
	10	Transportation system provides efficient movement of people & goods for economic activity	17	Mobility
	11	Transportation finance is equitable and locally self-sufficient	18	Finance Equity
	12	Transportation system does not contribute to economic vulnerability of society	19	Economic Vulnerability

3.0 ECONOMIC LITERATURE REVIEW

Based on CST's definition, existing sustainability literature, and considerations for factors such as Haughton's equity issues, four elements were developed to describe the economic domain of transportation sustainability. Existing literature illustrates how transportation economics and transportation finance currently interfaces with aspects of transportation sustainability. Transportation economics and finance are two discrete and well-developed areas of study, but only works that are relevant to sustainability are included in this review. This literature review was conducted to gain a better understanding of the nature of the economic elements of transportation sustainability.

3.1 Transportation Equity and Efficiency

Social equity and efficient systems are implicit in the broader definition of sustainability, and these two underlying principles link the economic domain with the environmental and social domains of sustainability. Transportation equity is about fairness for people in society differentiated by income or class, and how their needs are considered in policy. (*11, 12*) Transportation efficiency is about the economic value and impact of transportation systems relative to the costs imposed on society and the environment. (*11, 12*) Equity and efficiency are important for sustainability overall, but they also have specific meaning for the economic domain.

Transportation equity is explained in many forms and describes how different groups of people should be treated. The two most common forms are summarized as follows: (*11*)

- Horizontal equity is concerned with the equal distribution of impacts, both costs and benefits, where no group, unless specifically justified, is favored by policy.
- Vertical equity is concerned with the distribution of impacts, both costs and benefits, to favor economically and socially disadvantaged groups.

These forms of equity interact with transportation economic issues when we are considering economic development, user costs and benefits, and external impacts. For example, decisions about the location of transportation investments benefit the local economy of one area over another. (*11*)

Transportation efficiency is achieved when the marginal value or benefits from transportation equal or are greater than the marginal price or costs of transportation. (*12*) Value is traditionally viewed as the contributions to gross domestic product (GDP), while the price is traditionally viewed as the monetary cost of infrastructure. (*11, 12*) However, Litman reports that even economists are re-evaluating what should be considered as benefits and costs, and have recommended that GDP be supplemented with additional measures that account for externalities. (*11*) To properly assess transportation efficiency, the costs of transportation must include both monetary costs and external costs that are considered within the social and environmental domains. (*11, 12*)

3.2 Economic Growth and External Costs

Transportation investments are often justified on the basis of advancing economic growth, (*2, 11, 13*) but equity and efficiency issues need to be considered for determining the benefits and costs of transportation infrastructure. This section explicitly evaluates the relationship between transportation activity trends and overall economic growth, not the economic value generated from transportation-related industries. Understanding the way in which economic activity is currently assessed is crucial for developing the proper indicators for transportation sustainability.

Transportation infrastructure does not necessarily lead to economic growth, (*2*) but many different types of transportation systems are economically viable and supportive of their respective local economies. (*4*) Despite a lack of evidence for a universal and definitive link between economic activity and transportation activity, the two are often viewed as being positively related. (*2, 14*) This seems to make intuitive sense, but it is being increasingly recognized that perhaps more important than the volume of transportation activity is how the movement of people and goods occurs. Past researchers have used mobility, measured in vehicles miles traveled (VMT), to represent transportation activity and suggested that GDP growth is dependent on VMT growth. (*14*) Some counter-arguments suggest this correlation exists because market distortions have created conditions for automobile dependency. (*16*) Studies have also shown that the marginal economic contribution from increasing mobility is declining. (*16*) In other words, there is a diminishing return on economic growth after a certain level of vehicular mobility is exceeded. Accessibility has been suggested as a better indicator for transportation activity than mobility, (*16*) because economic activity should reflect peoples' ability to access service and goods instead of vehicles' ability to move people and goods. Unfortunately, measuring accessibility is difficult as there are no developed systems for doing this. (*16*)

External costs must be included in economic analysis to better understand the true overall costs of transportation. (*12, 16*) The economic efficiency of the transportation system is inaccurate without factoring in external costs. (*12, 16*) Furthermore, when external costs are ignored, there is no account of who bears these costs, resulting in transportation equity issues. In practice, the traditional accountancy framework looks only at monetary costs and excludes external costs from transportation analysis. (*3, 12, 16*) Even when considered, various studies show conflicting results on how external costs such as pollution and fatalities should be calculated. (*12*) Based on differing methodologies and the nature of these externalities, it is difficult to place a monetary value on things such as environmental degradation or the loss of human life. (*3*) External costs of transportation have typically been ignored, but metrics for transportation sustainability can account for these externalities by explicitly considering them in the environmental or social domains without having to monetize them. (*9*)

3.3 Transportation Finance and User Costs

This section primarily focuses on how equity and efficiency principles are related to users' out-of-pocket costs and transportation finance. Transportation finance is concerned with the funding and distribution of money for building, maintaining, and operating our transportation systems.

