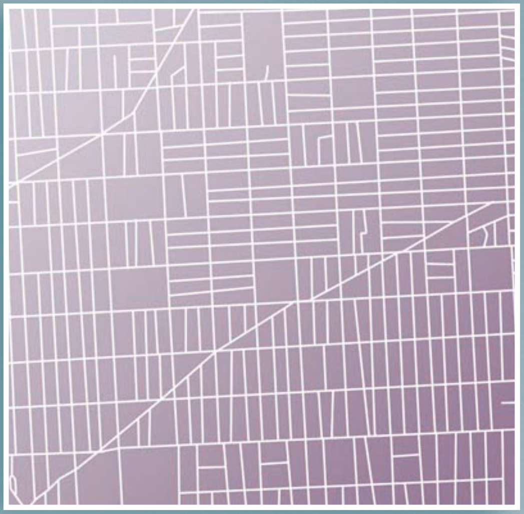
Characteristics and Performance of Regional TRANSPORTATION Systems



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Cover illustration: All figures are samples of the street network at the same scale (one square mile) from the Philadelphia metropolitan area. The images illustrate the considerable variation that occurs in intersection type, intersection density, and block size within a region.

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EXECUTIVE SUMMARY

The purpose of this study is to examine and define characteristics of regional transportation systems and measure overall system performance. We measure the degree of connectivity, the pedestrian environment, and availability of transit in 13 metropolitan areas. We test the hypothesis that a smart growth transportation system—one that features a relatively dense and well-connected network of streets, shorter block sizes, and extensive transit service—will produce improved transportation and environmental outcomes (reflected by fewer vehicle trips and miles of travel, less congestion, and fewer vehicle emissions) as compared to a conventional transportation system. A conventional system has fewer connections between streets, larger blocks with more circuitous pedestrian routes, and limited transit service. To evaluate a related hypothesis, that decreasing population density and increasing road supply will decrease congestion, the study looks at changes in traffic congestion over time for a set of metropolitan regions with stable or declining population and growing urbanized areas.

A smart growth transportation system typically includes the following elements:

- Multiple route choices between points
- Short blocks and frequent opportunities to cross streets on foot
- A wide variety of street types that provide both access and mobility
- Sidewalks and bicycle facilities that provide direct and safe travel routes
- Use of access management; e.g., highways linking towns, but not bisecting or bypassing them, and driveways strategically located on commercial arterials
- A network of dense, frequent public transit service

Because they feature higher street connectivity, a more pedestrian-friendly environment, shorter route options, and more extensive transit service, these systems are expected to exhibit superior environmental and transportation performance in terms of: lower vehicle miles of travel (VMT) per capita, fewer auto trips per capita, lower average auto trip distance, less congestion, greater use of public transit, and fewer vehicle emissions. We test this hypothesis by comparing 13 metropolitan areas of differing size on several key regional transportation supply and performance measures.

In selecting the 13 metropolitan areas for analysis, we identified 5 matched sets that are similar in population but appeared to differ in terms of system performance. Additional criteria used to select regions include population density, the presence of a single central city (as opposed to areas with multiple centers such as Dallas-Ft. Worth, Minneapolis-St. Paul, etc.), and data availability. Regional transportation system supply is characterized using indicators that include block size, street network density, intersection density, the percent of four-way intersections, and transit service density. We also measured the amount of lane-miles available per capita, though this was not used as a characteristic to define a transportation system. Regional transportation system performance is characterized using indicators such as VMT per capita, vehicle trips per capita, congestion delay, transit trips per capita, vehicle crash statistics, and on-road emissions.

Each of the 13 metropolitan areas is ranked within its size group in terms of how well it exhibits smart growth system characteristics or superior performance. In four of the five size groups, the smart growth system is found to perform best. Compared to their peers, Philadelphia, Pittsburgh, New Orleans, and Erie generally have smaller blocks, a denser network of streets and intersections, and more extensive transit service. These same regions, compared to their peers, generally exhibit lower VMT per capita, shorter vehicle trip length, less congestion, more transit trips, and fewer pollutant emissions. In the fifth size group, Omaha and Little Rock are essentially equivalent in terms of smart growth system characteristics, so the relationship between supply and performance is unclear.

These results suggest that system characteristics do affect performance, and that regions with more characteristics of a smart growth transportation system experience more efficient vehicle travel and modest improvements in traffic congestion. The table below summarizes results, with regions exhibiting more characteristics of a smart growth transportation system shown in bold.

Population, Density, and *Selected* Supply and Performance Rankings for the 13 Study Regions

Performance Rank

1-3 ranking within groups, ties allowed

			Selected Supply Measures (1 most exemplifies a smart growth system)					**Selected Performance Measures** (1 most exemplifies superior performance)			
	Urbanized area population (2000)	Urbanized area pop. density (persons per sq. mile)	Median block size	Center-line miles per sq. mile	Inter-sections per sq. mile	Percent of inter-sections that are four-way	Transit revenue-hour density	VMT per capita per day	Vehicle trips per capita per day	Average vehicle trip length	Delay per peak-period traveler
Philadelphia	5,149,079	2,861	**1**	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**1**
Atlanta	3,499,840	1,783	3	2	3	3	2	3	2	2	2
Houston	3,822,509	2,951	2	1	2	1	3	2	1	2	2
Pittsburgh	1,753,136	2,057	**1**	**2**	**2**	**1**	**1**	**1**	**1**	**2**	**1**
Tampa/St Peters.	2,062,339	2,571	2	1	1	1	3	1	2	1	2
St. Louis	2,077,662	2,506	3	1	2	2	2	2	3	1	2
New Orleans	1,009,283	5,102	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Charlotte	758,927	1,745	2	2	2	3	2	2	3	2	2
Nashville	749,935	1,741	2	2	2	2	3	2	2	2	2
Omaha	626,623	2,768	2	1	1	1	1	1	1	1	-
Little Rock	360,331	1,753	1	2	2	1	1	2	1	2	-
Erie, PA	194,804	2,472	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**-**
Binghamton, NY	158,884	2,079	1	2	2	2	1	2	2	1	-

As a point of interest, we looked at lane-miles supplied per 1000 residents to see if there was a connection to performance. Some contend that the amount of roadway per person should have an impact on transportation performance, yet our data suggested no clear relationship.

Transportation system characteristics are among many factors that affect travel behavior and system performance. Other factors, such as regional economic conditions and the spatial arrangement of land uses, are complex and difficult to control for in a study such as this. Population density is one factor that can influence system performance and can be controlled for at the regional level. Previous research has shown that higher density is correlated with more travel by walking, bicycling, and transit; shorter automobile trips; and lower auto ownership per household.

Comparing cities that have similar density but different system characteristics allows a better test of the effect of system characteristics on performance. For example, Philadelphia and Houston are closely matched in density, but Philadelphia ranks higher than Houston on smart growth supply measures of block size, intersection density, and transit service, and also on system performance measures of VMT per capita, trip length, traffic congestion, and transit ridership. Tampa/St. Petersburg and St. Louis are also closely matched in density and show a similar relationship between supply and performance. These comparisons support our conclusion that system characteristics are at least partially responsible for superior transportation and environmental performance.

Overall, the findings suggest that characteristics such as: greater street connectivity, a more pedestrian-friendly environment, shorter route options, and more extensive transit service have a positive impact on performance. When we examined the impact of lane miles supplied per person, we found that there was not a clear relationship between greater or lesser amounts of roadway per person and system performance. In order to better isolate the issue and examine it more closely, we look at changes in traffic congestion over time for a set of metropolitan regions with stable or declining population and roadway capacity additions. We use traffic congestion as a surrogate for performance because there is consistent and available data and our budget did not permit further performance measure development.

In the Detroit, Pittsburgh, and Buffalo metropolitan areas, congestion levels have increased between 1982 and 2000 despite growth in urbanized land area and road capacity, and stable population growth. For example, congestion delay in Detroit rose from 14 hours per peak-period traveler per year in 1982 to over 50 hours in 2000, while the metro area population grew by an average of only 0.3 percent per year. During the same period, urbanized land area expanded 21 percent, and total lanes miles increased by 13 percent.

While the sample includes only three regions, they all show a pattern of stable or declining population, expanding urban boundaries, additional road capacity, and increasing traffic congestion. While no conclusions can be drawn about cause and effect, this sample does suggest that lane additions and lowering densities do not, by themselves, prevent worsening congestion. Indeed, we can see from both parts of the study that there is little correlation between the supply of lane mileage per person and system performance. Instead, it seems that greater connectivity, transit availabilty, and pedestrian-friendliness are at least partially responsible for superior transportation and environmental performance.

1 INTRODUCTION

This study begins to examine and describe characteristics of regional transportation systems. Very little research exists that defines typologies for regional transportation systems and attempts to measure their performance. Less attention has been paid to how the specific characteristics of the transportation *system* affect travel modes, routes, distances, and environmental quality. Characteristics of the road network and transit service can influence the choice of travel mode and the choice of travel route. Walter Kulash, in his groundbreaking research on traffic patterns in Traditional Neighborhood Developments (TND), examined how *individual streets* designed according to TND standards could out-perform conventional designs in terms of traffic flow and capacity. His research demonstrated that putting the same amount of traffic on the same amount of pavement, but on differently configured roads, creates significant differences in vehicular capacity, travel speed/travel times, and safety.[1]

This study classifies transportation systems as either “smart growth” or “conventional.” Smart growth is defined by a set of principles, including mixing of land uses, preserving open space, providing transportation choices and a variety of housing options, making efficient use of existing infrastructure, and creating compact development that is walkable and attractive. Places that employ multiple smart growth strategies are also supported by transportation systems that enhance accessibility to numerous destinations, provide transportation choices (with convenient linkages between modes), and are pedestrian-friendly. Research has consistently shown that households and employees in centrally located, compact, mixed-use, pedestrian-oriented communities tend to drive less and walk, bicycle, and take transit more.[2] These changes in travel associated with smart growth development patterns have been shown to result in fewer air pollution emissions.[3] By contrast, a conventional system has fewer connections between streets, larger blocks with more circuitous pedestrian routes, and limited transit service.

This study tests the hypothesis that a regional smart growth transportation system—one that features a relatively dense and well-connected network of streets, shorter blocks, and extensive transit service—will improve transportation and environmental outcomes as compared to a conventional system. We expect this to be evident in lower vehicle miles of travel (VMT) per capita; fewer auto trips per capita, fewer auto-related emissions, less traffic congestion, and more transit use. We test this hypothesis by comparing 13 metropolitan areas of differing size on several key regional transportation supply and performance measures.

Other studies have analyzed the street network at the local level and found significant differences between neighborhoods, differences often related to the age of initial development.[4] Few studies have attempted to measure street network characteristics for an entire region. Given that nearly all metro areas feature an older urban core with a grid street network and newer suburbs with less connected street patterns, this study assesses whether significant transportation system differences can be observed across regions.

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[1] See Kulash, Walter, “Traditional Neighborhood Development: Will the Traffic Work?” October 1990, presentation at the 11th Annual Pedestrian Conference in Bellevue WA. Available online at http://user.gru.net/domz/kulash.htm.

[2] See for example: Cervero, Robert and Kara Kockelman, 1997, “Travel Demand and the 3Ds: Density, Diversity, and Design,” *Transportation Research Record D: Transport and the Environment*, Vol. 3, pp. 199-219; and U.S. EPA, January 2001, *Our Built and Natural Environments: A Technical Review of the Interactions Between Land Use, Transportation, and Environmental Quality*, EPA 231-R-01-002.

[3] For empirical research on the effects of urban form on vehicle emissions, see Frank, Lawrence D., Brian Stone Jr., and William Bachman, 2000, “Linking Land Use with Household Vehicle Emissions in the Central Puget Sound: Methodological Framework and Findings, *Transportation Research Record D: Transport and the Environment*.

[4] See for example: Southworth, Michael and Eran Ben-Joseph, 1997, *Streets and the Shaping of Towns and Cities*. McGraw Hill: New York.

Finally, this study evaluates changes in traffic congestion over time for a set of metropolitan regions with stable or declining population and growing urbanized area. The purpose of this analysis is to examine if, as some have suggested, decreasing density and increasing roadway capacity improve transportation system performance.

This study is exploratory and as such its limits should be understood. Many factors other than transportation system characteristics influence travel and transportation system performance, such as land use patterns, personal income, and regional economic conditions. A more thorough analysis of the network and its surroundings would consider the effects of land use and micro-scale design issues such as the mix of uses and the densities of those uses, pedestrian and transit-orientation, and the balance of jobs and housing in a region. Aside from population density, this study does not attempt to control for these other factors.

Other limitations are related to the accuracy of the travel and transportation system performance data reported by metropolitan planning organizations (MPOs). Measurements of vehicle travel at the regional scale have an inherent margin of error, and MPOs may use different techniques to develop travel measures. Finally, the study introduces some data inconsistencies by comparing some measures developed at the urbanized area with those developed for regions defined by metropolitan statistical areas (MSA) or MPO boundaries. Study limitations are discussed in more detail in Section 4.3.

Because of these limitations, this study should be considered an initial exploratory step that will help to inform options for characterizing smart growth transportation systems on a regional scale and also shed light on how system characteristics affect travel and system performance. It is clear from our research that more work is needed to explore further the relationships between system supply and performance measures at the regional scale.

2 DEFINING REGIONAL TRANSPORTATION SYSTEMS

In order to evaluate and define transportation systems, we use three characteristics: connectivity, pedestrian environment, and available transit.[5] These three general supply characteristics are the basis of a growing body of research into the impacts of urban form on travel behavior. A regional system can fall along a continuum for any one of the categories. A transportation system that supports the goals of smart growth is one that creates walkable communities to encourage pedestrian trips, provides a range of transportation choices, and creates access to a wide range of origins and destinations. From a facility design standpoint, a smart growth transportation system typically includes the following elements:

- Multiple route choices between points
- Short blocks and frequent opportunities to cross streets on foot
- Sidewalks and bicycle facilities the provide direct and safe travel routes
- A wide variety of street types that provide both access and mobility
- A network of dense, frequent public transit service

While not accounted for in this study, a smart growth transportation system would also be intimately related to surrounding land uses. For instance, residential and employment densities would be sufficient to support high quality transit service, and land uses would be mixed to reduce trip distances between commercial, residential and institutional areas. Yet from a transportation facility standpoint, a smart

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[5] We arrived at these supply characteristics by examining variables included in similar research. For a synthesis of the studies consulted, refer to: Ewing, Reid and Robert Cervero, 2001, “Travel and the Built Environment,” paper presented at the 80th Annual Meeting of the Transportation Research Board, Washington, DC.

growth transportation system emphasizes the key concepts of connectivity, an enhanced pedestrian environment, and opportunities for viable public transit. Table 1 highlights some of the differences between a smart growth transportation system and the type of system that has dominated transportation construction in the post-World War II period (a style we term "conventional").

Table 1: Transportation System Characteristics

Characteristic	Smart Growth	Conventional
Connectivity	There are many available routes in the street network between two points. Pedestrian routes are direct.	There are few available routes between two points. Pedestrian routes are circuitous.
Pedestrian environment	Blocks are small (i.e., it takes most people less than five minutes to walk one block), sidewalks are continuous, and streets have frequent crosswalks or signals. Traffic moves slowly (e.g., average vehicle speed is 25 mph or less).	Blocks are large (i.e., it take most people more than five minutes to walk one block), sidewalks are discontinuous or non-existent, and streets have few crosswalks or signals. Traffic moves quickly (e.g., average vehicle speed is over 25 mph).
Available transit	Transit service is dense (most people can walk to stops near their homes and/or workplaces) and frequent (transit vehicles arrive every 15 minutes or less throughout the day).	Transit service is sparse (most people cannot walk to stops at either their home or workplace) and infrequent (transit vehicles arrive at intervals longer than 15 minutes, and do not run throughout the day).

Connectivity

Connectivity refers to the degree to which streets intersect with other streets. Connectivity can be measured for an individual street by counting the average number of intersections per mile on that street. Or it can be measured collectively, by counting the number of intersections per square mile in an area. This study uses the second definition: the greater the number of intersections per unit area, the greater the connectivity.

High connectivity is associated with smart growth because it means more route choices between a given origin and destination. For drivers, this can reduce congestion because it allows traffic to move along a number of different routes instead of being funneled onto a single route. A system with high connectivity provides pedestrians and bicyclists with the most direct route options and allows them to avoid routes with heavy or dangerous traffic. Higher connectivity also improves access to possible activity destinations.

A study by Portland Metro found that increasing connectivity on arterial streets improved traffic flow on the arterial streets, and also reduced vehicle hours of delay, VMT, and vehicle trip length for the entire sub-area.[6] The study does suggest that there is a point at which increasing street connectivity may actually increase vehicle delay. The study suggests that the optimum level of connectivity is 10-16 arterial intersections per linear mile (a measure of individual street connectivity).

