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ESTIMATING VALUES OF THE TRANSIT LAND-USE MULTIPLIER EFFECT FROM PUBLISHED FEDERAL HIGHWAY ADMINISTRATION AND FEDERAL TRANSIT ADMINISTRATION DATA

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ABSTRACT

Efforts to quantify greenhouse gas emission reduction from the substitution of transit travel for personal vehicle travel now recognize that persons who travel by transit travel fewer miles per day than persons who travel by personal vehicle. In the transit industry the relationship is known as the "land-use multiplier" and among researchers the name "transit leverage" has come into general use. The land-use multiplier is the result of many factors including more efficient land use, which allows shorter trip distances, more walking trips, and trip chaining associated with transit trips. Recognition and confirmation of the land-use multiplier is important in transportation policy development and accurate measurement of the effect is important to specific planning decisions.

One cause of the effect allows a test of its scale from existing data. A tenant of travel budget theory is that across populations people travel about the same amount of time every day. The underlying principal is that time, a twenty-four day, is a fixed factor for behavior and the total amount of time in a typical day that can be allowed for traveling is constant across places and historical periods. Given this fixity, if all travelers are using the same travel mode at approximately the same speed, the distance traveled per person per day will be the same across populations. The distance traveled in urbanized areas for person miles in personal roadway vehicles is collected by the Federal Highway Administration annually and the passenger miles traveled on transit in urbanized areas is collected annually by the Federal Transit Administration. These data allow regressions across urbanized areas to verify that the total amount of travel per person is constant across those areas. The resulting regressions are very high with coefficients of determination exceeding 0.94 each year over the past two decades.

Travel speed on transit is typically slower than by personal vehicle over entire areas but not necessarily in corridors or otherwise congested areas. The transit travel decision is based on a combination of factors in addition to travel speed including accessibility of destinations, costs, convenience, and the ability to do other activities such as reading while traveling. Since average travel speed, including walking access and egress to the transit stop or station, is at a lower travel speed than the average speed of personal vehicles, an adjustment for that should improve the accuracy of the average travel distance to population regression. Constants are applied to increase the miles traveled on transit to equal an estimate of the miles that would have been traveled if transit riders had driven personal vehicles. As the constant is increased the coefficients of determination also increase, maximizing at values over 0.98 for each year over the past two decades. At the coefficients of determination maximization points the constant, or the number of private vehicle person miles replaced by a single transit passenger mile, ranges from 5 to 7 miles. These values are typically higher than the ratios from most other research because they are a comparison of transit passenger miles to private vehicle person miles while most other studies measure transit passenger miles compared to private vehicle vehicle miles of travel.

INTRODUCTION: THE LAND-USE MULTIPLIER, A MEASUREMENT OF TRANSIT IMPACT

Estimating the impact of transit travel on energy use, greenhouse gas emissions, and other air pollutant emissions is not a simple calculation. Transit travel, on average, represents a different pattern from average automobile travel. Transit travel is typically in higher density areas where destinations are accessible with shorter trips, includes a longer pedestrian access trip portion than personal vehicle travel (termed automobile in the remainder of this paper but also including SUVs, vans, and small trucks used for personal travel), and includes a significant trip chaining component when measured as overall travel tours. Because of this a simple comparison of energy use and emissions of the average transit passenger mile of travel to the average person mile of travel in an automobile is not valid.

The average transit trip is in a more congested urban area than the average automobile trip. The average transit trip is a work trip whereas the average automobile trip is not. The automobile trips replaced by transit trips are at lower occupancy levels than the average of all automobile trip. A simple direct comparison, therefore, does not compare transit trips to the automobile trips that transit more often replaces and seriously understates the impact of transit on reducing energy use and air pollutant emissions. But an even greater distortion of simple direct comparisons is the underlying assumption that transit travelers travel the same distance aboard a vehicle as automobile travelers. This is not the case. The average transit rider travels a shorter distance aboard the transit vehicle over the course of a day than the the average automobile users travels in an automobile. This phenomenon is now termed the "land-use multiplier," and has been included in recommended methodologies by the American Public Transportation Association (APTA) Standards Development Program Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit. (American Public Transportation Association 2009)