Transportation is the second largest expense for households and is related to housing locations. For example, the Center for Housing Policy reports that many families finding more affordable housing in exurban locations end up spending some, if not most, of these savings on transportation. (*15*) This predicament has encouraged the use of location-efficient mortgages to allow people to qualify for loans to purchase more expensive housing in central city locations where transportation costs are often lower. Transportation user costs are an equity issue because people do not always have viable choices in terms of transportation options. (*11*) Transportation costs are often also a greater burden for lower income households. (*11, 15*) If the cost of car ownership is equal, the lower income household must spend a greater percentage of its budget on transportation. In this regard, transportation costs are regressive, meaning they impact households of different wealth levels to different extents. (*11*) However, locations where more modes of travel are available generally exhibit lower transportation costs overall, (*11, 15*) and households with no cars do not follow the regressive trend found in automobile-owning households. (*11*) Continuing on the issue of equity, automobile ownership has benefited lower income groups in some situations, but automobile-oriented solutions appear to not be suitable in every setting. (*11*) The equity issues related to user costs are illustrated through the financial burden that transportation places on households. This financial burden is dependent on the availability of affordable housing and transportation options.

Transportation is funded through many sources, some from automobile user costs, but the collection and distribution of those funds can conflict with equity and efficiency principles, especially when subsidies are considered. Automobile ownership contributes to the overall financing of transportation systems through items such as gasoline taxes and highway tolls, but these user fees only pay for about two-thirds of the total monetary cost of our transportation system. (*11, 12, 16*) The remaining one-third must come from other sources, indicating the extent to which transportation is subsidized. A subsidy is defined as, "a transfer of economic resources by the government to the buyer or seller of a good or service that has the effect of reducing the price paid, increasing the price received, or reducing the cost of production of the good or service." (*12*) In this case, government funds from another source reduce the perceived cost of transportation by a third. However, subsidies are not always monetary transfers. Ignoring external costs is another form of subsidy. (*12*) Without including external costs, the degree of subsidization is understated. (*12*) When external costs are considered, users are paying even less than two-thirds of the cost for transportation. (*11, 12*)

An example when equity is affected through subsidies is during the allocation of public funding from the federal government to states, or from states to their counties and towns. Two comparable jurisdictions do not always receive comparable per capita funding, which affects horizontal equity. (*11*) This unequal distribution of funds ultimately means that the recipients of transportation benefits are not necessarily the same people who paid for it. (*11*) To minimize subsidies and unequal distribution, pricing reforms have been suggested so that users pay the full cost of transportation, which includes monetary and external costs, through higher fuel tax or road pricing. (*11, 12*) These strategies are criticized for being regressive because they increase out-of-pocket costs which burdens lower-income families more, but the equity of these strategies is dependent on how prices are structured, what alternatives are available, and how revenues are used. (*11*) For example, in some cases, congestion pricing has benefitted lower income commuters by improving transit service, and everyone overall by reducing traffic and its associated external impacts. (*11*)

Without paying for the full monetary and external cost of transportation, subsidies mask the true cost of transportation for users, thereby creating market distortions that can lead to economic inefficiency. (*12, 16*) Market distortions occur when consumer options are limited, prices do not reflect costs, and economic inequity exists. (*16*) Subsidies can cause market distortions. For example, a number of observers point out that subsidies mask the inefficiency of the road system, which encourages additional vehicle travel with decreasing marginal economic value while external costs continue to grow. (*11, 12, 14*) Subsidies exist for both personal vehicles and public transit, but to properly assess the efficiency of these systems we must compare the benefits, external costs, and monetary subsidies. By masking the full monetary and external costs of transportation, subsidies can cause an inefficient system to appear efficient which perpetuates a cycle of inefficiency.

3.4 Discussion

Although presented in a linear manner above, the economic aspects of transportation are inter-related through the overarching themes of equity and efficiency. These abstract concepts become more tangible as they are manifest through subsidies and the resulting market distortions that ultimately impact economic growth, external costs, transportation finance, and user costs. Overall economic growth and external costs represent transportation ideas that are less visible to individuals. In contrast, transportation finance and user costs represent impacts that are more visible to individuals because it directly affects disposable income.

Although transportation activity and economic growth are related, there is no evidence to associate growth with any specific type of transportation system. Most transportation policy and planning decisions inevitably focus on tradeoffs between social equity and economic efficiency. The traditional strategy has focused solely on improving economic efficiency, assuming that an efficient solution leads to equitable outcomes. (*12*) However, past practices to improve efficiency did not consider environmental or social externalities. (*11, 12*) Ignoring these externalities essentially subsidizes the transportation system which causes market distortions. Subsidies mask these distortions, so what is perceived as improving efficiency may in fact perpetuate a cycle of inefficiency. These are cumulative and synergistic effects which can cause significant harm to our society and economy. (*11*) The emerging view for transportation policy and planning is that social and environmental objectives deserve greater attention alongside economic goals and objectives. (*13*)

External costs are discussed in the literature, but were not explicitly included in our metric for the economic domain of transportation sustainability. Contemporary transportation economics is beginning to account for externalities by attempting to monetize the social and environmental impacts, but these externalities are directly assessed in our metric for transportation sustainability. The metric we developed accounts for environmental degradation and social inequity from transportation in the respective environmental and social domains. This allows the economic domain to focus on the purely economic considerations pertinent to transportation sustainability.