Grid street patterns tend to foster high connectivity, whereas conventional street patterns with numerous cul-de-sacs and large block sizes do not. One study of street typology found that within a 100-acre tract, a strict grid street pattern contains 26 intersections, whereas a street pattern with a high number of cul-de-sacs contains only 8 intersections.[7] (An intersection was defined as the junction of two streets that provide

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[6] Daisa, James M., Tom Kloster, and Richard Ledbetter. "Does Increased Street Connectivity Improve the Operation of Regional Streets? Case Studies from the Portland Metro Regional Street Design Study." Unpublished paper.

[7] Southworth, Michael and Eran Ben-Joseph, 1997, *Streets and the Shaping of Towns and Cities.* McGraw Hill: New York.

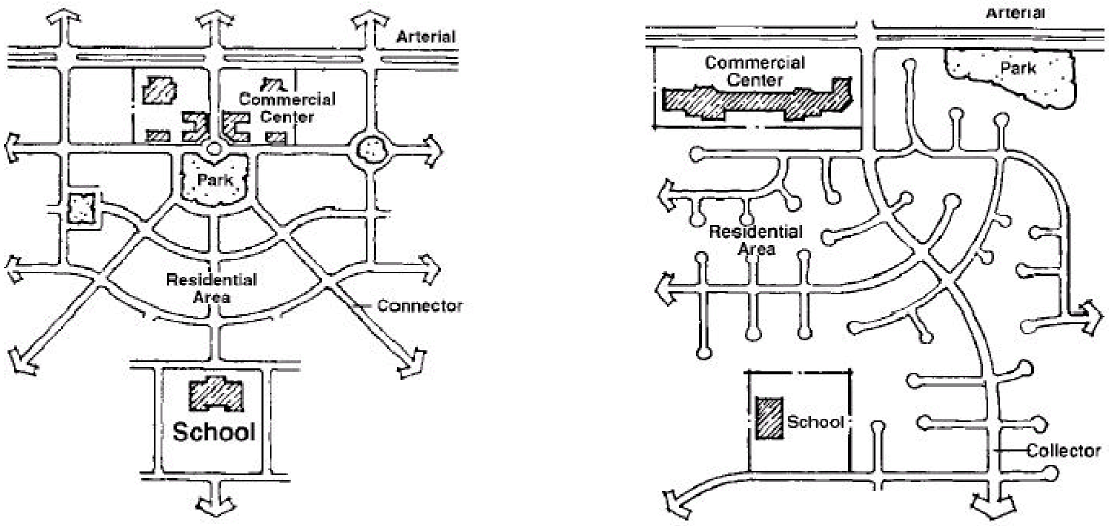
route choice, including a T-intersection or a four-way intersection; a cul-de-sac meeting a street was not defined as an intersection because it does not provide a choice of route).

Figure 1 illustrates the difference in connectivity between a smart growth street network on the left and a conventional street network on the right. The smart growth network streets are more interconnected, so the majority of intersections are four-way. There are also parallel streets going north-south and east-west, meaning that both pedestrians and vehicles have several route choices and can travel beyond the neighborhood without using the arterial. Finally, major destinations such as the school, commercial center, and park are served by several streets converging from different directions.

In contrast, the conventional street network has few interconnected streets. Most streets are cul-de-sacs, so they have only one ingress and egress point, and there are a higher proportion of three-way intersections than the figure on the left. There are fewer parallel routes. This means that pedestrians or vehicles traveling between two points have few route choices. Finally, major destinations like the school and the park are located along a street, rather than at an intersection, meaning that all traffic to and from those destinations will be funneled onto a single route.

Note that although grid street networks tend to be rectilinear, and conventional street networks tend to be curvilinear, neither network type has to intrinsically be one or the other, although to provide the parallel routes integral to its efficiency, a grid network will tend toward a more rectilinear design. As Figure 1 shows, the grid pattern can curve and vary to provide interest, and to accommodate both civic and natural features. In sum, the important characteristic is connectivity, which we focus on and quantify, not linearity.

Figure 1: Comparison of a Smart Growth Street Network to a Conventional Street Network



Source: Calthorpe Associates.

Pedestrian Environment

The “pedestrian environment” characteristic evaluates the degree to which pedestrians can walk comfortably and safely, and reach destinations without following circuitous routes. Since approximately one-fifth of all trips are less than one mile (about a 20-minute walk), walking can constitute an important travel mode, as well as a source of exercise.[8]

A variety of street design factors affect the pedestrian environment, including street connectivity (discussed above), block size, sidewalk continuity, and ease of street crossing. Shorter blocks create more frequent intersections and more potential route choices for drivers, bicyclists, and pedestrians. A continuous sidewalk network makes walking safer and more convenient. Similarly, street crossings facilitate easy and safe pedestrian movement when they are well marked, frequently spaced, and not impeded by heavy or fast vehicle traffic. This suggests that a network comprised of more streets with narrow widths, fewer lanes, and slower and less concentrated traffic will create a more positive experience for the pedestrian.

Several metropolitan areas have attempted to characterize the pedestrian environment quantitatively at the zonal level to use as an input in a regional travel demand forecasting model. For example, the Land Use, Transportation, Air Quality (LUTRAQ) study in the Portland, Oregon region created a pedestrian environment factor (PEF) for each zone based on four parameters: ease of street crossings, sidewalk continuity, local street connectivity (grid vs. cul-de-sac), and topography. The LUTRAQ study suggests that a 10 percent regional reduction in VMT could be achieved by increasing the quality of the pedestrian environment to a level on par with Portland's most pedestrian-oriented zones.[9]

Available Transit

In addition to the street network characteristics described above, another component of smart growth transportation systems is the availability of transit service. The extent of transit service can be measured in a variety of ways, including the number of routes, the frequency of service, the hours of operation, the number of transit stops per square mile, the percentage of population or jobs located within a quarter mile of transit, and other measures.

Table 2 shows "quality of service" measures to evaluate transit performance from a customer's point of view.[10] Unlike conventional transit performance measures, which reflect the transit operator's point of view, these measures deliberately take a rider's perspective—and better reflect the characteristics that would make a rider choose transit.

Table 2: Transit Service Measures

	Unit of Analysis		
	Transit Stop	**Route Segment**	**System-wide**
Availability	**Frequency:** Length of time between vehicle arrivals	**Hours of Service:** Number of hours per day during which service is provided	**Service Coverage:** Area within walking distance of transit service
Quality	**Passenger Loads:** Amount of space per rider	**Reliability:** On-time performance	**Transit/Auto Travel Time:** Difference in door-to-door travel time between transit and driving

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[8] According to the 1995 National Personal Transportation Survey, 17 percent of trips are less than one mile. Most travel surveys are likely to undercount short walking trips to some degree because survey respondents may not recognize them as "trips" on par with auto and transit trips.

[9] Parsons Brinckerhoff Quade and Douglas, Inc., December 1993, *Making the Land Use Transportation Air Quality Connection, The Pedestrian Environment, Volume 4A*, Prepared for 1000 Friends of Oregon.

[10] Kittleson & Associates, Inc., 1999, *Development of Transit Capacity and Quality of Service Principles, Practices and Procedures*. Prepared for the Transit Cooperative Research Program.

Conventional Transportation System

In contrast to a smart growth transportation system, a conventional system has the following characteristics:

- A local street network with a large portion of cul-de-sacs and poor connectivity, thus requiring more circuitous routes
- A disconnected sidewalk system
- Wider local, collector, and arterial streets
- A reliance on multi-lane arterial streets to travel beyond the immediate neighborhood and to reach commercial districts
- Large intersections of arterial streets with turning lanes and multi-phase signals
- Limited transit service

3 DEVELOPMENT OF SUPPLY AND PERFORMANCE MEASURES

A transportation system that supports smart growth provides better connectivity, allowing more direct auto trips and making walking/bicycling trips more attractive. The literature suggests that the results will include lower VMT per capita, fewer auto trips per capita, shorter average auto trip distance, less congestion, and greater use of transit. By reducing vehicle travel, a smart growth transportation system may also reduce vehicle emissions and vehicle crashes. We test this hypothesis by comparing 13 metropolitan areas of differing size on several key regional transportation supply and performance measures.

We characterize regional transportation system *supply* using the following measures:

- Block size
- Street network density (lane-miles and centerline miles)
- Intersection density
- Percentage of four-way intersections
- Percentage of major-minor intersections
- Transit revenue-hour density
- Transit stop density

The first five measures are developed using geographic information system (GIS) files of street networks, and the last two are available from national transit statistics and transit operators.

We characterize regional transportation system *performance* using the following measures:

- VMT per capita
- Vehicle hours of travel per capita
- Average vehicle trip length
- Vehicle trips per capita
- Vehicle ownership per household
- Average annual delay per peak-hour traveler
- Transit trips per capita

- Vehicle emissions per capita (ozone nonattainment and maintenance areas only)
- Vehicle crash fatalities per capita and per VMT

The following sections discuss the selection of the 13 study regions and the development of supply and performance measures in greater detail.

3.1 Selection of Study Regions

We selected 13 metropolitan areas to compare transportation supply and performance measures. Our goal was to select pairs of regions that are similar in size but different in terms of system performance. The following criteria were used in selecting the sample:

Data Availability. Because this report relies on existing data we needed to work with MPOs to supply it. We contacted a number of MPOs to assess the availability and quality of transportation system performance data, and through this process, ruled out several regions that had been initially selected.

Size. To make comparisons of system supply and performance between metro areas of similar size, we selected regions in five size groups. We used 2000 Census data to rank urbanized areas based on size. For this study we use the Census definition of "urbanized area," which defines areas around urban centers settled at a minimum population density. [11] Within each size category, we identified candidate sets of regions similar in size.

VMT Per Capita. We used VMT per capita per day, as reported in the Federal Highway Administration's (FHWA) *Highway Statistics 2000*, as an initial indicator of system performance. For each set of cities, we attempted to select one in the lowest daily VMT per capita quartile and one in the highest. For the final analysis, VMT and other system performance data were obtained directly from MPOs.

Separateness. We attempted to select metropolitan areas dominated by a single central city and not adjacent to areas that might create anomalous travel patterns, such as an international border.

Population Density. In addition to transportation supply characteristics, a variety of land use factors likely affect system performance. We attempted to control for one of these factors—population density—in the three largest size groups by selecting two cites that are comparable in terms of density. Population density was defined as persons per square mile in the urbanized area.

Table 3 shows the selected sample regions with their population, population density, VMT per capita, and median household income for 1999. Although we did not control for income and it was not a criterion for selecting regions, it is presented here to show the extent of variation in income levels.

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[11] See http://www.census.gov/geo/www/cob/ua_metadata.html for an explanation of the urbanized area definition.

Table 3: Population and VMT per Capita in the 13 Study Regions

	Urbanized area population	Urbanized area population density (persons/sq mi)	VMT per capita per day	Median household income
Philadelphia	5,149,079	2,861	18.8	$47,528
Atlanta	3,499,840	1,783	33.4	51,948
Houston	3,822,509	2,951	26.6	44,761
Pittsburgh	1,753,136	2,057	24.8	37,467
Tampa Bay/ St. Petersburg	2,062,339	2,571	24.3	37,406
St. Louis	2,077,662	2,506	30.0	44,437
New Orleans	1,009,283	5,102	16.0	35,317
Charlotte	758,927	1,745	33.7	46,119
Nashville	749,935	1,741	31.0	44,223
Omaha	626,623	2,768	21.8	44,981
Little Rock	360,331	1,753	32.0	39,145
Erie, PA	194,804	2,472	16.2	36,627
Binghamton, NY	158,884	2,079	33.1	36,374

Sources: U.S. Census 2000; Individual metropolitan planning organizations.
Note: Although the initial selection of regions was made with VMT data from 2000 *Highway Statistics*, this table shows VMT as provided by MPOs, since these are the figures used in the report analyses.

3.2 Transportation Supply Measures

We characterize transportation supply using measures of block size, street density, intersection type and density, and transit service. All block and street network variables were calculated using a spatially accurate street vector GIS database, developed by Geographic Data Technology (GDT) and obtained from the Bureau of Transportation Statistics (BTS). This GIS-format database is essentially a version of the TIGER files that has been enhanced to more accurately represent street layout. It is available state by state. For cases in which an urbanized area crosses state boundaries, street files were edge-matched together so that the cross-state streets appear seamless. The street data were then "clipped" by the polygon that represents the urbanized area boundary.[12] [13] More specific definitions of the five variables follow, with greater details available in the Appendix.

Block Size

A block is an area bounded by streets that can be circumnavigated on foot or by vehicle. Using this definition, blocks may be the traditional downtown small square blocks as well as the large curvilinear or amorphous shapes of office parks and residential subdivisions. A large proportion of small blocks are

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[12] GIS data capture all features as points, lines or polygons. The database represents streets as lines. Areas bounded by lines are called polygons. To "clip" a polygon is to discard irrelevant sections and retain only the area needed for analysis.

[13] For this study we are using the definition of "urbanized area" provided by the U.S. Census. See http://www.census.gov/geo/www/cob/ua_metadata.html for further information.

associated with a fine-grained street network that encourages pedestrian activity, whereas larger blocks indicate a coarser grained network and longer walking distances. We expect the smart growth regions to be characterized by a large percentage of small blocks.

We used the GDT street files to build polygons representing individual blocks and then calculated the area of each block. Block size is presented using two statistics: the percentage of blocks under four acres and the median block size. We use the median block size, rather than the mean, because the mean can be heavily skewed by the presence of a few very large blocks that do not reflect the prevailing development pattern (e.g., parks, campuses, military installations).

A rectangular block of four acres is approximately 200 feet wide by 800 feet long. Pedestrians walking in a neighborhood of four-acre blocks typically encounter an intersection every 800 feet or less, or every 3 minutes (assuming a typical walking speed of 3 miles per hour).

Results of the analysis of block size are shown in Table 4. The study regions show large variation in the two measures, particularly among the metro areas with population over 1 million. Median block size ranges from a low of 2.7 acres (Pittsburgh) to a high of 8.9 acres (Atlanta). Pittsburgh and New Orleans have the greatest portion of blocks under four acres (65 percent and 64 percent), while Atlanta and Charlotte have the smallest portion (23 percent and 24 percent). The Appendix contains histograms of block size for each region.

Table 4: Block Size Measures for the 13 Study Regions

	Total number of blocks	Median block size (acres)	Percent under 4 acres
Philadelphia	60,403	3.9	51.4%
Atlanta	21,966	8.9	23.3
Houston	36,610	5.8	34.4
Pittsburgh	26,599	2.7	65.3
Tampa/ St. Petersburg	31,214	4.0	50.0
St. Louis	23,230	5.2	35.5
New Orleans	16.450	3.1	63.8
Charlotte	5,577	7.8	23.5
Nashville	7,203	7.9	24.3
Omaha	10,020	4.8	37.5
Little Rock	6,128	3.7	52.5
Erie	2,748	5.4	29.0
Binghamton	1,926	5.1	35.5

Street Network Density

Street network density measures the extent of the roadway system per unit area. A denser network of streets shortens distances between intersections, which improves pedestrian connectivity, and provides greater route choice for vehicles. A less dense street network typically creates greater walking distances for pedestrians and funnels traffic on to fewer streets. We calculate this measure as street *centerline* miles within the urbanized area divided by the total urbanized area to obtain centerline miles per square mile. Centerline miles for each given metropolitan area are available directly from the GDT street files. Note that while this measure gives a sense of the extent and coverage of the roadway network, it does not capture street connectivity. We address roadway connectivity through the intersection variables, discussed below.

We also calculate street *lane-mile* density for comparison purposes. The street network files do not indicate the number of lanes associated with a street segment, so we assumed a fixed number of lanes for each street type. Street type is identified using the Census-designated FCC (feature class code) value, which is a detailed breakdown of traditional functional classifications. See the Appendix for a description of these assumptions. Note that lane-mile density is not as clearly associated with a smart growth transportation system as centerline mile density because it does not distinguish between areas with many two-lane streets (good pedestrian connectivity) and areas with a few multi-lane streets (poor pedestrian connectivity).

We calculate lane miles per 1000 people. This figure captures the amount of roadway supplied per 1000 residents in the metropolitan area. However, this is not a measure that differentiates a smart growth system from a conventional system, rather we've included it to see if there is any noticeable correlation between roadway space per person and performance.

Street network density measures are shown in Table 5. With the exception of New Orleans, the study regions show less variation in these measures. The highest and lowest values in each size group are generally within 25 percent of each other. Note that centerline density is closely correlated with lane-mile density—in all regions, lane-miles are 2.3 to 2.5 times the number of centerline miles. This suggests that the regions do not exhibit large differences in the distribution of streets by functional class.