The "land-use multiplier" measures the amount in-vehicle automotive travel is reduced for each in-vehicle mile of transit travel. The "land-use multiplier" has also been called "transit leverage" and "transit multiplier" as well as other terms in earlier research. The current term "land-use multiplier" will be used throughout this paper in place of other terms used in previous research. Researchers have found that for each mile traveled on transit results in a reduction in automobile travel of 1.3 up to 14.4 miles of automobile travel in different areas for different purposes. The APTA Standards Development Program attributes this disproportionate reduction to (1) higher density development allowing reduced trip lengths while maintaining or improving overall accessibility; (2) development levels associated with transit facilitating bicycle and pedestrian travel, (3) transit facilitating trip chaining where trip purposes are combined into a single tour, also enhanced by the accessibility of different types of destinations, and (4) reduced vehicle ownership for households with transit access. (American Public Transportation Association 2009, 32-33)

LAND-USE MULTIPLIER ESTIMATES IN THE LITERATURE

Bailey, Mokhtarian, and Little were the first researchers to formally apply the concept of the "land-use multiplier" to estimating transit impacts on energy use and emissions. (Bailey, Mokhtarian, and Little 2008) *The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction,* written for the American Public Transportation Association by ICF International, found that transit travel nationwide saved fuel and reduced carbon dioxide emissions approximately three times the amount that would result from the direct substitution of transit travel for private vehicle travel.

Several researchers, however, had previously noted this phenomenon in the context of transit benefits without applying it to specific estimates. Their results are reported on Table 1. Pushkarev and Zupan in *Urban Rail in America: An Exploration of Criteria for Fixed-Guideway Transit*, found that in "addition to the direct diversion of the equivalent of 11.6 billion vehicle-miles (18.7 billion vkm) of auto travel to rail annually, the six rail regions affected an indirect savings of four times as much auto travel (47.1 billion vehicle-miles or 75.7 billion vkm) in the earlier 1970s." (Pushkarev and Zupan 1980, 31) This study, unlike the one by Bailey, Mokhtarian, and Little which applied to the aggregate of all U.S. transit, was limited to a select set of rail systems. Each of the studies listed on Table 1 apply to different grouping of transit modes, cities, and time periods which in part influences the wide variation in their results.

Newman and Kenworthy found their data for large urban areas around the world to suggest a relationship in which one kilometer of transit travel replaces three and one-half kilometers of automobile travel. They found that modal travel data for 31 world cities "show that the more transit there is the lower the total travel per capita. This means that for every automobile passenger kilometer reduced by a modal switch there is a potential overall total reduction in passenger kilometers and if a transfer from transit occurs then it is likely total travel will increase...Our global data suggest there is a ["land-use multiplier"] more like 3.5 to 1 car passenger kilometers into transit passenger kilometers." (Newman and Kenworthy, 1992, 355) Newman and Kenworthy propose that "The mechanisms for this ["land-use multiplier"] could include the incorporation of several trip purposes into one when transit is taken as there are invariably more destinations at transit points, the obvious increase in biking and walking when urban transit is taken, and the reduction in travel distances as land use changes." (Newman and Kenworthy, 1992, 355)

Holtzclaw reports the results of several studies concerning the "land-use multiplier". (Holtzclaw 1995) He found a relationship of one mile of transit travel replacing four miles of automobile travel in a comparison of the San Francisco Bay area communities of Walnut Creek and Danville-San Ramon and one mile of transit travel replacing eight miles of automobile travel in a comparison of San Francisco and Danville-San Ramon. Holtzclaw attributes these relationships to shortened trip lengths resulting from higher densities and better transit service.

Holtzclaw also reports the results of other studies he conducted as well as additional studies by Newman and Kenworthy and by the Metropolitan Transportation Commission in the San Francisco Area. His report describes the result as a reduction in vehicle miles travelled (VMT) per transit passenger mile. This is a comparison in different units. The average occupancy of a motor vehicle of all types in all uses has been about 1.6 over the past several years, although the 2009 NHTS reported a higher value of 1.67 and the 2010 FHWA Highway Statistics reported a surprising drop to 1.38 for light duty vehicles. (National Household Travel Survey 2011, 33; Federal Highway Administration 2012, Table VM-1) This would mean that to convert the reported data to the relationship of motor vehicle person miles to transit passenger miles requires a multiplication by about 1.6. Other studies indicate that some of the data may be ratios of person to passenger miles, not vehicle to passenger miles. The data comparisons in this section are based on an interpretation of the literature and comparisons of vehicle miles to passenger miles are converted to a comparison of person miles to passenger miles on Table 1. Because of this and other data problems, these data should be treated as general and not predictive or useable for specific calculations. It should also be noted that transit data are "passenger" data, they do not include vehicle operators, conductors, or other transit employees aboard the vehicles. Transit employee travel is excluded from comparisons used to estimate transit benefits because they are derived travel, that is, their travel would not occur if they were not providing transit service. The inclusion of transit employee travel would artificially increase the "land-use multiplier" factors.