Mode choice is prominent in CST's definition of transportation sustainability and appears throughout the literature related to user costs and market distortions. However, mode choice was also not directly included as a broad goal or element in our metric for the economic domain. Litman discusses the importance of distinguishing between goals and objectives, which was used to support this decision. (*5*) Mode choice represents more of an objective to reach various goals in the social and economic domains, rather than an outright goal in and of itself. External costs and mode choice are factored in throughout the overall metric, where they may be more suitable than in the economic domain.

This literature review provides a foundation for expanding CST's definition of the economic domain, and demonstrates where economics interact with the other domains of transportation sustainability. Equity provides a way to link economic and social impacts, while efficiency (which includes external environmental costs) provides a way to link economic and environmental impacts. These connections demonstrate the inter-related nature of sustainability. Transportation metrics developed with sustainability as a theme include considerations for the environment, society, and economy.

4.0 VARIABLES FOR ASSESSING THE ECONOMIC DOMAIN OF TRANSPORTATION SUSTAINABILITY

This section describes the four elements and their respective variables composing the economic domain of transportation sustainability. These elements, derived from CST's definition and our literature review, incorporate broader economic aspects, rather than just growth, and are listed as follows:

- Transportation is Affordable for Individuals
- Transportation Provides Efficient Movement of People & Goods for Economic Activity
- Transportation is Financed in an Equitable Manner
- Transportation is Resilient to Economic Fluctuations

To assess these elements, as discussed in previous sections, it is acceptable to use one or two key variables that best represent the broad outcomes and goals of each element at the state-wide geographic scale. The general methodology for each variable is provided, and sources of data are identified.

4.1 Transportation is Affordable for Individuals

This goal represents the direct out-of-pocket user costs of transportation and highlights the interaction between the economic and social domains. Affordability is an economic consideration that is closely associated with accessibility, a social good. (*9*) It is an important goal for transportation sustainability because it captures equity issues, such as the regressive nature of transportation costs that create more of a financial burden for lower income households.

This goal represents what portion of income is spent on transportation to provide access to goods and services. The *percentage of median household income spent on transportation*, which includes automobile and transit costs, was calculated to represent this goal on the state-wide level. Automobile costs per household were estimated for each state by using national values for the cost of car ownership and car use by miles driven, and state values of car ownership per household and VMT per household. The national costs of car ownership and car use were estimated by the American Automobile Association. (*17*) Car ownership data was extrapolated from the US Census, (*18*) and VMT data came from the Federal Highway Administration (FHWA). (*19*) Household transit costs were estimated using the total sum of transit fare revenue earned dividing by the number of households per state. Transit data was available from the Federal Transit Administration (FTA). (*20*) Our results are comparable to existing studies that use similar methodologies, which found that the typical household spends 20-30% of income on transportation. (*15*)

4.2 Transportation Provides Efficient Movement of People & Goods for Economic Activity

Transportation movement must be efficient to provide the most economic benefits with fewest costs. Total state VMT, which includes personal and truck travel, were compared to GDP for each state in two different ways. Inspired by sustainability indicators established by the Federal Statistical Office of Germany, (*10*) we calculated the *ratio of current level of GDP to VMT* and *ratio of the growth rate of GDP to VMT*. State GDP data was provided from the Bureau of Economic Analysis (BEA), (*21*) and VMT from FHWA. (*19*) Current levels of GDP to VMT are an assessment of the absolute economic productivity relative to the amount of existing vehicle travel per state. Growth rates of GDP to VMT are an assessment of the marginal economic activity from additional vehicle travel. Higher values for both categories indicate a more efficient system, but it is wrong to assume that each unit of travel produces a specific dollar amount. These indicators capture only the general trend of the relationship between economic and transportation activity.

4.3 Transportation is Financed in an Equitable Manner

Transportation finance is complex, and equity issues are involved at many levels, but the variable we selected to represent this element measures the distribution of federal funds to the states. In addition to user costs, revenue for projects can come from taxation or bonding. Taxes affect present-generation equity by having a larger impact on lower income households, or through the unequal redistribution of funding for transportation investments. Bonds, in contrast, infringe on future-generational equity because money is borrowed and interest must be paid, and can be described as essentially borrowing money from future generations. Furthermore, transportation finance should be as locally self-sufficient as possible because if a jurisdiction is dependent on financial assistance for maintenance, they are more vulnerable when those funds are no longer available. Although equity issues for transportation funding exist at many levels, we assessed this goal by calculating *what percent of a state's total transportation expenditure is from federal funding*. Many transportation projects span multiple years, and some states receive more funding one year than the next, (*11*) so it is more appropriate to look at a span of years. Unfortunately, quality data was not consistently available spanning any range of years so we only used data for a single year. The two major sources of federal funding for transportation we looked at were from FHWA and FTA, (*19, 20*) and state's total transportation expenditure from the Bureau of Transportation Statistics. (*22*)

4.4 Transportation is Resilient to Economic Fluctuations

This final goal provides a broader perspective by assessing the resiliency of transportation systems to economic fluctuations. The previous elements described the costs of transportation from an internal perspective: cost to households, efficient growth, and equity of funding. However, external factors outside of the transportation realm that indirectly affect the economy must be considered. One aspect of this issue is the global competition for resources needed to build, maintain, and operate transportation systems. Of particular concern is fuel, illustrated by the impact that the price volatility of crude oil in recent years has had on the economy. (*9*) A resilient transportation system is one that can endure sudden shocks, such as a drastic increase in price for petroleum. (*9*) Furthermore, since fuel is mostly imported, expenditure on fuel represents money that leaves our economy. Therefore, for this goal we calculate the *percentage of wealth (GDP) spent on fuel* to measure the resiliency of our economy and transportation system against the rising cost of and dependency on limited resources. Total expenditure on fuel was estimated using the price per barrel and the number of barrels of crude oil consumed by the transportation sector for each state. Crude oil information was supplied by the Energy Information Administration, (*23*) and GDP from BEA. This goal links the economic domain to the environmental domain through concerns for resource consumption.