Table 5: Roadway and Intersection Measures for the 13 Study Regions

	Centerline miles per sq. mile	Lane-miles per sq. mile	Total Lane-miles per 1000 capita[14]	Intersections per sq. mile	Percent four-way intersections	Percent major-minor intersections
Philadelphia	10.6	25.1	9.1	57.1	27.9%	22.6%
Atlanta	7.8	18.3	10.5	31.3	14.6	20.6
Houston	10.5	24.6	8.5	50.9	32.8	19.0
Pittsburgh	10.6	25.8	12.5	59.0	27.9	24.7
Tampa/ St. Petersburg	11.9	27.1	11	68.5	26.8	20.4
St. Louis	11.4	27.2	10.9	58.7	24.7	24.8
New Orleans	17.0	41.0	8.5	106.8	52.2	32.1
Charlotte	7.9	19.0	11	34.7	17.4	25.9
Nashville	8.3	20.4	12.1	33.3	21.3	26.8
Omaha	12.7	30.5	11.3	70.7	33.2	23.6
Little Rock	10.4	25.9	15	54.7	30.1	32.2
Erie	11.1	26.4	10.6	54.9	38.3	27.1
Binghamton	9.6	24.1	12	46.0	21.4	28.2

Intersection Variables

Intersection density. Intersection density is defined as the number of intersections per square mile. Greater intersection density implies shorter walking distances and more route choices, whereas lower intersection density implies longer walking distances and fewer route choices.[15] Note that highway

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[14] Lane-miles per capita are generated from GIS analysis and census population figures.

[15] To identify intersections in street network GIS files, we wrote a computer program to count the number of additional street segments that are connected to each street segment endpoint. An endpoint joined to two or more

segments are not included in this total, because limited-access facilities are not generally associated with pedestrian connectivity and vehicle route choice at the neighborhood level.

Percentage of four-way intersections. Four-way intersections are an indicator of a grid street network and high connectivity. Non-grid street networks are characterized by a large percentage of three-leg T or Y intersections. Using the GDT street network files, we identified the number of intersections that are characterized by the joining of exactly four street segments, and divided this value by the total number of intersections. Again, highway segments are not included in the calculation of this measure.

Percentage of major-minor intersections. This variable measures the percentage of intersections that connect major streets (highways and arterials) to minor streets (local streets). Street networks with a high degree of connectivity should exhibit a larger proportion of major-minor intersections compared to conventional street networks in which arterial streets have relatively few access points. Unlike the previous two measures, this measure does include highway segments.

Street type is identified again using the Census-designated FCC value. Each intersection is classified as major-major, major-minor, or minor-minor. We then divided the number of major-minor intersections by the total. This measure involves more uncertainty than the other intersection measures, in part because classification of street type may not be performed consistently across regions. For example, an arterial street may be classified as a "county road" (FCC 030) in one jurisdiction and a "neighborhood road" (FCC 040) in another. For this reason, we are less confident that this measure reflects the characteristics of a smart growth transportation system as compared to the other intersection measures.

Table 5 shows the intersection measures for the 13 study areas. Again, New Orleans stands out with a far higher intersection density and percent of four-way intersections than the other regions. Intersection density varies significantly within size groups—New Orleans, Omaha, and Tampa lie at the high end of the spectrum; Atlanta, Nashville, and Charlotte are at the low end. Note that the region with the highest intersection density in each group does not always have the greatest proportion of four-way intersections. The percent of major-minor intersections shows less variation across regions and does not appear to be strongly correlated with the other intersection measures.

Figures 2 through 5 illustrate the considerable variation that occurs in intersection type, intersection density, and block size. All figures are samples of the street network at the same scale (one square mile) from the same metropolitan area (Philadelphia). Figures 2 and 3 show grid street patterns with a high portion of four-way intersections, although Figure 2 shows higher intersection density and smaller block size than Figure 3. Figures 4 and 5 show non-grid street patterns and irregular blocks. Figure 4 shows a moderate portion of four-way intersections and some small blocks that could be easily circumnavigated by foot. Figure 5 illustrates how the presence of cul-de-sacs creates a large portion of three-way intersections and large irregular blocks that make for a difficult walking environment.

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additional segments in one location constitutes an intersection. The total number of intersections is then divided by urbanized area to yield intersection density.

Figure 2: Dense Grid Street Network

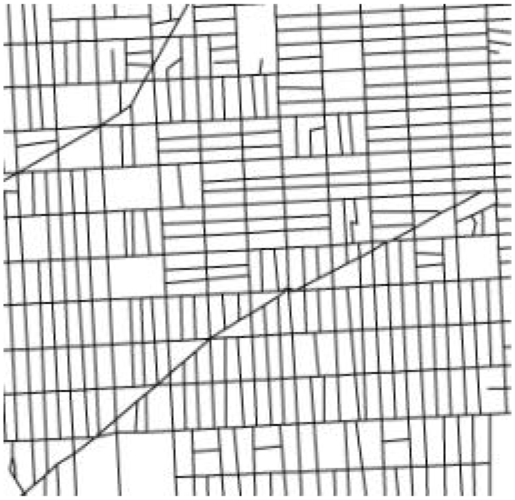

Figure 3: Larger Grid Street Network

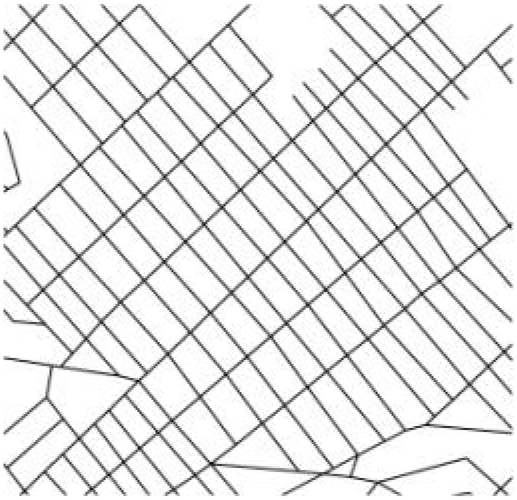

Figure 4: Loosely Interconnected Street Network

Figure 5: Poorly Interconnected Street Network

Transit Variables

We attempted to develop measures of transit service coverage analogous to the street network measures. We believe the best such measure is service density calculated as transit stops per hour per route-mile. This measure would have allowed us to capture the extent of transit options (frequency and proximity) available to a typical household in the region. Unfortunately, our research found that transit agencies are not able to provide the data needed to calculate this measure. In particular, most transit agencies do not maintain a database that includes by route the number of stops, frequency, and route length. As an alternative, we use two simpler measures to capture transit service: revenue-hour density and transit stop density.

We explored developing transit service density measures based on both area and population. A measure based on area should ideally be calculated using transit service area as the denominator. Unfortunately, transit service area is not measured in a consistent manner, and the service area figures provided to us by transit agencies were sometimes counterintuitive. For example, the major transit provider in St. Louis reports a service area of 3,600 square miles, more than four times larger than region’s urbanized area and almost twice as large as the reported service area of Philadelphia's primary transit provider. Similarly, Erie and Binghamton are nearly identical in urbanized area, but Erie's transit service area is 80 square miles and Binghamton's is 712. We also considered using urbanized area as a proxy, but found this alternative to be unacceptable because urbanized area is not necessarily consistent with transit service provision. We therefore elected to calculate transit service measures based on urbanized area population rather than land area.

Revenue-hour density. Revenue-hour density is defined as annual revenue-hours (the number of hours that vehicles operate in revenue service) per capita. This measure shows the intensity of transit service provided to the service area, as opposed to revenue-mile density (annual revenue-miles per capita), which reflects service distance and would likely favor areas with extensive commuter rail systems. Information on the number of annual revenue-hours operated by each system was obtained from the Federal Transit Administration's National Transit Database (NTD) for 2000.

Transit stop density. Transit stop density is the number of transit stops per capita, which gives a coarse indication of transit system access. We obtained the number of stops directly from the major transit providers in each of the 13 regions. Transit supply measures are presented in Table 6.

Table 6: Transit Supply Measures for the 13 Study Regions

	Urbanized area population	Revenue-hour density (annual rev. hours per 1,000 persons)	Transit stop density (transit stops per 1,000 persons)
Philadelphia [a]	5,149,079	1,540	3.4
Atlanta	3,499,840	860	3.4
Houston	3,822,509	680	2.8
Pittsburgh	1,753,136	1,340	9.7
Tampa/St. Petersburg [b]	2,062,339	450	5.5
St. Louis	2,077,662	640	6.8
New Orleans	1,009,283	920	2.8
Charlotte	758,927	880	5.0
Nashville	749,935	470	4.8
Omaha	626,623	450	8.0
Little Rock	360,331	460	4.2
Erie	194,804	580	2.9
Binghamton	158,884	620	5.9

Source: Revenue hours of service from National Transit Database, 2000; number of stops from individual transit agencies.

Notes: a) Philadelphia has two major providers, SEPTA and NJ Transit. Per capita measures are based only on SEPTA figures and the Philadelphia urbanized area population in Pennsylvania, 3.57 million. b) Transit service figures for Pinellas Suncoast Transit and the Hillsborough Area Regional Transit Authority are summed for Tampa/St. Petersburg.

Several metro areas have more than one transit agency. We generally developed measures only for the main provider in each region. Six regions have only one provider, and five other regions have at least

80 percent of their fixed route service supplied by a single operator. The two exceptions are Philadelphia, which has rail and bus service supplied by both SEPTA and New Jersey Transit, and Tampa/St. Petersburg area, with major bus service provided by both Hillsborough Area Regional Transit and Pinellas Suncoast Transit. In Philadelphia, we used only the SEPTA figures because it was not possible to determine the portion of New Jersey Transit service provided in the Philadelphia area (as opposed to elsewhere in New Jersey). In Tampa/St. Petersburg, we added together the service figures for the two bus providers. In all regions, we summed bus and rail service, but excluded demand-responsive service.

Note that there is not always a strong correlation between revenue-hour density and transit stop density. New Orleans, for example, has the highest revenue-hour density in its size cohort but the lowest transit stop density. This is likely due to the very high population density of New Orleans and the frequent transit service provided over a relatively small land area.

3.3 Transportation Performance Measures

We measure transportation system performance in five categories: automobile use, roadway congestion, transit use, traffic safety, and emissions. Many of these measures are frequently used in long-range transportation plans and other comprehensive planning efforts.

Automobile Use

We asked the metropolitan planning organization (MPO) in each of the 13 study regions to provide the following regional performance measures:

- Vehicle miles of travel (VMT) per capita (average weekday)
- Vehicle hours of travel (VHT) per capita (average weekday)
- Vehicle trips per capita (average weekday)
- Average vehicle trip length (average weekday)
- Vehicle ownership per household

These measures, shown in Table 7, are typically estimated using the MPO's regional travel demand model. In a few cases, the measures come directly from a household travel survey. It should be noted that the sophistication and quality of the models varies greatly among regions. Larger regions often maintain more complex models that are better able to estimate mode choice and to account for the effects land use and urban design on walking trips.

Measures of automobile use are designed to capture the extent of travel conducted by automobile. In most cases, greater levels of VMT, VHT, vehicle trips, and trip lengths correspond with higher motor vehicle emissions of criteria pollutants and greenhouse gases, and more negative effects on air and water quality.

VMT per capita per day measures how many miles individuals drive each day. This performance measure is typically the one most closely correlated with automobile emissions. Lower VMT per capita can be an indicator that other travel modes (transit, ridesharing, walking, bicycling) are viable and widely used, and that vehicle trips are shorter because of route directness and more extensive land use mixing and a better regional balance of jobs and housing.

VHT per capita per day shows the average amount of time motorists spend driving each day. A lower rate of VHT per capita can indicate that destinations are closer together and therefore take less travel time to reach, or that there is less traffic congestion in an area, or that other route choices are available to avoid congestion.

Vehicle trip rates measure the propensity of individuals to take automobile trips. Lower vehicle trips per capita typically indicates that other travel modes are used more widely. Because an automobile emits a burst of pollutants every time it is started, reducing vehicle trips can have significant air quality benefits, even if VMT remains unchanged.

Vehicle trip length measures the average distance of automobile trips. Shorter average trip lengths mean that more direct routes are available and that destinations are closer together and transport distances are minimized. Both VHT and average vehicle trip length are related to accessibility, which refers to "the ease with which desired activities can be reached from any location."[16]

Vehicle ownership per household is not, strictly speaking, a measure of system performance. However, many studies have found that households with fewer vehicles tend to drive less. Lower auto ownership is enabled by neighborhoods that offer dense and frequent transit service, a well-connected and pleasant pedestrian environment, and commercial and employment locations in close proximity to residences.

It can be argued that vehicle ownership is an independent variable, influenced more by personal choice and household income than the transportation system, and many MPOs treat it as such in their travel demand forecasting. However, some studies have found that high quality transit systems and the ability to access destinations on foot has some influence on household vehicle ownership.[17] Given these relationships we elected to include vehicle ownership as a system performance measure.

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[16] Ewing, Reid, 1995, "Measuring Transportation Performance," *Transportation Quarterly*, Vol. 49.

[17] See for example, Holtzclaw, John, "Designing Cities to Reduce Driving and Pollution: New Studies in Chicago, LA and San Francisco," presented at the Air & Waste Management Association's 90th Annual Meeting & Exhibition, June 8-13, 1997, Toronto, Ontario, Canada 97-TP60.02; Schimek, Paul, 1996, "Household Motor Vehicle Ownership and Use: How Much Does Residential Density Matter?", Washington DC: National Research Council, Transportation Research Board; and Kockelman, Kara M. 1997; "Travel Behavior as a Function of Accessibility, Land Use Mixing and Land Use Balance: Evidence From the San Francisco Bay Area," Washington, D.C.: National Research Council, Transportation Research Board.

Table 7: Automobile Use Measures for the 13 Study Regions

	VMT per capita per day	VHT per capita per day	Vehicle trips per capita per day	Average vehicle trip length (miles)	Vehicle ownership per household
Philadelphia	18.8	1.1	3.1	6.7	1.5
Atlanta	33.4	1.3	3.0	9.6	2.2
Houston	26.6	0.7	2.7	9.7	1.7 [b]
Pittsburgh	24.8	0.8	2.6	9.8	1.5
Tampa/ St. Petersburg	24.3	0.8	2.9	8.5	1.6
St. Louis	30.0	1.0	4.0	8.6	1.7 [b]
New Orleans	16.0	0.5	2.5	5.1	1.4
Charlotte	33.7	1.0	4.4	10.6	1.8
Nashville	31.0	0.8	2.8	11.1 [a]	1.8
Omaha	21.8	0.6	3.4	6.7	1.7
Little Rock	32.0	0.8	3.5	9.1 [a]	2.1
Erie	16.2	0.4	1.7	9.5	1.6 [b]
Binghamton	33.1	1.1 [c]	3.8	8.0	1.8

Source: Individual metropolitan planning organization for each region (See Appendix for details).
Notes: (a) ICF Consulting estimate based on reported VMT and vehicle trips; (b) ICF Consulting estimate based on U.S. Census data; (c) drivers only.

Congestion

Roadway congestion is another measure of transportation system performance. Unfortunately, many MPOs do not maintain data on roadway congestion, and among those that do, congestion is not reported in a consistent manner. As an alternative, we obtained roadway congestion estimates from the Texas Transportation Institute's (TTI) *2002 Annual Urban Mobility Report*. This report estimates congestion using a consistent methodology at the level of urbanized area. We recognize that the TTI estimates have several limitations—most notably, the measure is generally not based on actual delay but rather on estimates of traffic volume and highway capacity.[18]

Table 8 shows a common traffic congestion measure, delay per peak-period traveler (private vehicle road travelers only). The measure is calculated as the total annual person road delay divided by the number of peak-period road travelers, with the peak period defined as 6:00 a.m. to 9:30 a.m. and 3:30 p.m. to 7:00 p.m. Note that TTI congestion estimates are developed only for the 75 largest metro areas; no information is available for Little Rock, Erie, and Binghamton.

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[18] To estimate congestion in each urban area, TTI uses information about the volume of travel and the road capacity from HPMS data. Travel delay is calculated based on standard equations estimating travel time based on a roadway volume to capacity ratio.

Table 8: Congestion Measure for the 13 Study Regions

	Average annual delay per peak-period traveler (hours)
Philadelphia	42
Atlanta	70
Houston	75
Pittsburgh	15
Tampa/St. Petersburg	45
St. Louis	43
New Orleans	22
Charlotte	47
Nashville	44
Omaha	25
Little Rock	N/A
Erie	N/A
Binghamton	N/A

Source: Texas Transportation Institute, *2002 Annual Urban Mobility Report*, Exhibit A-5.