Table 1: Reports Measuring Auto Travel Distance Replaced by Transit Travel

Year of Study or Data	Auto Vehicle Miles of Travel Reduction per Transit Passenger Mile (a)	Auto Person Miles of Travel Reduction per Transit Passenger Mile (* Calculated from VMT Data)	Source
1980	2.9	* 4.6	Newman and Kenworthy, reported in Holtzclaw 1995.
1980	---	3.5	Newman and Kenworthy 1992
1980	3.6	* 5.8	Newman and Kenworthy, reported in Holtzclaw 1995.
1980	4.0	* 6.4	Pushkarev and Zupan, 1980.
1990	4.4	* 7.0	MTC/RAFT 2010 Project, reported in Holtzclaw 1995.
1991	4.0	* 6.4	Holtzclaw, 1995.
1991	8.0	* 12.8	Holtzclaw, 1995.
1994	1.4	* 2.2	Holtzclaw, 1995.
1994	9.0	* 14.4	Holtzclaw, 1995.
2007	1.9	* 3.1	Bailey, Mokhtarian and Little, 2007.
2009	---	1.3 to 6.3	New York MTA, reported in APTA Working Group, 2009,
2009	4.0	* 6.4	Litman, 2009

(a) Studies with amounts shown in this column reported their results in vehicle miles of travel, which are converted with a standard multiplier of average automobile vehicle occupancy to a person mile value shown in the next column.

The additional "land-use multiplier" reports surveyed by Holtzclaw found ratios from as small as 1 passenger mile of transit travel replacing 2.2 miles of motor vehicle person travel to a 14.4 mile replacement factor. Litman found in his recent *Rail Transit in America* a 4.0 "land-use multiplier" replacement rate in a study of 130 U.S. cities. (Litman 2009)

The New York Metropolitan Transportation Authority (NYMTA) used several combinations of methodologies and approaches to calculate the "land-use multiplier," found values ranging from 1.3 to 6.3 for different geographies. (American Public Transportation Association 2009, 33, 38-41)

The basic argument that follows in this paper has been presented before at conferences but has not been published in any manner except in a Conference Proceedings only distributed to conference attendees; it is not accessible on-line or in print other than in manuscript from the author. (Neff 1996(a), 1996(b), 2010) This paper includes additional years of data testing, additional references, and a hopefully improved and more focused argument as well as corrections of many errors in those earlier presentations.

TESTING FOR THE LAND-USE MULTIPLIER USING EXISTING DATA

This paper develops a methodology for testing for the existence of the "land-use multiplier" and measuring its value from published, nationally collected, recurring data. It is based on Travel Time Budget Theory which states that people, across populations, on average allow the same amount of time on a normal day for the same activities. Among those activities is travel and time measurement studies have found that people travel for 60 to 70 minutes on a typical day across nations and across history. Time-budget theory recognizes that time, 24 hours a day, is fixed. When used in travel analysis it recognizes that speed and distance may change, but time does not.

Travel Time Budget Theory

Time use studies record the exact amount of time used for specific activities by large samples of individuals. Among those activities travel and the amount of time used for travel has been found to be consistent across countries and over time. Usually referred to the "hour" spent in travel every day, the typical study finds that over a large population group, a average person on a typical day spends about 70 minutes traveling.

The travel time budget concept asserts that a measured similarity in average daily travel time can be found for average travelers among places and over time. The average traveler in different places using different travel modes over different distances will spend the same amount of time traveling on a typical day. This similarity is the result of people allocating a portion of their day to each activity they normally engage in. Each person uses an amount of time for travel. Although the variation between individuals may be immense, when personal daily travel times are averaged over sufficiently large population groups, such as urban areas, a similar amount of time is found to be spent on travel in different places, in different size areas, and over time.