5.0 RESULTS AND ANALYSIS

After the metric is populated with the datasets for the economic domain, a score is produced for each state. This process used aggregation and normalization techniques as part of the computational methodology for our hierarchical composite index framework. (*9*) Aggregation of the components produces a single final score which incorporates a broad spectrum of information and types of data. A normalization process to create dimensionless relative values is necessary prior to aggregation because the datasets representing the variables come in different units. (*9*) The datasets are normalized using linear scaling transformation to rebase the values on a scale of 1 to 100. These techniques make comparisons between small and large states more reasonable, and allow indicators measured in different units to be combined. This methodology also allows for individual weighting of the indicators if desired, but it is common for composite indices to utilize an equal weighting scheme. (*9*)

To provide better comparisons, the FHWA suggests that states be categorized around certain characteristic such as infrastructure, populations, or vehicle miles traveled. (*19*) State transportation performance can vary greatly because of these differences. (*19*) For our analysis, we use a methodology that identifies the degree of urbanization for each state as a proxy to indicate the local intensity of infrastructure and physical conditions. (*24*) This methodology distinguishes between rural and urban states by calculating the percentage distribution and density of the population in central cities, small urban clusters, and metropolitan statistical areas. Central cities are the core of metropolitan statistical areas, and must have a minimum population of 50,000 with density greater than 1,000 people per square mile. Small urban clusters must meet these density requirements and have a total population between 10,000 and 50,000 people. This system was used to identify peer states in order to assess if urbanity is a factor when evaluating economic sustainability in the transportation context.

The data collected and assembled for the economic domain of transportation sustainability is summarized in Table 2 for each state, grouped into four distinct categories. These four groups, rural, rural-urban, urban-rural, and urban, reflect varying degrees of urbanity. After the variables are normalized and aggregated, a final composite score represents each state's overall and relative performance for the economic domain. This value is included in Table 2, and is graphically portrayed in Figure 2 without distinctions for urbanity. Figure 2 highlights the worst and best performing states in red and dark green respectively.

A strictly geographic analysis, interpreted from Figure 2, suggests that the mid-west and deep-south are the worst performing regions. These regions indicate states where households on average spend a larger portion of income on transportation, the least amount of economic growth is related to transportation activity, a larger share of state's transportation expenditures come from federal funds, and a larger portion of state's wealth is spent on fuel. In contrast, the best performing states are located in the north-east and on the west-coast. Regional differences in policy and historic development patterns could possibly explain these geographic distributions in transportation sustainability. (*9*)

Table 2 considers the degree of urbanity and details the average performance of rural, rural-urban, urban-rural, and urban states. The overall composite score for urban states is significantly greater, almost double, than that of rural states. Reviewing the averages across all four levels of urbanity, the overall score consistently increases across the rural to urban gradient. These results suggest that urbanization, and thus land form, have a significant impact on the economic domain of transportation sustainability.

The composite score for the economic domain, the degree of urbanity, and the automobile mode share for each state are analyzed together in Figure 3. The initial results for all states exhibit a weak negative correlation between automobile mode share and the score for the economic domain of transportation sustainability. This relationship is much stronger when the level of urbanity is considered. Figure 3 shows, with an exception for the rural states, a distinct relationship exists attributing a lower score with higher automobile mode shares and a higher score with lower automobile mode shares. Furthermore, an analysis of variance (ANOVA) was conducted to test if urbanity was a significant factor in contributing to the differences between the states. The results of this analysis are included in Figure 3. Comparing the mean composite scores for each level of urbanity shows that level of urbanity is statistically significant in explaining this measure of sustainability. These results suggest that the best performing states, for the economic domain, are more urban. In addition, states of any level of urbanity with lower car mode share generally performed better.

Our findings seem to be consistent with the idea in the literature that high automobile use may undermine the economic domain of transportation sustainability in several ways. Based on the literature the explanation for this is likely due to ineffective accounting of external costs and subsidies leading to market distortions, as states with high automobile shares coincide with a low composite score. This suggests that transportation is less affordable for individuals and less efficient for the overall economy in these states.