Transit Use

Measures of transit use assess the degree to which a region's residents take advantage of alternatives to automobile travel. Although transit use is clearly related to transit supply—people will ride transit more frequently if there is more of it to ride, and transit service will be cut back if it lacks ridership—transit use also depends on the transportation system as a whole in that good connectivity and a supportive pedestrian environment will improve access to transit stops.

We compiled transit trips per capita based on annual unlinked transit trips as reported in the National Transit Database (NTD)[19]. This measure is not strictly analogous to vehicle trips per capita because NTD data are reported on an annual basis rather than an average weekday. However, the NTD transit measure has the advantage of being developed using a consistent methodology and is comparable across regions. Table 9 shows transit usage measured as weekly transit trips per capita.

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[19] An unlinked transit trip is a trip on one transit vehicle. A person riding one vehicle from origin to destination takes one unlinked trip; a person who transfers to a second vehicle takes two unlinked trips; etc. A linked trip includes all segments on all vehicles used to travel from origin to destination.

Table 9: Transit Use Measure for the 13 Study Regions

	Weekly unlinked transit trips per capita
Philadelphia	1.18
Atlanta	0.92
Houston	0.44
Pittsburgh	0.82
Tampa/St. Petersburg	0.48
St. Louis	0.48
New Orleans	1.07
Charlotte	0.34
Nashville	0.18
Omaha	0.13
Little Rock	0.19
Erie	0.28
Binghamton	0.47

Source: National Transit Database, 2000.

Traffic Safety

Traffic safety is an important measure of regional transportation system performance. The National Center for Statistics and Analysis at the National Highway Traffic Safety Administration maintains a database of fatal roadway accidents called the Fatality Analysis Reporting System (FARS). FARS data consist of information on all fatal motor vehicle crashes within the U.S., including commercial vehicles and crashes that kill pedestrians and bicyclists. We obtained the number of annual fatalities for every region by totaling fatalities for all counties in the MPO.

Table 10 contains two comparisons of annual fatality rates: per million population and per billion VMT. The first measure reflects the likelihood of a traffic fatality for all residents within the MPO area, regardless of the amount of driving. A lower rate of traffic fatalities per capita generally indicates less vehicle use, as well as a safer driving environment. The second measure reflects the likelihood of a traffic fatality per mile driven. Differences in this measure are due to characteristics of the driving environment (roadway design and type, vehicle speeds, etc.) and the driving population (age, driving skill, etc.).

While the data report gross fatalities, they do not examine some of the underlying factors that influence roadway safety. For instance, the data do not capture seat belt usage and laws in various jurisdictions, which play a critical role in reducing fatalities, nor do the data reflect an area’s drunken driving trends.

Table 10: Traffic Safety Measures for the 13 Study Regions

	Fatalities per million population per year	Fatalities per billion VMT per year
Philadelphia	66	9.6
Atlanta	119	9.8
Houston	137	14.2
Pittsburgh	99	10.9
Tampa/St. Petersburg	179	20.2
St. Louis	89	8.1
New Orleans	112	19.2
Charlotte	145	11.8
Nashville	175	15.5
Omaha	81	10.1
Little Rock	190	16.3
Erie	135	22.9
Binghamton	107	8.9

Source: Fatality Analysis Reporting System (FARS), National Highway Traffic Safety Administration.

Emissions

If a smart growth transportation system results in less automobile use as compared to conventional systems, this should be evident as fewer air pollution emissions from on-road vehicles. We obtained the emissions inventory for on-road sources of nitrogen oxides (NO_x) and volatile organic compounds (VOC) for regions classified as nonattainment or maintenance areas for ozone, shown in Table 11. For these nine regions, the emissions estimates were originally developed for the State Implementation Plan (SIP); emissions estimates were not available for the other four regions. In the case of the Philadelphia region, emissions data were available only for the Pennsylvania and New Jersey portions of the metro area, and emissions per capita was calculated using only the population in the corresponding counties.

Vehicle NO_x emissions are primarily caused by steady-state vehicle operation, and thus a function of VMT. Vehicle VOC emissions are caused by steady-state operation as well as vehicle starts and refueling, and thus a function of VMT, vehicle trips, and other factors. The data in Table 11 show that NO_x emissions are generally correlated with VMT, with the exception of Nashville. VOC emissions are less correlated with VMT. A number of factors may contribute to the counterintuitive results in some size groups. One is vehicle speed; per mile NO_x emission rates rise rapidly at higher vehicle speeds, so metro areas with higher average speeds may experience more NO_x emission per VMT. Another factor is vehicle mix; heavy-duty vehicles (with diesel engines) have higher NO_x emission rates than light-duty vehicles, and some regions may have a larger portion of truck activity. A third factor, as mentioned above, is the influence of vehicle starts and refueling on VOC emissions. Still another factor is the existence of control measures, such as use of reformulated fuels, inspection and maintenance programs, and refueling vapor controls. In regions where these types of control measures are being implemented, NO_x and VOC emissions per VMT may be lower.

Table 11: On-Road Emissions in the 13 Study Regions[20]

	NO_x per capita (grams per day)	VOC per capita (grams per day)	VMT per capita per day
Philadelphia	44.7	40.1	18.8
Atlanta	72.2	33.0	33.4
Houston	66.8	28.6	26.6
Pittsburgh	63.8	41.0	24.8
Tampa/St. Petersburg	61.7	39.8	24.3
St. Louis	85.0	45.7	30.0
New Orleans	N/A*	N/A*	16.0
Charlotte	93.0	42.9	33.7
Nashville	125.2	47.8	31.0
Omaha	N/A*	N/A*	21.8
Little Rock	N/A*	N/A*	32.0
Erie	78.7	43.6	16.2
Binghamton	N/A*	N/A*	33.1

Source: State Implementation Plans.
Notes: All data for 1999 except Tampa (2000), St. Louis (2000), and Charlotte (1997). Partial data used for Philadelphia (Pennsylvania and New Jersey portions only). New Jersey emissions data is in draft form only.
* New Orleans, Omaha, Little Rock, and Binghamton are not designated as nonattainment for ozone air quality standards and thus not required to develop an emissions inventory. The necessary data on vehicle speeds and fleet mix were not available to support calculation of NO_x and VOC emissions for these regions.

4 COMPARISON OF SUPPLY AND PERFORMANCE MEASURES

This section discusses the relationship between the transportation system supply and performance measures, the effects of population density, and some limitations of this analysis.

4.1 Relationship Between Transportation System Supply and Performance

Do smart growth transportation systems perform better in terms of reducing vehicle travel, congestion, pollutant emissions, and vehicle fatalities? To answer this question, we must first identify which regions exhibit the characteristics of a smart growth transportation system. Compared to a conventional system, we expect a smart growth transportation system to exhibit the following characteristics:

- Smaller median block size—Smaller blocks are associated with a more pleasant and convenient pedestrian environment and more route choices.

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[20] It is unclear what drives some of the large variations in NO_x in areas that have similar amounts of VMT (e.g. Nashville's VMT/capita is 31 and the NO_x level is 125.2g/d/capita, whereas Charlotte has 33.7VMT/capita and NO_x counts of 93g/d/capita.) These figures may differ due to varying technology controls, different fleet mixes, or other factors that are not discernable from these data.

- Greater percent of blocks less than four acres—Blocks under four acres are typically less than 800 feet long and thus are easily traversed by pedestrians. A larger portion of small blocks is associated with a more pleasant and convenient pedestrian environment and more route choices.
- Greater street centerline mile density—A denser network of nonhighway streets is associated with shorter distances between intersections, which improves pedestrian connectivity, and shorter or more direct route choice for vehicles.
- Greater intersection density—Greater intersection density implies better street connectivity, shorter walking and driving distances, and more route choices.
- Greater percent of four-way intersections—Four-way intersections are an indicator of a grid street network and high connectivity. A smaller portion of four-way intersections is typical of non-grid street networks with many cul-de-sacs.
- Greater percent of major-minor intersections—This measure indicates the degree to which major streets (highway and arterials) are connected to minor streets (local streets). Street networks with a high degree of connectivity should exhibit a larger portion of major-minor intersections compared to conventional street networks in which arterial streets have relatively few access points.
- Greater transit revenue-hour density—Regions with more extensive transit network coverage and more frequent service should exhibit greater density of transit revenue hours.
- Greater transit stop density—Greater density of transit stops implies more extensive coverage of transit service and better access to transit by the region's residents and workers.

Table 12 summarizes the supply measure values and ranks the regions within each size cohort in terms of smart growth characteristics. The regions are ranked as 1, 2 or 3, with the best value in terms of smart growth characteristics in each size cohort receiving a rank of 1. Regions are ranked as tied if their values are within 10 percent of each other.[21]

Within the first three size groups, the first region listed clearly exhibits more characteristics of a smart growth transportation system than its peers. Among the largest cities, Philadelphia ranks equal to or higher than Atlanta and Houston on seven of the eight measures. In the next size group, Pittsburgh ranks the same or higher than Tampa and St. Louis on all but two measures. New Orleans tops Charlotte and Nashville on seven of eight measures.

The picture is less clear for the smallest two size groups. Omaha and Little Rock as essentially tied, with each city ranking first on three measures. Erie has a slight edge over Binghamton, ranking higher on three measures and lower on two.

Thus, we conclude that among the study regions Philadelphia, Pittsburgh, New Orleans, and Erie most exemplify the characteristics of a smart growth transportation system within their respective size groups. These four regions are shown in bold type in Table 12.

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[21] In two cases, the mid-scoring region was within ten percent of both the highest and lowest regions, but the highest and lowest regions were not within ten percent of each other. In such cases, the middle region was ranked with the region it scored closest to.

Table 12: Summary and Ranking of Transportation Supply Measures

	Median block size (acres)		Percent of blocks under 4 acres		Centerlines miles per square mile		Intersections per square mile		Percent of four-way intersections		Percent of major-minor intersections		Transit revenue-hour density		Transit stop density	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Philadelphia	**3.9**	**1**	**51%**	**1**	**10.6**	**1**	**57**	**1**	**28%**	**2**	**23%**	**1**	**1,540**	**1**	**3.4**	**1**
Atlanta	8.9	3	23%	3	7.8	2	31	3	15%	3	21%	2[a]	860	2	3.4	1
Houston	5.8	2	34%	2	10.5	1	51	2	33%	1	19%	2[a]	680	3	2.8	2
Pittsburgh	**2.7**	**1**	**65%**	**1**	**10.6**	**2**	**59**	**2**	**28%**	**1**	**25%**	**1[b]**	**1,340**	**1**	**9.7**	**1**
Tampa/St. Petersburg	4.0	2	50%	2	11.9	1	69	1	27%	1	20%	2	450	3	5.5	3
St. Louis	5.2	3	36%	3	11.4	1	59	2	25%	2	25%	1[b]	640	2	6.8	2
New Orleans	**3.1**	**1**	**64%**	**1**	**17.0**	**1**	**107**	**1**	**52%**	**1**	**32%**	**1**	**920**	**1**	**2.8**	**2**
Charlotte	7.8	2	24%	2	7.9	2	35	2	17%	3	26%	2	880	2	5.0	1
Nashville	7.9	2	24%	2	8.3	2	33	2	21%	2	27%	2	470	3	4.8	1
Omaha	4.8	2	38%	2	12.7	1	71	1	33%	1	24%	2	450	1	8.0	1
Little Rock	3.7	1	53%	1	10.4	2	55	2	30%	1	32%	1	460	1	4.2	2
Erie	**5.4**	**1**	**29%**	**2**	**11.1**	**1**	**55**	**1**	**38%**	**1**	**27%**	**1**	**580**	**1**	**2.9**	**2**
Binghamton	5.1	1	36%	1	9.6	2	46	2	21%	2	28%	1	620	1	5.9	1

[a] Atlanta's 20.6% was closer to Houston's 19% than to Philadelphia's 22.6%; therefore Atlanta and Houston are both ranked 2, while Philadelphia is ranked 1. [b] Tampa's 26.8% was closer to Pittsburgh's 27.9% than to St. Louis' 24.7%; therefore, Tampa and Pittsburgh are ranked together as 1, while St. Louis is ranked 2.

Superior performance of a transportation system is characterized by the following elements:

- Lower VMT per capita—VMT is the most common measure of automobile use. Lower VMT generally indicates fewer vehicle emissions of air pollutants and greenhouse gases, and less negative effect on air and water quality. It is also an indicator that household needs can be accomplished with less driving.
- Lower VHT per capita—Lower VHT means less time spent traveling in automobiles, which generally indicates fewer vehicle emissions of air pollutants and greenhouse gases and possibly less roadway congestion. Lower VHT also indicates a greater degree of mobility and accessibility and overall convenience.
- Fewer vehicle trips per capita—Fewer vehicle trips generally indicates greater use of transit, ridesharing, walking, and bicycling. Because automobiles emit a large burst of pollutants when started, reducing vehicle trips has air quality benefits even if VMT remains unchanged.
- Shorter average trip length—Shorter trips are possible when residential, commercial, and employment locations are located in close proximity and when routes are more direct. Shorter trip length may indicate less automobile use and associated environmental impacts (unless it occurs in conjunction with more vehicle trips).

- Lower automobile ownership per household—Lower auto ownership is possible in neighborhoods where transit, walking, and bicycling are viable options. This gives households a choice about how many vehicles to own. Other research has found that households with fewer vehicles tend to drive less, generating fewer negative effects on air and water quality.
- Less annual delay per peak-period traveler—This measure indicates the amount of congestion faced by automobile commuters. Less roadway congestion is a sign of superior performance of the roadway system and may reflect the presence of viable alternatives to driving.
- More weekly transit trips per capita—This measure indicates the extent of transit use of a region's residents. Transit trips generally result in much lower pollutant and greenhouse gas emissions than automobile trips.
- Fewer traffic fatalities per billion VMT per year—A lower score on this measure indicates a safer driving environment.
- Fewer traffic fatalities per million population per year—A lower score on this measure indicates less vehicle use as well as a safer driving environment.
- Lower on-road NO_x emissions per capita—NO_x is a primary component of ground-level ozone (smog). On-road NO_x emissions are correlated with the amount and speed of vehicle travel (light-duty and heavy-duty vehicles). Per-mile emissions of NO_x tend to rise at speeds over 30 mph. Lower NO_x emissions per capita indicate less automobile travel and possibly lower vehicle speeds.
- Lower on-road VOC emissions per capita—VOCs are a primary component of ground-level ozone. On-road VOC emissions are correlated with the amount of light-duty vehicle travel and the number of light-duty vehicle starts. Lower VOC emissions per capita indicate less automobile use.

Table 13 summarizes the transportation performance measures and ranks the regions in terms of superior performance within each size cohort. Our results found that every region identified as the smart growth system (in bold) exhibits the best overall performance. Compared to their peers, Philadelphia, Pittsburgh, New Orleans, and Erie have lower VMT per capita. Philadelphia and Pittsburgh rank highest within their respective groups on eight of the eleven performance measures, while New Orleans ranks highest on all but one measure.

The largest three smart growth regions experience considerably less congestion and more transit trips than their peers. These results suggest that system characteristics can affect performance—regions with more smart growth characteristics in their transportation systems exhibit less vehicle travel and traffic congestion.[22] In the fifth size group, Omaha and Little Rock are essentially equivalent in terms of smart growth system characteristics, so the relationship between supply and performance is unclear.

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[22] Some of the results in Table 13 are ambiguous or contradict the overall conclusion. For example, Philadelphia does not have the lowest VHT per capita among its peers, despite top ranking on other auto use and congestion measures. This may be a product of differences in MPO methods for estimating travel time. For example, VHT figures for Houston exclude intra-zonal trips, which may have the effect of reducing this measure.