A basic condition of human behavior is that every day has 24 hours. Each person has daily activities of work, sleep, and other necessary activities that, on a typical day, remain relatively fixed for them. In the long-run the amount of time they take from the 24 hours to travel cannot increase without stealing time from other activities. Change in travel distance is, therefore, a function of speed rather than time spent traveling.

If this theory holds true, measured across aggregations, people will travel the same amount of time on a typical day. Travel speed on transit, including the walk to the transit stop, is typically slower than by personal vehicle over entire areas although not necessarily in corridors or otherwise congested areas. This means that fewer miles will traveled by transit, especially on the transit vehicle, than in an automobile in the same amount of time. With destinations closer together because of the agglomeration effect associated with transit use, auto users will also need to travel less and the "land-use multiplier" factor increases by reducing miles traveled for those that continue to travel by automobile. The transit travel decision, however, is based on a combination of factors in addition to travel speed including accessibility of destinations, monetary costs, convenience to do other activities such as reading while traveling, access to multiple activities in denser areas, and avoiding the need to find parking.

This section will review travel time budget literature and establish that a fixed daily allowance for travel time exists. The earliest reported examples of the effect the existence of a travel time budget are in Medieval Europe. The Standing Advisory Committee on Trunk Road Assessment in Great Britain has noted extremely long term travel stability. It has found that "less well quantified work has suggested that the average amount of time spent on journeys to work has remained stable for some six centuries. As faster methods of transport have been used, catchment areas have widened and trip distances have increased." (Standing Advisory Committee on Trunk Road Assessment 1994, 40) White reports a travel budget effect to explain the abandonment of settlements in Germany from the eleventh to the thirteenth centuries. (White 1962) His explanation that change in travel speed resulted in change in distance travelled, not in time use, shows the likely validity of travel time budget theory.

> "When historical geographers began to study abandoned fields and settlements in Germany, they assumed that these has been deserted either during the Thirty Years War or after the Black Death of 1348-50. To their astonishment they found that abandonment of settlements, but not of fields, began in the eleventh century and occurred with great frequency in the thirteenth. Not only were peasants moving to neighboring cities while still going out each day to their fields; villages were absorbing the inhabitants of the hamlets in their vicinity. In a period when the total population of Europe was increasing rapidly, places long inhabited were losing their identity because of a "balling" of peasants into larger and larger villages. . . . How is it that, beginning in the eleventh century, so many of them were able to [move into larger village]?
>
> "The answer seems to lie in the shift from ox to horse as the primary farm animal. The ox moved so slowly that peasants using oxen had to live close to their fields. With the employment of the horse for both ploughing and for hauling, the same amount of time spent going to and from the fields would enable the peasant to travel a much greater distance." (White 1962, 67-68)

Often cited as a founder in travel time research, Yacov Zahavi, along with James Ryan, reported the results of four travel surveys, in Washington, D.C., in 1955 and 1968 and in Minneapolis-St. Paul in 1958 and 1970. (Zahavi and Ryan 1980) In each case users of automobiles travelled faster than transit users, but on a daily aggregate travel basis the automobile user also travelled more often and farther than the transit user. Faster travel, therefore, did not always result in less total travel time during the day. In two instances the aggregate travel time for transit users was higher than for automobile users, in one instance automobile travel time was greater, and in one instance the times were virtually identical. Mixed-mode travelers, using both automobiles and transit, had average speeds and trip lengths, times, and frequencies that fell between the single mode numbers. Zahavi and Ryan found that it "is clear, then, that travelers have used the increase in highway travel speeds to travel farther than to maintain their travel distance and reduce their expenditure of travel time. This trend is most clearly seen in the travel-time-per-traveler statistics. In both cities in both survey years and across all household sizes, an average of 1.1 h[ours] can be observed." (Zahavi and Ryan 1980, 21)

In an earlier publication, Szalai reported the time use for multiple activities reported in 15 surveys in 12 countries. (Szalai 1972). The summary data for this publication shows total travel time in the 15 studies to range from 35 to 89 minutes per day. Despite this large spread in overall travel time, Robinson, Converse, and Szalai find in a chapter within this publication a constancy of work travel times across the sample.