TABLE 2 Economic Domain Data and Composite Score for the States Grouped by Urbanity

	States	Variables					Composite Score
		% of Household Income Spent on Transportation	Absolute GDP per VMT	Change in GDP per VMT Growth Rate	% of Transportation Expenditure from Federal Funding	% of GDP spent on fuel	
RURAL STATES	Alaska	20.59%	8.71	0.49	25.25%	5.95%	38.62
	Arizona	28.48%	3.91	1.47	15.10%	2.63%	53.49
	Arkansas	33.71%	2.87	1.46	34.92%	3.66%	27.06
	Idaho	31.03%	3.30	2.59	30.98%	3.03%	38.24
	Iowa	28.72%	4.16	2.24	19.14%	2.86%	38.24
	Kansas	29.88%	3.89	1.97	17.61%	2.68%	50.68
	Kentucky	34.99%	3.16	1.88	20.80%	3.88%	37.14
	Maine	29.09%	3.19	1.43	21.54%	3.22%	44.53
	Mississippi	41.06%	1.63	0.38	42.31%	4.84%	5.96
	Montana	35.35%	3.03	1.63	40.78%	4.23%	18.54
	Nebraska	29.42%	4.13	1.77	22.13%	2.62%	47.52
	New Mexico	33.56%	2.80	1.40	18.32%	3.32%	41.84
	North Dakota	30.89%	3.64	3.24	33.20%	3.79%	34.58
	Oklahoma	33.85%	2.87	1.72	25.43%	3.84%	34.13
	South Dakota	32.78%	3.91	3.37	31.12%	3.01%	38.22
	Vermont	30.55%	3.20	1.98	31.89%	2.73%	38.08
	West Virginia	31.62%	2.81	0.92	28.88%	3.32%	34.35
	Wyoming	35.50%	3.37	1.28	29.49%	4.20%	26.79
	Rural Average	**31.73%**	**3.59**	**1.73**	**27.16%**	**3.54%**	**36.00**
RURAL-URBAN STATES	Alabama	35.34%	2.68	1.79	32.34%	3.64%	28.10
	Colorado	23.38%	4.84	1.48	18.28%	2.24%	58.25
	Georgia	30.34%	3.48	1.56	14.10%	2.90%	51.09
	Indiana	29.89%	3.49	4.65	22.53%	3.13%	49.84
	Louisiana	31.50%	4.57	0.71	27.98%	3.78%	33.44
	Minnesota	24.78%	4.41	1.66	16.75%	2.48%	57.16
	Missouri	30.45%	3.31	1.40	22.49%	3.24%	42.33
	New Hampshire	21.63%	4.30	1.77	22.71%	2.32%	56.45
	North Carolina	32.96%	3.77	1.41	21.30%	2.41%	44.65
	Oregon	26.96%	4.55	6.69	19.02%	2.58%	62.84
	South Carolina	31.97%	2.97	0.94	41.03%	3.62%	23.12
	Tennessee	34.90%	3.44	1.61	26.60%	3.22%	35.12
	Utah	29.03%	3.93	1.41	22.48%	2.87%	45.74
	Washington	23.93%	5.45	3.26	12.86%	2.58%	64.41
	Wisconsin	27.03%	3.92	2.45	16.61%	2.35%	56.86
	Rural-Urban Average	**28.94%**	**3.94**	**2.19**	**22.47%**	**2.89%**	**47.29**
URBAN-RURAL STATES	California	25.49%	5.49	3.18	15.44%	2.27%	62.06
	Florida	29.16%	3.60	0.89	16.37%	2.65%	50.29
	Hawaii	21.24%	6.00	0.74	15.66%	3.71%	55.16
	Illinois	23.94%	5.74	2.57	12.96%	2.07%	65.33
	Michigan	27.88%	3.63	0.31	22.89%	2.52%	45.90
	Nevada	24.32%	5.84	1.71	13.43%	2.41%	61.35
	Ohio	27.06%	4.18	1.60	24.91%	2.71%	47.04
	Pennsylvania	25.90%	4.91	1.92	18.81%	2.26%	56.03
	Texas	29.85%	4.72	1.98	20.21%	2.96%	47.79
	Virginia	24.91%	4.68	2.50	13.35%	2.57%	61.13
	Urban-Rural Average	**25.98%**	**4.88**	**1.74**	**17.40%**	**2.61%**	**55.21**
URBAN STATES	Connecticut	21.14%	6.62	1.89	35.83%	1.48%	51.52
	Delaware	25.46%	6.49	1.67	19.13%	1.51%	59.85
	District of Columbia	16.33%	20.13	3.86	12.40%	0.22%	94.45
	Maryland	21.21%	4.68	1.60	21.16%	2.12%	58.74
	Massachusetts	21.16%	6.39	3.84	16.57%	1.71%	69.84
	New Jersey	21.46%	6.06	1.12	26.21%	2.70%	51.83
	New York	21.10%	8.08	3.14	15.24%	1.16%	72.91
	Rhode Island	23.61%	5.41	1.19	43.49%	1.69%	39.84
	Urban Average	**21.43%**	**7.98**	**2.29**	**23.75%**	**1.58%**	**62.37**