Table 13: Summary and Ranking of Transportation Performance Measures

	VMT per capita per day		VHT per capita per day		Vehicle trips per capita per day		Average vehicle trip length		Vehicle ownership per household		Annual delay per peak-period traveler (hours)		Weekly transit trips per capita		Fatalities per billion VMT per year		Fatalities per million population per year		NO_x emissions per capita (grams per day)		VOC emissions per capita (grams per day)	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Philadelphia	**18.8**	**1**	**1.1**	**2**	**3.1**	**2**	**6.7**	**1**	**1.5**	**1**	**42**	**1**	**1.18**	**1**	**9.6**	**1**	**66**	**1**	**45**	**1**	**40**	**3**
Atlanta	33.4	3	1.3	3	3.0	2	9.6	2	2.2	3	70	2	0.92	2	9.8	1	119	2	72	2	33	2
Houston	26.6	2	0.7	1	2.7	1	9.7	2	1.7	2	75	2	0.44	3	14.2	2	137	3	67	2	29	1
Pittsburgh	**24.8**	**1**	**0.8**	**1**	**2.6**	**1**	**9.8**	**2**	**1.5**	**1**	**15**	**1**	**0.82**	**1**	**10.9**	**2**	**99**	**2**	**64**	**1**	**41**	**1**
Tampa/St. Peters.	24.3	1	0.8	1	2.9	2	8.5	1	1.6	1	45	2	0.48	2	20.2	3	179	3	62	1	40	1
St. Louis	30.0	2	1.0	2	4.0	3	8.6	1	1.7	1	43	2	0.48	2	8.1	1	89	1	85	2	46	2
New Orleans	**16.0**	**1**	**0.5**	**1**	**2.5**	**1**	**5.1**	**1**	**1.4**	**1**	**22**	**1**	**1.07**	**1**	**19.2**	**3**	**112**	**1**	**N/A**	**-**	**N/A**	**-**
Charlotte	33.7	2	1.0	3	4.4	3	10.6	2	1.8	2	47	2	0.34	2	11.8	1	145	2	93	-	43	-
Nashville	31.0	2	0.8	2	2.8	2	11.1	2	1.8	2	44	2	0.18	3	15.5	2	175	3	125	-	48	-
Omaha	21.8	1	0.6	1	3.4	1	6.7	1	1.7	1	25	-	0.13	2	10.1	1	81	1	N/A	-	N/A	-
Little Rock	32.0	2	0.8	2	3.5	1	9.1	2	2.1	2	N/A	-	0.19	1	16.3	2	190	2	N/A	-	N/A	-
Erie	**16.2**	**1**	**0.4**	**1**	**1.7**	**1**	**9.5**	**2**	**1.6**	**1**	**N/A**	**-**	**0.28**	**2**	**22.9**	**2**	**135**	**2**	**79**	**-**	**44**	**-**
Binghamton	33.1	2	1.1	2	3.8	2	8.0	1	1.8	2	N/A	-	0.47	1	8.9	1	107	1	N/A	-	N/A	-

4.2 Discussion of Lane-Miles Supplied and Performance

While not included as a ranked supply measure, we wanted to examine the relationship between lane miles per capita (1000) and system performance. Though not documented in the literature, some have suggested that increasing the amount of miles of roadway per person should have a salutory impact on transportation performance.

The lane miles per 1000 persons are included in Table 14, and the bolded regions are those with the best overall performance scores. Within its cohort, New Orleans has the *least* lane miles/person and has the best overall performance. Conversely, Pittsburgh has the *most* lane miles/person in its cohort and has the best overall performance. These results suggest that lane miles per capita alone are not a dominant factor in determining performance. Rather, factors such as connectivity, transit availability, and an improved pedestrian environment seem to have a more pronounced affect on performance. The second part of this study focuses more particularly on this issue and explores it in greater depth.

Table 14: Lane Miles per 1000 Capita 13 Study Regions

	Lane miles per 1000 capita
Philadelphia	**9.1**
Atlanta	10.5
Houston	8.5
Pittsburgh	**12.5**
Tampa/ St. Petersburg	11
St. Louis	10.9
New Orleans	**8.5**
Charlotte	11
Nashville	12.1
Omaha	**11.3**
Little Rock	15
Erie	**10.6**
Binghamton	12

4.3 Effects of Population Density

Transportation system characteristics are just one of many factors that affect travel behavior and system performance. Some of these factors, such as regional economic conditions and the spatial arrangement of land uses are complex and difficult to control for in a study such as this. Population density is one factor that can influence system performance and can be controlled for at the regional level.

Studies suggest that people living in areas of higher density residential development generally travel more by walking, bicycling, and transit, take shorter automobile trips, and own fewer automobiles per household.[23] There are several reasons for this. First, higher densities tend to bring more destinations within an acceptable range for walking. Second, higher densities can support more frequent transit service, which makes this option more attractive. Finally, higher density tends to have higher land values and thus higher prices for parking, which encourages drivers to find alternative travel modes.

Given that density is known to affect travel behavior, we focus on pairs of regions that are closely matched in density (see Table 3 for population density). In these regions, are smart growth transportation system characteristics associated with superior performance? If so, then the superior performance is likely a result of the supply characteristics at least in part, rather than a result of density differences. The answer to this question appears to be yes.

Philadelphia and Houston best exemplify this relationship. Philadelphia has an urbanized area population density within three percent of Houston's. Yet Philadelphia ranks higher than Houston on smart growth supply measures of block size, intersection density, and transit service. These results suggest that a) density is not likely to be a critical determinant of system performance in this example and b) that system characteristics are partially responsible for Philadelphia's superior system performance in terms of lower VMT per capita, less traffic congestion, higher transit ridership, and fewer pollutant emissions.

Tampa and St. Louis also support this conclusion. Although closely matched in density, Tampa ranks better than St. Louis on smart growth street network measures, and shows superior performance in terms of VMT per capita, vehicle trips per capita, and vehicle trip length.

These results suggest several interesting concepts. The first, as demonstrated by looking at Philadelphia and Houston (areas with like densities), is that higher density regions that do not have a transportation system with smart growth characteristics tend not to perform at the same level as areas that effectively combine density with a smart growth transportation system. Second, the effects of density and a smart growth transportation system on performance are not additive but synergistic, creating enhanced performance when the two are combined.

4.4 Study Limitations

Several factors limit our ability to draw conclusions from the approach just described. Because of these limitations, this study should be considered exploratory research that helps inform options for characterizing smart growth transportation systems on a regional scale and also sheds light on how system characteristics affect travel and system performance. In the process of conducting this study, it became apparent that a great deal of research should be done to better examine how various investments in infrastructure are performing—environmentally, economically, and from a traditional transportation engineering perspective. This work should be seen as a beginning of that inquiry.

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[23] See for example: Holtzclaw, John, 1994, *Using Residential Patterns and Transit to Decrease Auto Dependence and Costs*, National Resources Defense Council; Cervero, Robert, 1996, "Mixed Land Uses and Commuting: Evidence from the American Housing Survey," *Transportation Research*, Vol. 30, No. 5; Frank, L. and G. Pivo, 1994, "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit and Walking," *Transportation Research Record 1466*.

Methodological Limitations

In addition to transportation system characteristics, many other factors influence travel and transportation system performance. Aside from population density, we do not attempt to control for these factors in the study. For example, employment rates affect travel patterns—driving and congestion tend to increase when the economy is strong and unemployment is low.

Differences in income levels may contribute to differences in vehicle use. Higher income individuals tend to drive more (because they can afford more reliable automobiles, they take more non-work trips, etc.). In comparing the median household income to VMT (both shown in Table 3), there does appear to be a relationship between income and vehicle travel, although the relationship is not entirely consistent. In the three largest size cohorts, the region with the highest average income exhibits the highest per capita VMT (Atlanta, St. Louis, and Charlotte). However, this trend does not hold in the two smallest size cohorts.

Land use is also likely responsible for some of the differences in transportation system performance that we observe. In terms of the four-step travel demand forecasting process, the regional arrangement of land use strongly affects trip distribution (i.e., where trips go once they are generated). Transportation system supply would affect mode choice, because high connectivity and a pedestrian-friendly environment can make some modes more attractive and affect route assignment, because a well-connected grid system allows shorter, more direct routes. However, it may be that the effects of land use on trip distance (and hence VMT) would partially or fully obscure the influence of system supply.

Finally, the study does not account for intra-regional variations. The averages for each region may mask significant differences in everything from transit density to VHT per capita. This may be particularly true for regions such as Philadelphia where a substantial portion of the central city and inner ring suburbs developed before the prominence of the automobile but the outer portions developed later along an auto-centered model. The scope of this study did not allow for the consideration of sub-regional variations.

Data Limitations

For measures of automobile use, we rely primarily on data developed and reported by the MPOs. The advantage of these data is that they are developed locally and hence should be more accurate than national sources based on sampling (like HPMS, FHWA’s Highway Performance Monitoring System). A disadvantage is that MPOs may use different techniques to develop travel measures, making comparisons across regions inappropriate. Although we attempted to collect data that are comparable, we did not review the details of travel modeling practices and therefore cannot ensure that all figures are reported on a consistent basis.

Even when developed with a consistent methodology, measurements of regional vehicle travel have a margin of error. VMT is often estimated using a travel model calibrated to traffic counts on higher functional class roads. Travel on local streets and minor collectors is not directly included in travel models, but rather is usually added to the VMT total as a fixed percentage. Yet it is this local street travel that we expect to be most influenced by street connectivity. It may be that the errors associated with estimating regional VMT are a significant portion of the reported differences in VMT per capita between regions.

Transit data, either reported in the NTD or reported directly to us, may suffer from inconsistent methodologies applied by transit agencies. It may also be true for the reported number of transit stops, which in some cases are unpublished estimates supplied to the study team.

Area Definition Limitations

In our GIS analysis of street networks, we use the definition of urbanized area provided by the 2000 U.S. Census. The urban area boundary is drawn using a complicated process that accounts for density as well as the relationship between outlying communities and the central core. As a result, the urban area boundary meanders extensively and often includes long narrow extensions from the central core. Because we used this boundary to “clip” the street network for our analysis, many streets on the urban fringe get cut off when they enter a rural area. The resulting street network is not the one actually provided to drivers on the urban edge, and it may distort some of the street network measures. However, we assume that any distortion occurs consistently across regions, and therefore our comparative analysis is valid.

Another area definitional issue is raised by the MPO-provided performance data. MPO boundaries are often political ones (e.g., counties), and most MPOs cover an area far larger than the actual urbanized area. The MPO system performance data is usually reported for the travel demand modeling area, which may or may not be the same as the MPO’s jurisdictional boundary. Thus, we introduce an unavoidable inconsistency by comparing supply measures based on urbanized area with performance measures based on MPO model area boundaries. Because the non-urban areas within MPO boundaries contain few inhabitants and few travelers, we believe any errors caused by this inconsistency are minimal.

4.5 Further Research

The results of this analysis strongly suggest 1) a critical need for further and more extensive research and 2) a need for better and more consistent data collection across jurisdictions.

The U.S. invests billions of dollars in transportation improvements, yet there is very little research examining how these investments affect transportation and environmental performance. The results of this study make clear that differences in transportation system characteristics can be observed at the metropolitan scale and can impact how various transportation investments perform. The study finds that regions with more characteristics of a smart growth transportation system tend to exhibit superior performance compared to regions of similar size. This finding is consistent with the previous research that examined transportation system effects at a more disaggregate scale (e.g., by census tract). Further research could address some of the methodological limitations described above. For example, metropolitan areas with similar income, unemployment, and vehicle ownership statistics could be chosen as a way to help control for the influence of economic factors. It might also be possible to incorporate and help control for land use patterns, if such data were available for entire metro areas in a consistent format.

This research has also demonstrated the need for more consistent data collection. The lack of data in some places, the variety of methods to develop particular measures of performance, and the housing of data within different agencies, make this kind of analysis more difficult. It seems that a large-scale effort to improve data collection and consistency would be a worthy endeavor.

A potentially interesting extension of this research would be to examine supply and performance measures at the sub-regional level. In terms of supply measures, GIS could be used to determine the portion of a metro area that exhibits smart growth system characteristics. Use of more disaggregate MPO travel demand model output or household travel survey data could produce some system performance measures (such as vehicle trips) at a sub-regional level.

5 LONGITUDINAL ANALYSIS

The findings from the first portion of the study suggest that characteristics such as: greater street connectivity, a more pedestrian-friendly environment, shorter route options, and more extensive transit service have a positive impact on performance. Yet when we examined the impact of lane-miles supplied per person, we found that there was not a clear relationship between greater or lesser amounts of roadway per person and system performance. In order to better isolate the issue and examine it more closely, this portion of the study looks at changes in traffic congestion over time for a set of metropolitan regions with stable or declining population and roadway capacity additions. We use traffic congestion as a surrogate for performance because there is consistent and available data over the requisite time period.

5.1 Methodology

We examine congestion changes and the implications for the environment in three metropolitan areas that a) have had stable or negative population growth, b) have increased urbanized land area, and c) have added roadway capacity. This section describes the sources for data and the method for defining and selecting study regions.

Data Sources

Many MPOs do not maintain data on roadway congestion, and almost none have these data for multiple points in time. Therefore, it was not possible to conduct this analysis using congestion data obtained directly from MPOs. As an alternative, we relied on data from the Texas Transportation Institute's (TTI) 2002 *Annual Urban Mobility Report*. This report estimates congestion using a consistent methodology conducted at a scale for which both population data and current urban area are also available. In addition, TTI data are readily available for any year from 1982 to 2000.

The *Urban Mobility Report* presents a variety of congestion measures; we chose to use "delay per peak-period traveler" because this measure best captures the degree of congestion faced by those traveling by automobile (as opposed to all modes) and is comparable across regions. The measure is calculated as the total road delay per person per year divided by the number of peak-period road travelers. The peak period is defined as 6:00 a.m. to 9:30 a.m. and 3:30 p.m. to 7:00 p.m.

We use data from FHWA's highway performance monitoring system (HPMS) to determine changes in road capacity over the study period. Note that HPMS does not have reliable data on lane-miles for minor roads (including minor arterials, collectors, and local roads). For the case of minor roads, we assume that all minor roads are two lanes, and therefore calculate lane miles by multiplying HPMS centerline miles by two. This generates a lower-bound estimate of capacity increases for minor roads.

Definition of Regions

We use urbanized area to define regions. This definition is consistent with available congestion data (TTI data is reported by urbanized area) and allows us to properly capture the actual increase in urban land area. Other regional boundaries, such as the metropolitan statistical area (MSA) or the MPO boundary, are typically defined to be consistent with county borders, and therefore incorporate large areas of undeveloped land. They may not change over time even as the region grows. Urbanized area boundaries, on the other hand, are defined by the Census Bureau as a standard separation between urban and rural territory.

Selection of Regions

Very few regions declined in population between 1980 and 2000, and most of those that did are small (under 500,000) and therefore not included in the TTI database. Table 15 shows urbanized area population for the 10 large regions that experienced the lowest annual growth rate between 1982 (the earliest year with TTI congestion data) and 2000. Note that while four of these regions declined in population during the 1980s and one declined across the entire 18-year period, not one declined during the 1990s.[24]

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[24] When measured at the MSA level, several regions show negative population growth during the 1990s.

Table 15: Ten Slowest Growth Regions[25]

Urbanized Area	Average growth per year 1982 to 2000	1982 Population	1990 Population	2000 Population
Pittsburgh, PA	-0.06%	1,810,000	1,780,000	1,790,000
Rochester, NY	0.09	640,000	615,000	650,000
Albany-Schenectady-Troy, NY	0.16	500,000	490,000	515,000
Buffalo-Niagara Falls, NY	0.18	1,075,000	1,065,000	1,110,000
Detroit, MI	0.30	3,810,000	4,000,000	4,025,000
Boston, MA	0.33	2,850,000	2,955,000	3,025,000
Cleveland, OH	0.41	1,750,000	1,790,000	1,885,000
New Orleans, LA	0.45	1,020,000	1,050,000	1,105,000
Louisville, KY-IN	0.48	770,000	810,000	840,000
St. Louis, MO-IL	0.48	1,870,000	1,960,000	2,040,000

We assume that annual population growth of 0.3 percent or less is essentially flat. Thus, among the regions for which congestion data are available, five urbanized areas fit the criterion of flat or declining population growth—the first five regions listed in Table 15. From this set we selected three regions for our study sample: Pittsburgh, Buffalo, and Detroit. This sample provides the maximum geographic diversity within the set of regions that satisfy the population growth criterion and includes the largest regions, which tend to have better system supply and performance information.

5.2 Results

Although all three regions declined or remained stagnant in total population, their urbanized areas continued to expand. Table 16 illustrates the extent of urbanized area expansion in each selected region.

Table 16: Change in the Extent of Urbanized Area[26]

	Urbanized Area (in square miles)			
	1982	1990	2000	% Change
Detroit, MI	1,090	1,255	1,315	21%
Pittsburgh, PA	680	750	1,010	49
Buffalo, NY	375	510	575	53

Road Capacity Growth

We use data from FHWA's HPMS to determine changes in road capacity over the study period. Table 17 shows the growth in total centerline miles between 1982, 1990, and 2000. Centerline miles represent additional road routes within the urban area, but do not account for lane additions to existing roads. This measure indicates new road construction in all three regions during the study period. Over the 18-year period, Detroit, Pittsburgh and Buffalo centerline miles per capita also increased.

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[25] Texas Transportation Institute, 2002, *2002 Urban Mobility Report*.
[26] Texas Transportation Institute, 2002, *2002 Urban Mobility Report*.