> "In terms of time consumed, the chief activity related to the main job for both employed women and employed men at all sites involved the trip to and from work. Commuting tends to add about 50 minutes to the workday for the typical employed male in our study, and 40 minutes for the employed woman. The dominant modes of transport to the job vary extremely widely across our sites, from walking in the Soviet Union site to public motorized transportation in Lima, Peru and the private automobile in the United States, with all mixtures, including the bicycle, in between. . . . there is a substantial range of distance to the workplace within each site, and of course time spent on the trip to work varies as a strong and direct function of that distance. Equally obvious is the fact that the quickest trips for equivalent commuting distances are accomplished by the automobile. But as we have already indicated, by far the most intriguing aspect of the trip to work cross-nationally is the relative constancy of average time allocated to this purpose across our sites in the face of the most complete variation in commuting technology. There seems to be a distinct preference toward using increased efficiency of transport to spread out in space, and modal distances to the workplace across our sites vary by a factor of fifteen or more, while time allocations remain in the average within an impressively narrow range." (Robinson, Converse, and Szalai 1972, 123)

Other early studies found average travel times not to be affected by other variables. In a study of Reading, United Kingdom, Downes and Morrell found location with respect to the town center to have little effect on travel time. "While these results show that there was a small increase in the average trip times for households located furthest from the town centre, the figures show that mean trip times were remarkably constant for all household types and areas." (Downes and Morrel 1981, 50) Zahavi found in a later study that it could be concluded "that regularities of travel-time frequency distributions are transferable among the four [Baltimore, Washington, London, and Reading, UK] cities, cities that are markedly different by such factors as size and car-ownership levels." (Zahavi 1982, 26) Bochner and Stuart reported that one "of the most important findings from the St. Louis analyses, again confirming the results of previous studies, involves the apparent tendency for persons to use daily travel time 'budgets'." (Boucher and Stuart 1978, 567) Chumak and Braaksma stated that their "analysis has included all the available data and that evidence to contradict the theory of the personal travel time budget has yet to be established." (Chumak and Braaksma 1981, 25) The Transport and Road Research Laboratory found travel budgets to be plausible when they are regarded "as constraints which have some elasticity with respect to ease of travel, rather than as overriding behavioral requirements: thus the constancy of average travel time arises because few people are prepared to spend more than about 90 minutes per day traveling while, equally, few people can satisfy their requirements adequately by spending less than, say, half an hour" (Transport and Road Research Laboratory 1980, xiii).

Repetitive nationwide surveys in the same countries have shown the same results over time. The United Kingdom Department for Transport conducted nationwide travel surveys 15 times from 1973 through 2008. (Department for Transport recurring; Department for Transport, Local Government and the Regions 2001) The average daily travel times per person found in those surveys is reported on Table 2. The surveys of travel time in Great Britain found average daily times to range from a low of 54.2 minutes in 1976 to a high of 63.3 minutes in 2005. The earliest surveys show large variations in daily average travel time but the newest surveys do not show this large variation. The increase in stability may be due to methodological improvements for the survey rather than any change in behavior.

Table 2: Average Daily Travel Time per Person in Minutes Reported in Recurring National Surveys, All Travel Purposes and All Travel Modes

Country	Number of Annual Surveys	Time Period of Surveys	Annual Average Minutes Traveled per Day			
			Highest Year	Yearly Average	Lowest Year	Most Recent Year
Great Britain (a)	17	1975-2011	63.3	60.3	54.2	59.8
Netherlands (b)	6	1975-2000	72.9	64.9	56.6	72.0
United States (c)	9	2003-2011	74.4	72.1	69.6	69.6
Finland (d)	4	1979-2009	73.0	68.5	61.0	68.0

(a) Department for Transport recurring; Department for Transport, Local Government and the Regions 2001
(b) van den Broek et al. 2004
(c) Bureau of Labor Statistics annual

(d) Statistics Finland 2013

In the Netherlands, 6 studies 26 years found daily travel times of 56.6 to 72.9 minutes. (van den Broek et al. 2004) The *American Time Use Survey* found daily travel time to range from 69.6 to 74.4 minutes in the United States in 9 studies over a 9 year period. (Bureau of Labor Statistics annual) In 4 studies over 4 years, Statistics Finland found average daily travel time to vary from 61.0 to 73.0 minutes. (Statistics Finland 2013) Each of these series of surveys appears to confirm time budgeting for travel purposes.