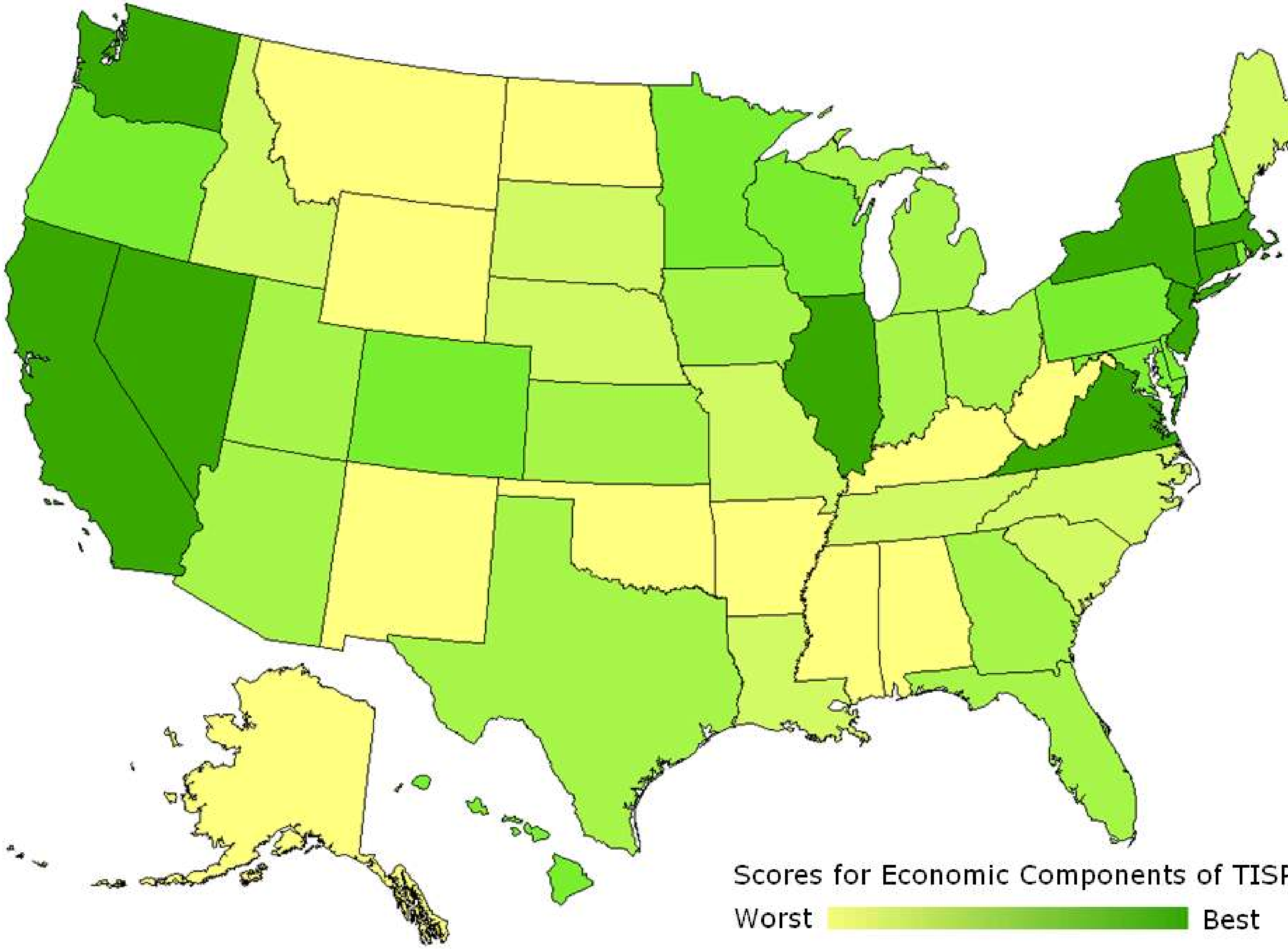
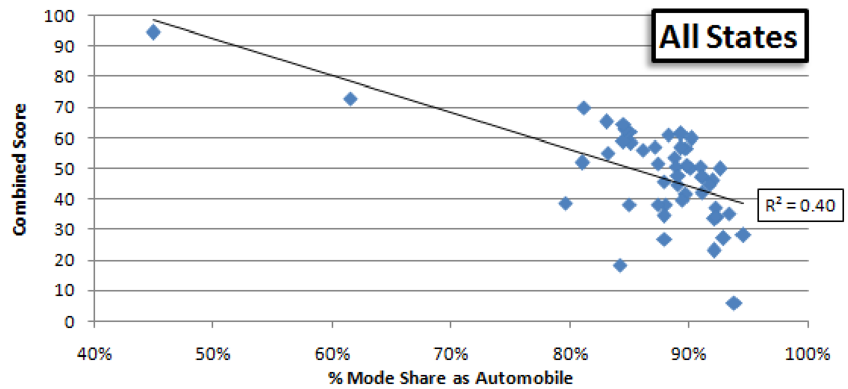
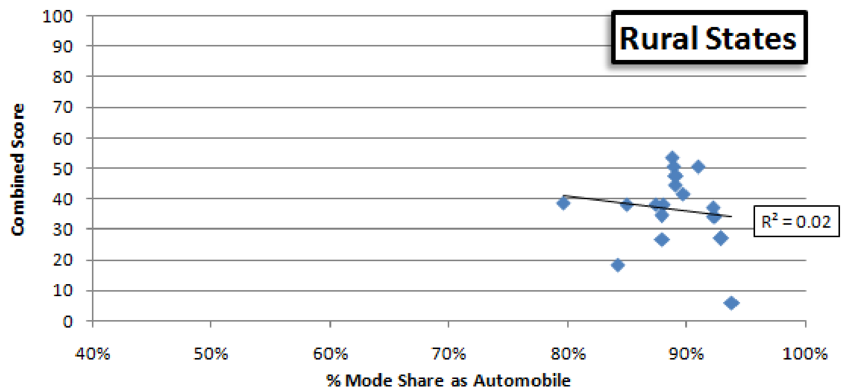
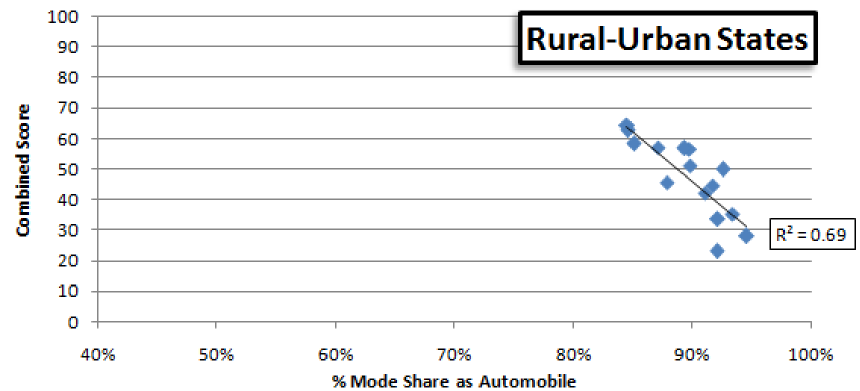