Table 17: Change in Total Centerline Miles and Centerline Miles per Capita [27]

	1982	1990	2000	% Change (1982 – 2000)
Total Centerline Miles				
Detroit	12,265	12,605	13,810	13%
Pittsburgh	7,695	7,565	8,440	10
Buffalo	3,285	3585	3,985	21
Centerline Miles per 1000 Capita				
Detroit	3.2	3.2	3.4	7%
Pittsburgh	4.3	4.3	4.7	11
Buffalo	3.1	3.4	3.6	17

While centerline miles represent changes in the number of road routes, lane-miles better represent the actual roadway capacity. Lane-miles are centerline miles weighted by the number of lanes of each road. Unfortunately, over the study period, HPMS reports lane miles only for major roadways (freeways and principal arterials). These are shown in the first series of columns in Table 18. As with centerline miles, major road lane-miles increase significantly for all three regions over the study period.

Minor roads (including minor arterials, collectors, and local roads) also represent important sources of regional road capacity, but consistent lane-mile data for minor roads are not available for the earlier portion of the study period. We assume that all minor roads have two lanes and apply this assumption to an estimate of minor road centerline miles to make a lower-bound estimate for minor road lane-miles.[28] The second series of columns in Table 18 presents the full study period estimates based on this assumption. As with major roads, minor road capacity additions are substantial for all three areas during the study period. These figures also show that additions of minor road lane-miles are at least double the additions of major road lane-miles, despite the conservative estimation methodology.

Table 18: Change in Roadway Lane Miles [29]

	Fwy and principal arterial lane-miles			Minor road lane-miles estimate			Total lane-miles estimate		
	1982	2000	% Change	1982	2000	% Change	1982	2000	% Change
Detroit	5,055	6,185	22%	22,466	25,016	11%	27,521	31,201	13%
Pittsburgh	2,430	2,745	13	13,852	15,296	10	16,282	18,041	12
Buffalo	1,585	1,670	5	5,736	7,102	24	7,321	8,772	20

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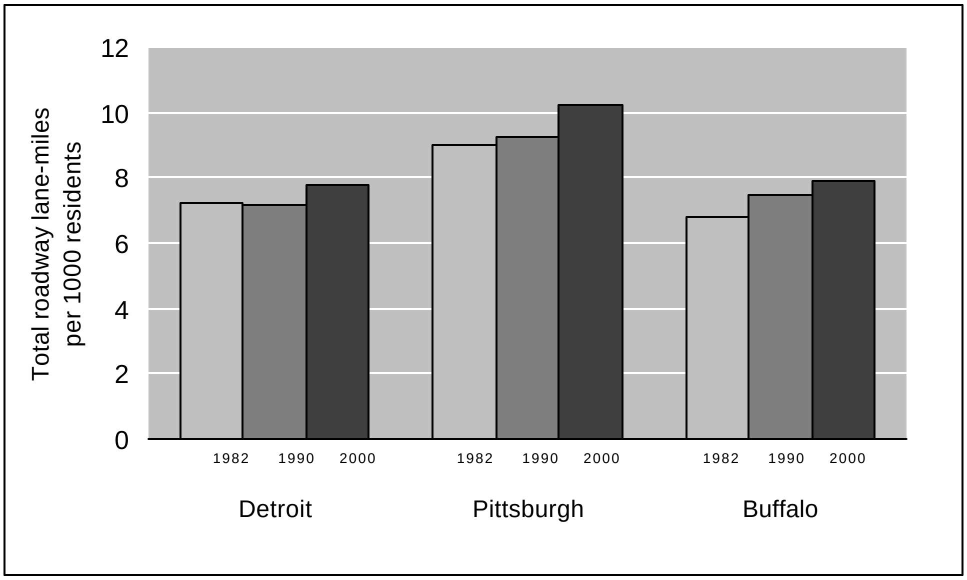
[27] Source: HPMS data.

[28] HPMS does not directly report centerline miles for minor roadways for 1982. Therefore, we calculated minor roadway centerline miles by subtracting major roadway centerline miles (available from raw HPMS data and provided to us by TTI) from total roadway centerline miles (reported in *Highway Statistics*).

[29] Source: HPMS data.

The roadway additions in Tables 17 and 18 can come from new road construction, roadway widening, and from roadways that becomes part of the urbanized area as the boundary is expanded. To control for roads that are incorporated because of an expanding urban boundary, we calculate lane-miles per person for the 3 study years. Figure 6 shows lane-miles per capita for all road types. Pittsburgh and Buffalo show an increase in road capacity per person throughout the study period, while Detroit shows a slight decline during the first decade, but an increase over the whole study period. This decline between 1982 and 1990 for Detroit occurs because the population grew more quickly than did road capacity.

Figure 6: Change in Total Roadway Capacity per Capita, 1982-2000 [30]



Congestion Impacts

This comparative analysis finds that congestion levels generally increased despite growth in land area and road capacity, and despite stable or declining population. Detroit and Buffalo experienced congestion increases across both decades, while congestion in Pittsburgh rose in the 1980s and then held steady, as shown in Figure 7.

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[30] Source: HPMS data.

Figure 7: Congestion Delay Over Time[31]

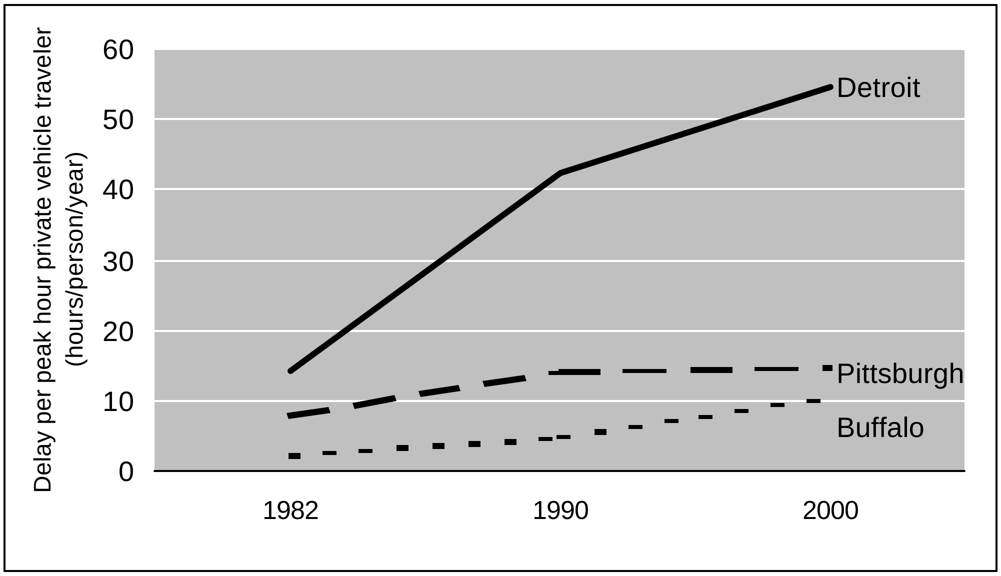

Table 19: Average Delay per Peak-Hour Private Vehicle Traveler (hours/person/year)

	1982	1990	2000
Detroit	14	42	55
Pittsburgh	8	14	15
Buffalo	2	5	11

Conclusion

While the sample includes only three regions, each shows a pattern of stable or declining population, expanding urban boundaries, additional road capacity, and increasing traffic congestion. While no conclusions can be drawn about cause and effect, this sample suggests that lane-additions and low-density growth do not by themselves prevent worsening congestion. Indeed, we can see from both the first portion of the study and this segment of the research that there is little correlation between the supply of roads per person and system performance.

These results of the entire study clearly show that a more comprehensive approach to measuring transportation system characteristics and their impacts on performance is needed. The results suggest that how transportation systems are built—with special attention paid to the degree of connectivity, pedestrian orientation and transit availability as well as targeted capacity additions—can impact how a system will perform, which has environmental implications. More research of this kind is need ed to ensure that transportation investments are meeting the goals and needs of the communities they serve. By looking at the transportation system as a whole and identifying its characteristics and examining their relationship to overall performance, we will be better able to maximize our investments.

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[31] Texas Transportation Institute, 2002, *2002 Urban Mobility Report*.

APPENDIX

5.3 Technical Notes on Development of Street Network Measures

The GIS-based analysis uses feature class codes (FCC) to develop the measures of roadway supply. A complete list of the FCC descriptions is below. The FCC value was used in developing the following measures:

- Total lane miles
- Total number of nonhighway intersections
- Total number of four-way nonhighway intersections
- Number of major-minor intersections

Total lane miles. We assume a fixed number of lanes for each road type:

- 1 lane: A01-A03, A50-A73
- 2 lanes: A00, A04-A07, A40-A48
- 4 lanes: A20-A38
- 6 lanes: A10-A18

Total number of nonhighway intersections. We distinguish between intersections involving one or more highways, and intersections of local roads. We assume that any intersection with one or more road segment of FCC value A10-A28 is a highway intersection, and the remainder is nonhighway intersections.

Total number of four-way nonhighway intersections. This measure uses the same intersection count as described above, except that we identify the number of nonhighway intersections with three legs, four legs, or more than four legs.

Number of major-minor intersections. We assume that "major" streets are FCC A10-A38, and "minor" streets are FCC A00-A07 and A40-A73. A major-minor intersection involves at least one street segment from each of these two categories.

Intersection density. To calculate the total number of intersections, we wrote a computer program that reviews and counts the number of street segments that are connected to more than one additional segment. If a street segment is connected to only one other street segment, even at an angle, then it is not considered an intersection. Any instance in which a street segment is joined to two or more additional segments in one location was considered an intersection.

FCC values:

A00	Road, classification unknown or not elsewhere classified
A01	Road, undivided
A02	Road, undivided, in tunnel
A03	Road, undivided, underpassing
A04	Road, divided
A05	Road, divided, in tunnel
A06	Road, divided, underpassing
A07	Road, divided, with rail line in center

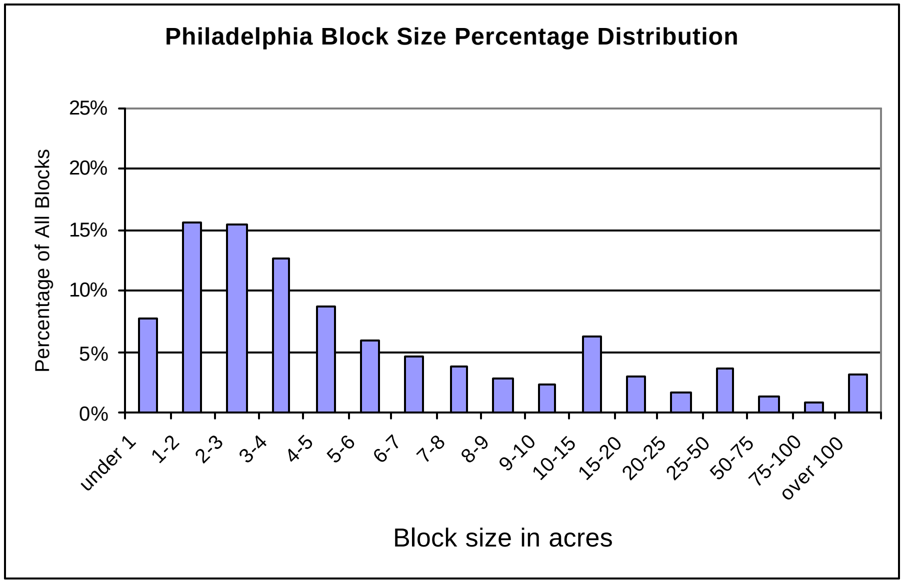
A10	Primary road, interstate highway and limited access road: This category includes interstate highways, primary U.S. highways, primary state highways, most multi-lane roads and most other limited access roads.
A11	Primary road, interstate highway and limited access road, undivided
A12	Primary road, interstate highway and limited access road, undivided, in tunnel
A13	Primary road, interstate highway and limited access road, undivided, underpass
A14	Primary road, interstate highway and limited access road, undivided, with rail line in center.
A15	Primary road, interstate highway and limited access road, divided
A16	Primary road, interstate highway and limited access road, divided, in tunnel
A17	Primary road, interstate highway and limited access road, divided, underpassing
A18	Primary road, interstate highway and limited access road, divided, with rail line in center.
A20	Secondary road, U.S. highway not classified A10, and state roads: This category includes the U.S. highways not classified as A10 state roads. Most of the roads in this category tend to be state level roads.
A21	Secondary road, U.S. highway not classified A11, and state roads, undivided
A22	Secondary road, U.S. highway not classified A12, and state roads, undivided, in tunnel.
A23	Secondary road, U.S. highway not classified A13, and state roads, undivided, underpassing
A24	Secondary road, U.S. highway not classified A14, and state roads, undivided, with rail line in center
A25	Secondary road, U.S. highway not classified A15, and state roads, divided
A26	Secondary road, U.S. highway not classified A16, and state roads, divided, in tunnel
A27	Secondary road, U.S. highway not classified A17, and state roads, divided, underpassing
A28	Secondary road, U.S. highway not classified A18, and state roads, divided, with rail line in center
A30	Connecting road, county roads, and roads not classified as A10 or A20: This category includes county roads, roads not classified A10 or A20 that connect towns or major features, and principal non-A10/A20 roads through built-up areas. Most of the roads in this category are county roads
A31	Connecting road, county roads, and roads not classified as A11 or A21, undivided
A32	Connecting road, county roads, and roads not classified as A12 or A22, undivided, in tunnel
A33	Connecting road, county roads, and roads not classified as A13 or A23, undivided, underpassing
A34	Connecting road, county roads, and roads not classified as A14 or A24, undivided, with rail line in center
A35	Connecting road, county roads, and roads not classified as A15 or A25, divided
A36	Connecting road, county roads, and roads not classified as A16 or A26, divided, in tunnel
A37	Connecting road, county roads, and roads not classified as A17 or A27, divided, underpassing
A38	Connecting road, county roads, and roads not classified as A18 or A28, divided, with rail line in center
A40	Neighborhood roads, city streets and unimproved roads: This category includes city streets in built-up areas, unpaved roads that are passable with an automobile in non-built-up areas, and all other remaining improved roads
A41	Neighborhood roads, city streets and unimproved roads, undivided
A42	Neighborhood roads, city streets and unimproved roads, undivided, in tunnel
A43	Neighborhood roads, city streets and unimproved roads, undivided, underpassing
A44	Neighborhood roads, city streets and unimproved roads, undivided, with rail line center
A45	Neighborhood roads, city streets and unimproved roads, divided
A46	Neighborhood roads, city streets and unimproved roads, divided, in tunnel
A47	Neighborhood roads, city streets and unimproved roads, divided, underpassing
A48	Neighborhood roads, city streets and unimproved roads, divided, with rail line center
A50	Class 5 road - (Jeep Trail)
A51	Class 5 road, undivided
A52	Class 5 road, undivided, in tunnel
A53	Class 5 road, undivided, underpassing
A60	Special Road Feature

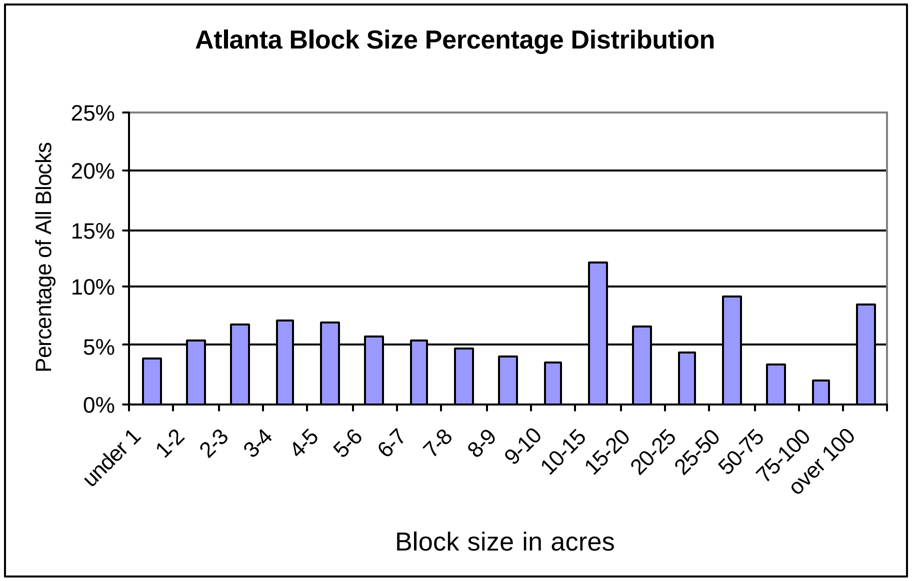
A61	Cul-de-sac
A62	Traffic circle
A63	Cloverleaf or interchange
A64	Service drive
A65	Ferry crossing
A70	Other thoroughfare
A71	Walkway
A72	Stairway
A73	Alley