Land-Use Multiplier Estimation Based on Travel Time Budget Theory: Methodology

The validity of the "land-use multiplier" proposition that every mile of travel on transit replaces more than one mile of travel in motor vehicles can be tested using available transit and motor vehicle travel data. Travel time budget theory holds that travel is a function of time, not distance, and that over population groups the average daily travel will be constant and has been measured at approximately 70 minutes per day. From travel budget theory, conclusions are then made that: (1) people, when measured in sufficiently large aggregations, will travel equal amounts of time every day, (2) their average travel time will not be related to the size of their area, either in population or land area, and (3) their average travel time will not be related to the density of their area.

These assumptions are used to develop a travel model where travel distance is equal to population times the speed of travel or (P) Population = (D) Distance divided by (S) Speed. Distance is a direct function of population. Since transit travel and motor vehicle travel have different speeds the model becomes (P) Population = (TD) Transit Distance divided by (TS) Transit Speed plus (MVD) Motor Vehicle Distance divided by (MVS) Motor Vehicle Speed. This model can be used to test a set of hypotheses of aggregate total travel time for an area and per capita travel time as a function of population size, land area, and density. One relationship should be found to be true:

(1) total travel in an area, measured in time, is a function of population size.

The remaining five relationships should be found to be true as expressed herein, where they are proposed as not true or false arguments:

(2) total travel in an area, measured in time, is not a function of land area.
(3) total travel in an area, measured in time, is not a function of population density.
(4) per capita travel in an area, measured in time, is not a function of population.
(5) per capita travel in an area, measured in time, is not a function of land area.
(6) per capita travel in an area, measured in time, is not a function of density.

Data sets reporting travel time for a large number of aggregations of travelers by mode do not exist. Two data sets, however, report travel distance by mode for urbanized areas in the United States. The data from these sets can be used not only to test the relationships of travel to area size but to also measure the relationship of travel distance between transit and automobiles.

The Federal Transit Administration (FTA) began publication of National Transit Database (NTD) data in 1979. (Federal Transit Administration annual) NTD reports include financial and operating data from all transit agencies in urbanized areas receiving federal financial assistance, either directly or indirectly. The data base includes virtually all transit operated in urbanized areas. The Federal Highway Administration (FHWA) publishes an annual *Highway Statistics* report. (Federal Highway Administration annual) Beginning in 1989 the FHWA report included travel statistics for urbanized areas over 200,000 population, later expanded to all urbanized areas. These data sets can be used to test travel relationships.

Data are compiled for a set of urbanized areas for each year from 1989 through 2008 and for 2010. Highway data for 2009 have not yet been published by the FHWA. The sample includes all urbanized areas over 200,000 population for which highway and transit data are both available.

Daily passenger miles of transit travel were calculated for each urbanized area for each year by addition of data for individual transit agencies reported in the NTD. The data are for transit passenger travel and do not include vehicle operators, conductors, or employees. Since transit employee travel would not be expected to occur if there were no transit service, this improves accuracy of the tests. The data for any transit agency that operates in more than one urbanized area are included in the UZA of the agency's headquarters, introducing a minor error in some amounts. Passenger Miles were converted to daily values by simple division of the number of days in the year.

Daily vehicle miles of travel for each UZA were taken from *Highway Statistics*. They were converted to person miles of travel by being multiplied by the average vehicle occupancy for the entire United States, also reported in *Highway Statistics*. This adds another assumption of consistent vehicle occupancy across all urbanized areas. Persons miles of travel in motor vehicles include all persons aboard the vehicles including drivers. Highway person miles of travel also include persons on long distance travel passing through the area. An assumption is made that these added miles are offset by UZA residents traveling outside the UZA. This assumption is not tested.

Population, land use, and density data are taken from the 1990 Census for the years 1989 through 2001 and from the 2000 Census beginning in 2002. Urbanized area data are only available from the Decennial Census. Only UZAs with populations over 200,000 persons were used. In the earliest years this was the bottom cut-off value for FHWA data reporting. This minimum level was maintained when the FHWA began publishing data for all UZAs because smaller areas might not have an adequate size population to be representative. The sample size of UZAs with both transit and motor vehicle data available ranged from 120 to 127 when the 1990 Census was used and from 136 to 144 when to 2000 Census was used. There was a slight increase in the values of coefficients of determination when the newer Census was first used. The increase is believed to be due to more recent population data being more accurate, and not to the increase in sample size.