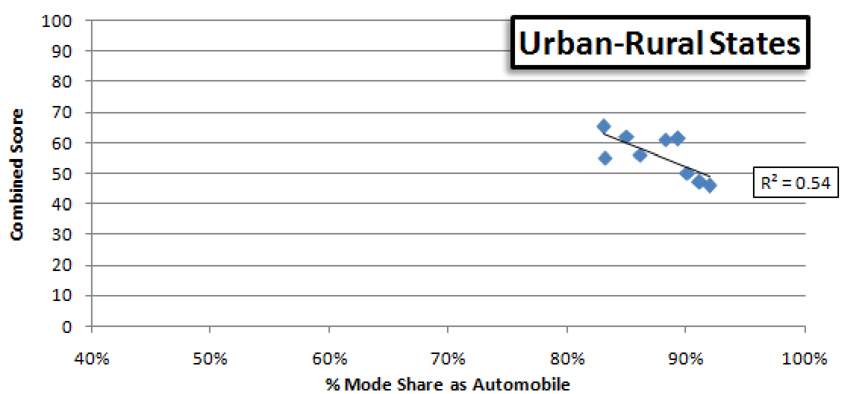
FIGURE 2 Normalized Aggregate Scores for the Economic Domain of Transportation Sustainability at State-Wide Level



Descriptives for Comparing Composite Mean Scores	Number of States	Minimum Score	Maximum Score	Mean Score	ANOVA Results Comparing Composite Mean Scores	Sum of Squares	df	Mean Square	F	P-Value
All States	51	6	95	47	Between Groups	4470	3	1490	10	<.001
Rural States	18	6	54	37	Within Groups	7050	47	150		
Rural-Urban States	15	23	64	47	Total	11520	50			
Urban-Rural States	10	46	65	55						
Urban States	8	40	95	62						







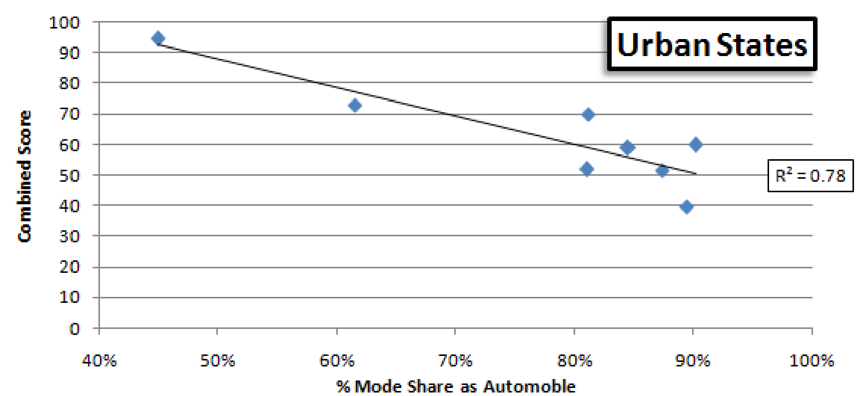


FIGURE 3 Comparing Mode Share to the Combined Score for Transportation Sustainability (Economic Domain) by Degree of Urbanity

6.0 CONCLUSIONS

This paper outlines the transformation of theoretical concepts of sustainability to a practical application that potentially provides valuable information to planners and policymakers. Using existing definitions and the sustainability literature, a composite index framework was used to create a metric that can quantify and measure a broad spectrum of characteristics related to transportation sustainability. The performance of the United States for the economic domain of transportation sustainability was evaluated at the state-wide level. An initial screening revealed regional differences in performance – states in the northeast and along the west coast generally performed the best. However, applying additional layers of analysis revealed the association between economic performance with the level of urbanization and automobile mode share for each state. Overall, urban states performed better than their rural counterparts. Furthermore, for each level of urbanity, a higher automobile mode share was consistently associated with lower scores. States with a lower score indicate where individuals and society spend more on transportation, where federal funds are a larger portion of state transportation expenditures, and where transportation is not efficient for economic growth. Based on the results of this work, more sustainable states on the basis of economic considerations are generally the ones that are more urban and provide more diverse modes of travel.