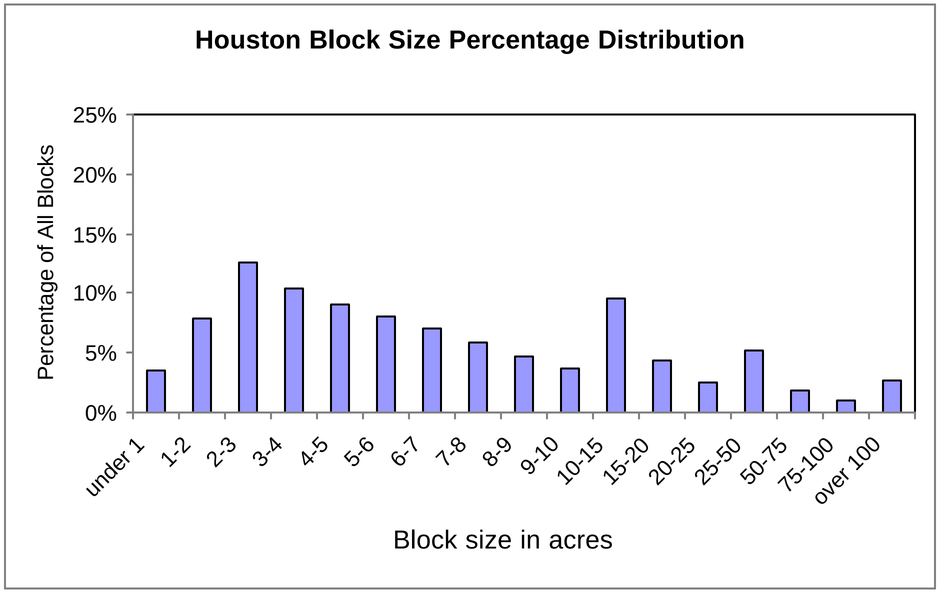
5.4 Block Size Histograms

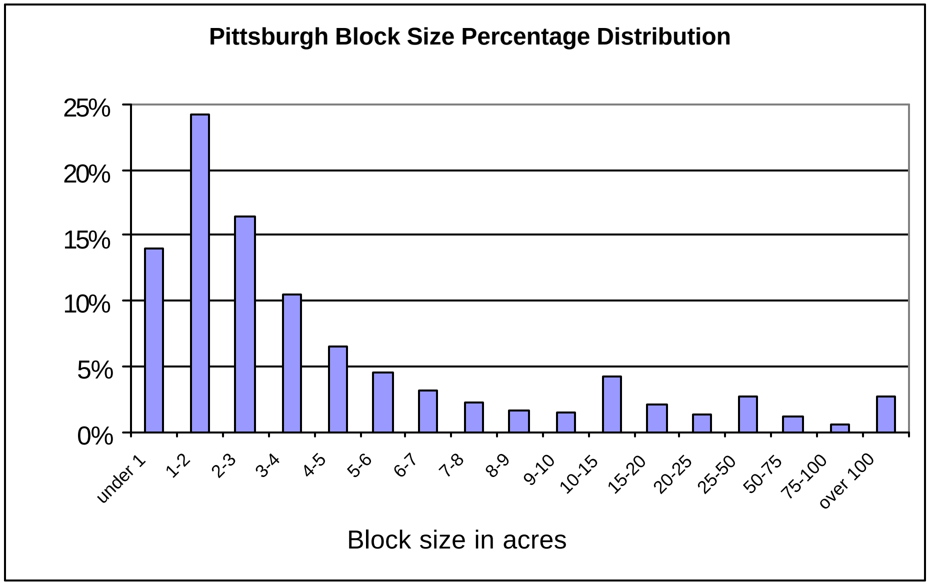
Block size calculations. We use the street network to build polygons that represent individual blocks. The area is automatically calculated for each polygon. No customized program was written to support this calculation, as area calculation for polygons is an inherent feature in the data table that accompanies all GIS polygon files in ESRI's desktop GIS tool, ArcInfo.

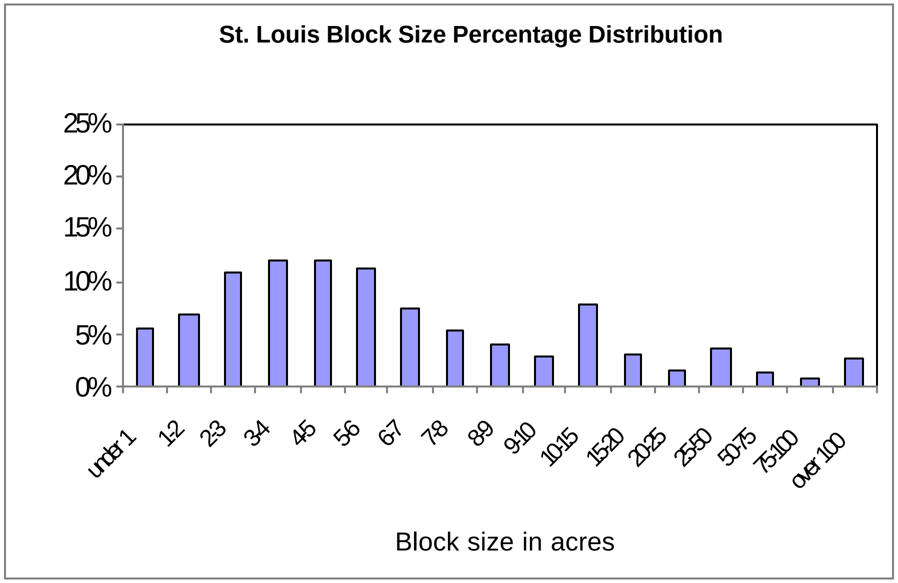
On the following pages are histograms of the block size data for each of the 13 regions. Note that for acres sizes up to 10 acres we used one-acre increments, whereas for larger sizes we combined several increments. This creates a "bump" in size beginning with the 10-15 acre increment.

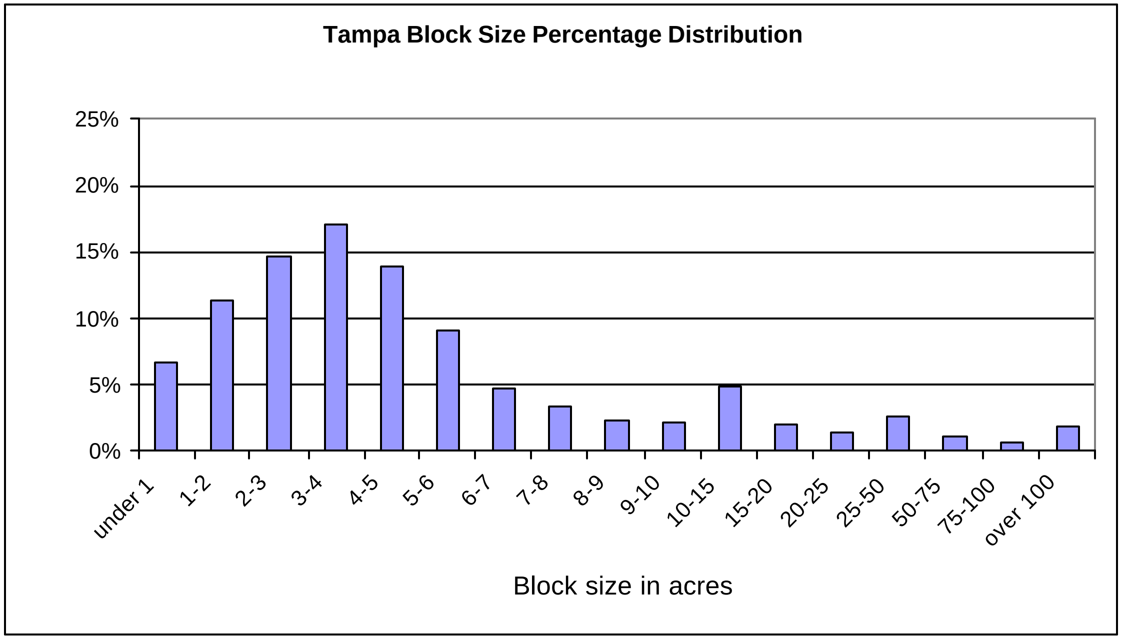

Philadelphia Block Size Percentage Distribution
Percentage of All Blocks
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres

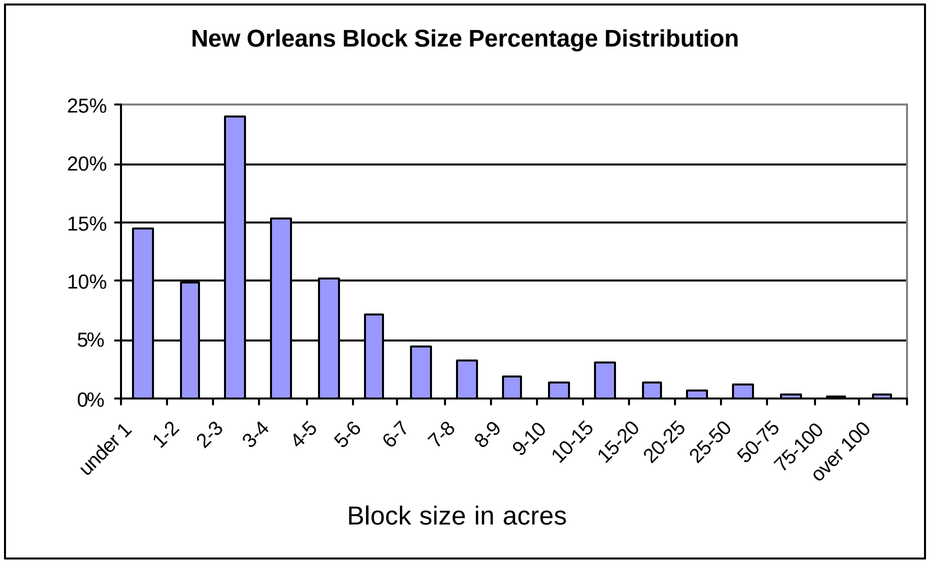

Atlanta Block Size Percentage Distribution
Percentage of All Blocks
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres

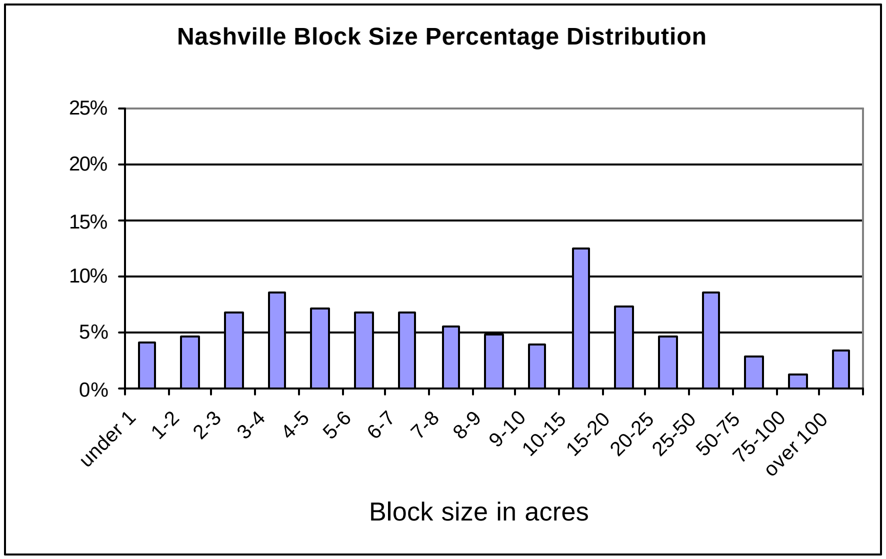

Houston Block Size Percentage Distribution
Percentage of All Blocks
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres

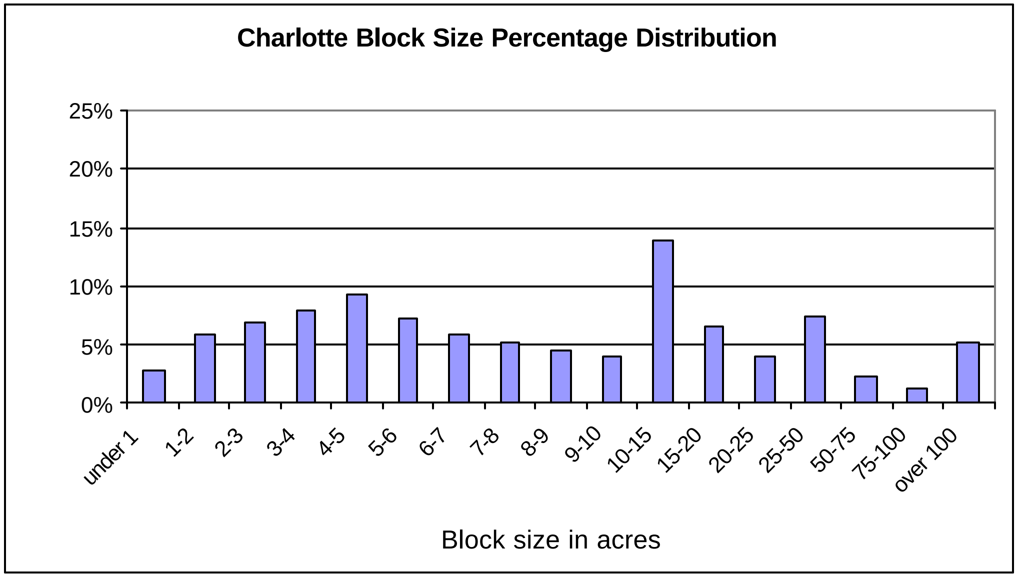

Pittsburgh Block Size Percentage Distribution
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres

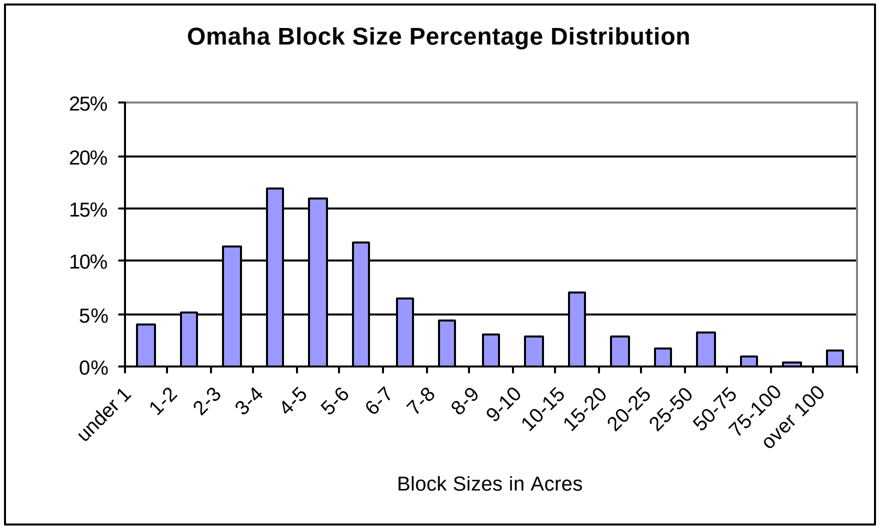

St. Louis Block Size Percentage Distribution
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres

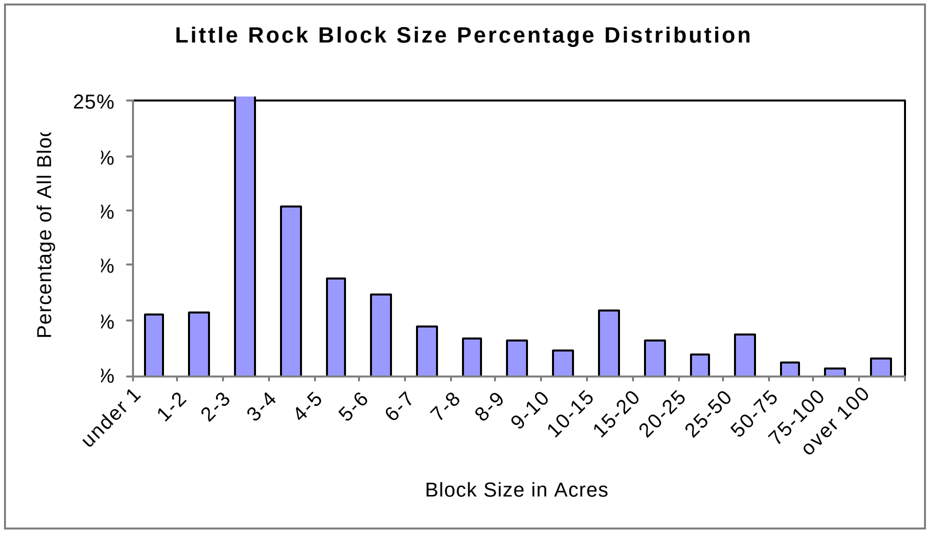

Tampa Block Size Percentage Distribution
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres

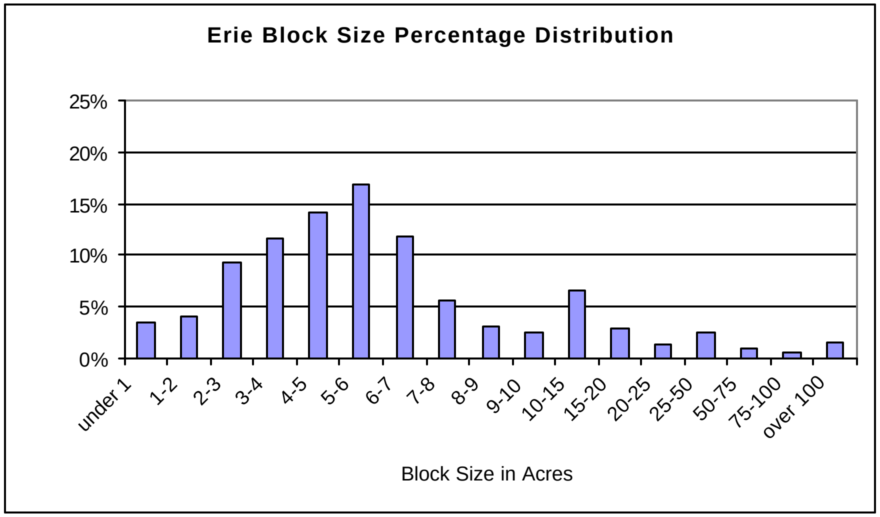

New Orleans Block Size Percentage Distribution
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres

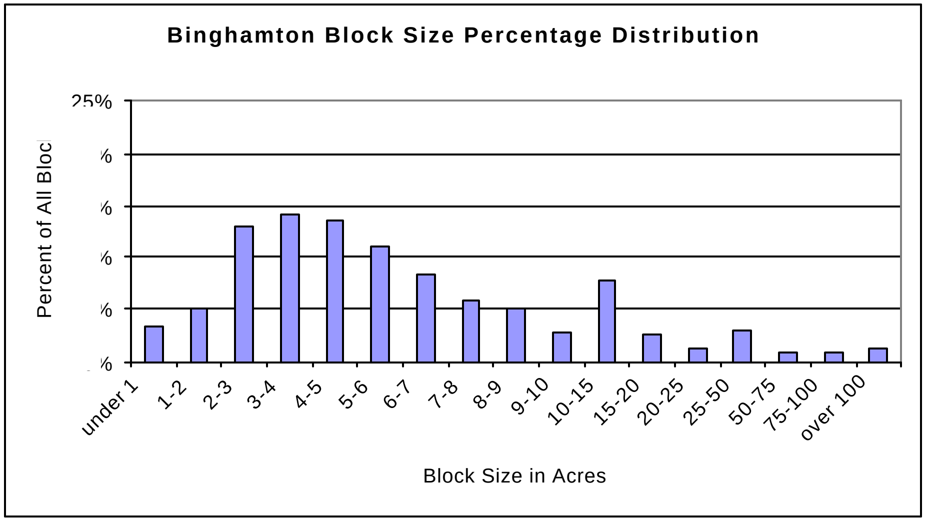

Nashville Block Size Percentage Distribution
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres


Charlotte Block Size Percentage Distribution
25%
20%
15%
10%
5%
0%
under 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-15
15-20
20-25
25-50
50-75
75-100
over 100
Block size in acres


Omaha Block Size Percentage Distribution


Little Rock Block Size Percentage Distribution


Erie Block Size Percentage Distribution


Binghamton Block Size Percentage Distribution

5.5 MPO System Performance Measure Notes

We contacted the 13 metropolitan planning organizations (MPOs) that serve the study regions in order to obtain data about automobile use. The agencies, data sources, and comments are shown in Table 20.

Table 20: Source of Automobile Use Statistics for 13 Study Regions

	MPO Name	**Data Source**	**Year**	**Comments**
Philadelphia	Delaware Valley Regional Planning Commission	Regional travel demand model	1997	
Atlanta	Atlanta Regional Commission	Travel Demand Model Output (published report)	2000, except Vehs/HH (2001)	Average vehicle trip length does not include truck trips. While MPO is 10 counties, ozone nonattainment area is 13 counties, so all figures are for 13 counties
Houston	Houston-Galveston Area Council		2000	Note that VMT includes intrazonal trips but VHT excludes them
Pittsburgh	Southwestern Pennsylvania Commission		2001	Although they have average vehicle trip length broken down by autos and trucks; this figure represents the average for all vehicles.
St. Louis	East West Gateway Coordinating Council	Legacy 2025 Travel Demand Model summary	2000	
Tampa Bay/ St. Petersburg	Each of 4 counties containing the urbanized area has a separate MPO. Data are from FDOT District 7, which also includes a 5th county (Citrus).	Tampa Bay Regional Transportation Analysis, Phase V, Technical Report #1: Validation of the Tampa Regional Planning Model Version 4.0	1999	Model statistics are for 5 counties, population 2.5 million.
New Orleans	Regional Planning Commission	Travel Demand Model run for 2005	2005 (see comments)	All data 2005, except vehicle trip length are based on 2001 survey and vehicles per household is from 1990 Census
Nashville	Nashville Area MPO		1998	
Charlotte	Charlotte-Mecklenburg MPO		2000	
Omaha	Metropolitan Area Planning Agency		2000	
Little Rock	Metroplan	Preliminary draft model using Tranplan software	2000	Model inputs developed quickly; MPO advised us to "use with caution."

Erie	Erie Area Transportation Study	Pennsylvania DOT	1999	Modeling done for air quality conformity analysis performed by PennDOT (by contractor Urbitran)
Binghamton	Binghamton Metropolitan Transportation Study	National Personal Transportation Survey	1995	Data from the New York Add-On to the 1995 National Personal Transportation Survey (a more extensive version, with specific information down to the metro level; over 11,000 survey responses).

Where information is missing a model name was not specified, nor were any particular comments made by the MPO regarding their data. Some data have been published; others were provided to ICF Consulting via personal communication (telephone or e-mail).

5.6 Compendium of All Data

Table 21, which begins on the following page, contains all of the data used in this study.

Table 21: Compendium of All Data

Region:	**Philadelphia**	**Atlanta**	**Houston**	**Pittsburgh**	**Tampa/St. Petersburg**	**St. Louis**
Regional Descriptions						
Population and Land Area						
2000 Population (MSA)	6,188,463	4,112,198	4,669,571	2,358,695	2,395,997	2,603,607
Percent Change 1990 to 2000 Population	5.0%	38.9%	25.2%	-1.5%	15.9%	45.0%
Urbanized Area Population	5,149,079	3,499,840	3,822,509	1,753,136	2,062,339	2,077,662
Land Area Urbanized Area SqMi - Census	1,800	1,963	1,295	852	802	829
Land Area Urbanized Area SqMi - GIS	1,872	2,006	1,318	853	839	835
Urbanized Area Population Density	2,861	1,783	2,951	2,057	2,571	2,506
Transportation Supply Measures						
Block Size						
Number of Blocks	60,403	21,966	36,610	26,599	31,214	23,230
Median Block Size (acres)	3.9	8.9	5.8	2.7	4.0	5.2
Percent of Blocks under 4 acres	51.4%	23.3%	34.4%	65.3%	50.0%	35.5%
Roadway Miles						
Total Centerline Miles	19,821	15,715	13,839	9,079	9,946	9,542
Total Lane-Miles	47,034	36,776	32,389	21,965	22,756	22,689
Intersection Counts						
Total Major-Minor Intersections	25,456	13,523	13,181	12,942	12,251	12,699
Total Four-Way Nonhighway Intersections	29,816	9,165	21,995	14,051	15,406	12,137
Total Nonhighway Intersections	106,850	62,898	67,072	50,334	57435	49,051
Total All Intersections	112,466	65,691	69,269	52,379	60,042	51,230
Roadway and Intersection Density						
Centerline Miles / Square Mile	10.6	7.8	10.5	10.6	11.9	11.4
Lane-Miles / Square Mile	25.1	18.3	24.6	25.8	27.1	27.2
Average Lanes / Mile	2.37	2.34	2.34	2.42	2.29	2.38
Nonhighway Intersections / Square Mile	57.1	31.3	50.9	59.0	68.5	58.7
Percentage 4-Way Intersections (nonhighway only)	27.9%	14.6%	32.8%	27.9%	26.8%	24.7%
Percentage Major-Minor Intersections	22.6%	20.6%	19.0%	24.7%	20.4%	24.8%

Table 21: Compendium of All Data, *continued*

Region:	**Philadelphia**	**Atlanta**	**Houston**	**Pittsburgh**	**Tampa/St. Petersburg**	**St. Louis**
Transit Supply Measures						
Total Annual Revenue Vehicle Hours	5,501,600	3,008,000	2,613,100	2,350,300	921,600	1,329,200
Total Transit Stops (approx)	12,155	12,038	10,600	17,054	11,300	14,141
Revenue Hours Density (per 1000 persons)	1,540	859	684	1,341	447	640
Transit Stop Density (per 1000 persons)	3.4	3.4	2.8	9.7	5.5	6.8
Transit Service Area	2,174	498	1,285	775	482	3,600
Revenue-Hours Density (service area)	2,531	6,040	2,034	3,033	1,912	369
Transit Stop Density (service area)	5.6	24.2	8.2	22.0	23.4	3.9
Revenue-Hours Density (urbanized area)	11,228	1,533	2,017	2,757	1,149	1,603
Transit Stop Density (urbanized area)	24.8	6.1	8.2	20.0	14.1	17.1
Transportation Performance Measures						
Automobile Use						
Daily VMT / Capita	18.8	33.4	26.56	24.81	24.26	30.04
Daily Vehicle Hours of Travel / Capita	1.10	1.29	0.70	0.82	0.84	1.04
Daily Vehicle Trips / Capita	3.10	3.02	2.74	2.56	2.90	4.01
Average Vehicle Trip Length	6.70	9.65	9.70	9.75	8.51	8.62
Vehicle Ownership / Household	1.5	2.2	1.7	1.5	1.6	1.7
Congestion Measures						
Annual Delay / Peak Hour Driver 2000	42	70	75	15	45	43
Transit Use						
Annual Unlinked Passenger Trips	317,254,700	167,067,200	87,379,100	75,130,700	18,597,200	52,137,300
Weekly Trips / Capita	1.18	0.92	0.44	0.82	0.48	0.48
Safety Performance Measures						
Total Fatalities	408	490	642	233	429	232
Fatalities / 10,000 Pop	0.66	1.19	1.37	0.99	1.79	0.89
Fatalities / 100 million VMT	0.96	0.98	1.42	1.09	2.02	0.81
Emissions						
Total NO_x Emissions (tons/day)	275.8	294.5	343.9	171.1	130.7	232.7
NO_x Emissions (grams/capita/day)	44.7	72.2	66.8	63.8	61.7	85.0
Total VOC Emissions (tons/day)	247.3	134.7	147.3	109.9	84.3	125.0
VOC Emissions (grams/capita/day)	40.1	33	28.6	41	39.8	45.7

Table 21: Compendium of All Data, *continued*

Region:	**New Orleans**	**Charlotte**	**Nashville**	**Omaha**	**Little Rock**	**Erie**	**Binghamton**
Regional Descriptions							
Population and Land Area							
2000 Population (MSA)	1,337,726	1,499,293	1,231,311	716,998	583,845	280,843	252,320
Percent Change 1990 to 2000 Population	4.1%	29.0%	25.0%	12.1%	13.8%	1.9%	-4.6%
Urbanized Area Population	1,009,283	758,927	749,935	626,623	360,331	194,804	158,884
Land Area Urbanized Area SqMi - Census	198	435	431	226	206	79	76
Land Area Urbanized Area SqMi - GIS	209	437	446	231	209	78	79
Urbanized Area Population Density	5,102	1,745	1,741	2,768	1,753	2,472	2,079
Transportation Supply Measures							
Block Size							
Number of Blocks	16,450	5,577	7,203	10,020	6,168	2,748	1,926
Median Block Size (acres)	3.1	7.8	7.9	4.8	3.7	5.4	5.1
Percent of Blocks under 4 acres	63.8%	23.5%	24.3%	37.5%	52.5%	29.0%	35.%
Roadway Miles							
Total Centerline Miles	3,544	3,433	3,702	2,940	2,164	868	757
Total Lane-Miles	8,553	8,313	9,087	7,053	5,401	2,073	1,907
Intersection Counts							
Total Major-Minor Intersections	7,487	4,104	4,464	4,115	3,831	1,236	1,110
Total Four-Way Nonhighway Intersections	11,629	2,641	3,161	5,421	3,430	1,648	779
Total Nonhighway Intersections	22,272	15,182	14,849	16,341	11,407	4,305	3,637
Total All Intersections	23,343	15,831	16,663	17,405	11,914	4,565	3,937
Roadway and Intersection Density							
Centerline Miles / Square Mile	17.0	7.9	8.3	12.7	10.4	11.1	9.6
Lane-Miles / Square Mile	41.0	19.0	20.4	30.5	25.9	26.4	24.1
Average Lanes / Mile	2.41	2.42	2.45	2.40	2.50	2.39	2.52
Nonhighway Intersections / Square Mile	106.8	34.7	33.3	70.7	54.7	54.9	46.0
Percentage 4-Way Intersections (nonhighway only)	52.2%	17.4%	21.3%	33.2%	30.1%	38.3%	21.4%
Percentage Major-Minor Intersections	32.1%	25.9%	26.8%	23.6%	32.2%	27.1%	28.2%

Table 21: Compendium of All Data, *continued*

Region:	**New Orleans**	**Charlotte**	**Nashville**	**Omaha**	**Little Rock**	**Erie**	**Binghamton**
Transit Supply Measures							
Total Annual Revenue Vehicle Hours	931,200	664,700	354,800	281,000	167,600	113,800	98,800
Total Transit Stops (approx)	2,816	3,800	3,600	5,000	1,500	570	935
Revenue-Hours Density (per 1000 persons)	923	876	473	448	465	584	622
Transit Stop Density (per 1000 persons)	2.8	5.0	4.8	8.0	4.2	2.9	5.9
Transit Service Area	75	242	484	193	111	80	712
Revenue Hours Density (service area)	12,416	2,747	733	1,456	1,510	1,423	139
Transit Stop Density (service area)	37.5	15.7	7.4	25.9	13.5	7.1	1.3
Revenue-Hours Density (urbanized area)	4,707	1,528	824	1,241	815	1,444	1,293
Transit Stop Density (urbanized area)	14.2	8.7	8.4	22.1	7.3	7.2	12.2
<u>Transportation Performance Measures</u>							
Automobile Use							
Daily VMT / Capita	16.01	33.7	31	21.85	31.96	16.20	33.08
Daily Vehicle Hours of Travel / Capita	0.52	1.01	0.80	0.64	0.81	0.38	1.06
Daily Vehicle Trips / Capita	2.51	4.39	2.8	3.35	3.5	1.7	3.75
Average Vehicle Trip Length	5.07	10.61	11.1	6.67	9.1	9.5	8.03
Vehicle Ownership / Household	1.4	1.8	1.8	1.7	2.1	1.6	1.8
Congestion Measures							
Annual Delay / Peak Hour Driver 2000	22	47	44	25	N/A	N/A	N/A
Transit Use							
Annual Unlinked Passenger Trips	56,246,700	13,404,400	6,924,700	4,315,200	3,582,200	2,863,600	3,843,600
Weekly Trips / Capita	1.07	0.34	0.18	0.13	0.19	0.28	0.47
Safety Performance Measures							
Total Fatalities	150	217	216	58	111	38	27
Fatalities / 10,000 Pop	1.12	1.45	1.75	0.81	1.90	1.35	1.07
Fatalities / 100 million VMT	1.92	1.18	1.55	1.01	1.63	2.29	0.89
Emissions							
Total NO_x Emissions (tons/day)	N/A	90.8	151.5	N/A	N/A	24.4	N/A
NO_x Emissions (grams/capita/day)		93.0	125.2			78.7	
Total VOC Emissions (tons/day)		41.9	57.9			13.5	
VOC Emissions (grams/capita/day)		42.9	47.8			43.6	

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