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CHAPTER 4: DISCUSSION

Since the Transportation Index for Sustainable Places (TISP) is an ongoing research endeavor, this section addresses additional development and thoughts pertaining to the project since the acceptance of publication for the paper *Quantifying the Economic Domain of Transportation Sustainability*.

Renaming the Urbanity Classifications

The naming and grouping of the urbanity classifications differ between the two papers in this thesis because we refined the hierarchical clustering methodology after our initial work was accepted for publication.

The original four clusters, as shown in *Quantifying the Economic Domain of Transportation Sustainability,* are labeled from most urban to most rural as: Urban, Urban-Rural, Rural-Urban, and Rural. The number of states in these four clusters is eight, ten, fifteen, and eighteen respectively.

The revised four clusters, as shown in *Selecting Peer States Based on Degree of Urbanism for Comparison of Transportation Systems*, are labeled from most urban to most rural as: High Density Suburb-Urban, Medium Density Suburb, Low Density Balanced, and Low Density Rural-Suburb. The number of states in these four clusters is thirteen, sixteen, ten, and twelve respectively.

Although these clusters changed, an analysis of variance (ANOVA) shows that the mean TISP scores between the revised peer state groups are still statistically significant.

Context of the Economic Structure of States

In addition to differentiating the states by degree of urbanism, consideration for the economic structure of each state may also be necessary for assessing the economic domain of transportation sustainability. The majority of the variables discussed in *Quantifying the Economic Domain of*

Transportation Sustainability are presented as a percentage or change over time, but one variable is expressed in terms of the existing level of gross domestic product (GDP) to vehicle miles traveled (VMT).

When comparing the existing levels of GDP between the states, it may be useful to understand the underlying economic structure of each state. This is important because higher household incomes and higher costs of living will directly contribute to a higher GDP. Therefore, for this particular variable that compares GDP to VMT, the differences between the states may be a direct result of state differences in incomes levels and costs of living.

Fortunately for our analysis, higher household incomes and costs of living generally coincide with degree of urbanism. In this regard, the four classification clusters can also function as a proxy to represent the underlying economic structure of each state.

Validity of Rural Comparisons

Although the results of this work indicate that urban states have more sustainable transportation systems than rural states, it is wrong to assume rural states cannot have sustainable transportation systems. The results show that the highest scoring rural states are comparable to the lowest scoring urban states.

The geographic scale of analysis can play a role in the TISP scores. Individual cities in rural states can have sustainable transportation systems, but can be overshadowed by the overall state characteristics that are more rural.

Furthermore, the structural framework of the TISP assesses the performance of each state relative to one another. This comparison will therefore always result in some states on the lower spectrum. Alternatively, there is future potential to assess the performance of each state against a specified target level, rather than relative to one another. Doing so may provide a better comparison of the states and show that rural states can meet target levels for objectives of transportation sustainability too.

CHAPTER 5: CONCLUSIONS

Findings

As understanding the relationship between transportation and sustainability continues to grow, metrics and indices will play an important role in helping to identify and assess the key issues. The TISP defines transportation sustainability and provides a more holistic framework for assessing the performance of transportation systems. The framework and components of the TISP are synthesized from existing sustainability literature and metrics. Conceptualizing transportation in terms of sustainability expands the scope of transportation from just accounting for mobility to including broader concerns from the environmental, social, and economic domains.

The TISP identifies twelve elements of transportation sustainability, but this thesis focuses on the four economic elements. The literature review explains how economic priorities are defined for transportation when sustainability is considered. The traditionally held idea is that the sole purpose of investing in transportation infrastructure is for economic growth. However, our literature review demonstrates a connection between the economic concerns of transportation sustainability and social equity and environmental conservation. Economic equity relates to the social side of sustainability through issues such as affordability. For example, a high cost of transportation can place a financial strain on households which subsequently limits the ability to access goods and services. Economic efficiency relates to the environmental side of sustainability through issues such as resource consumption. For example, growing consumption of petroleum in conjunction with dwindling natural reserves lead to higher prices which subsequently hampers the overall economy.

The results and methodological framework of the TISP shown in this thesis establishes an intellectual connection between transportation, sustainability issues from the economic perspective, and degree of urban development. The TISP shows that states that are more urban and offer more diverse modes of travel tend to have transportation systems that are more affordable, equitable, efficient, and resilient. These states have a lower cost of transportation for individuals, are less dependent on federal transportation funding, have faster growing economies relative to the growth of vehicle miles traveled, and overall consume less petroleum fuel for automobiles.

Future Work

The application of the TISP in this thesis looks at statewide transportation systems, but future research could examine the performance of citywide transportation systems. The TISP defines the twelve major elements of transportation sustainability, but the variables and datasets are not fixed. More appropriate or effective data can be available depending on the geographic scale of analysis. Data is sometimes unavailable at any scale for some of the elements of transportation sustainability. In this regard, the TISP helps to identify areas of data insufficiency and can encourage new research to develop the appropriate data for transportation sustainability.

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