Regressions are performed for the model stated above for Hypothesis (1) that total travel in an area, measured in time, is a function of population size.

(P) Population = (TPM) Transit Passenger Miles + (MVPM) Motor Vehicle Person Miles

Since one transit passenger mile is hypothesized to replace more than one motor vehicle person mile, a constant, the "land-use multiplier", is introduce to increase the number of transit passenger miles. The additional transit passenger miles represent the motor vehicle person miles replaced by transit travel.

(P) Population = [(LUM) Land-Use Multiplier times (TPM) Transit Passenger Miles] + (MVPM) Motor Vehicle Person Miles

The data are then regressed with the LUM increased by 0.1 for each regression until the resulting r^2 coefficient of determination is maximized. For each of the 21 years, the r^2 maximizes at a LUM value greater than 1.0. When the "land-use multiplier" is greater than 1.0, the regression line better depicts the equality of the population to total miles of travel relationship. This shows that, in the model, if more miles are applied the relationship improves indicating that the total mileage would be greater if all travel were by automobile and showing that transit travel does in fact replace a disproportionately larger amount of automobile travel.

Along with an r^2 a t test of significance is calculated for each coefficient of determination. The value of the t increases in the same pattern as the r^2 indicating the increased coefficient of determination is a significant result.

A similar methodology is used to test hypotheses 2 through 6 with the regressed variables changed as appropriate.

For Hypothesis (2) total travel in an area, measured in time, is not a function of land area, a relationship of (LA) Land Area = [(TM) Land-Use Multiplier times (TPM) Transit Passenger Miles] + (MVPM) Motor Vehicle Person Miles.

For Hypothesis (3) total travel in an area, measured in time, is not a function of population density, a relationship of (PD) Population Density = [(TM) Land-Use Multiplier times (TPM) Transit Passenger Miles] + (MVPM) Motor Vehicle Person Miles.

For Hypothesis (4) per capita travel in an area, measured in time, is not a function of population, a relationship of (P) Population = [(TM) Land-Use Multiplier times (TPMpC) Transit Passenger Miles per Capita] + (MVPMpC) Motor Vehicle Person Miles per Capita.

For Hypothesis (5) per capita travel in an area, measured in time, is not a function of land area, a relationship of (LA) Land Area = [(TM) Land-Use Multiplier times (TPMpC) Transit Passenger Miles per Capita] + (MVPMpC) Motor Vehicle Person Miles per Capita.

For Hypothesis (6) per capita travel in an area, measured in time, is not a function of density, a relationship of (D) Population Density = [(TM) Land-Use Multiplier times (TPMpC) Transit Passenger Miles per Capita] + (MVPMpC) Motor Vehicle Person Miles per Capita.

Land-Use Multiplier Estimation Based on Travel Time Budget Theory: Results

The results of the regressions described above are reported on tables and figures in this section. Each hypothesis as stated was upheld. Hypothesis (1) that total miles of travel is a function of population was supported. In the 21 annual data sets, the lowest r^2 between population and total person miles of travel was 0.9432 and the average r^2 was 0.9556. This relationship is, therefore, believed to be true. When the transit passenger miles were increased by a multiplier to represent the motor vehicle travel displaced by transit travel the average r^2 increased to 0.9887. The average "land-use multiplier" at the highest value of the r^2 was 6.4 with "land-use multipliers" for individual years ranging from a low of 5.0 in 2010 to a high of 7.5 in 1993. The lowest values are at the beginning and end of the test year period with the highest values in the middle. There is no apparent reason for this.

Each of the other five hypothesized relations were found to be correct, that is the relationships were not as strong as the population to total travel relationship. Hypothesis (2) where total travel is a function of land area has a high r^2, averaging .8832 over the 21 years; but much lower than the population to travel relationship. Land area is also a surrogate for population in that the range of densities of urbanized areas is limited such that land area will retain a similarity to population across areas. As the "land-use multiplier" increase the r^2 of land area to total travel shows a small decline.

Hypothesis (3) where total travel is a function of density has an average r^2 of 0.3142 over the 21-year period, much lower than population or land area. Its r^2 show little change as the "land-use multiplier" increases.

For Hypothesis (4), (5), and (6) there was little relationship between population, land area, or density and per capita travel.

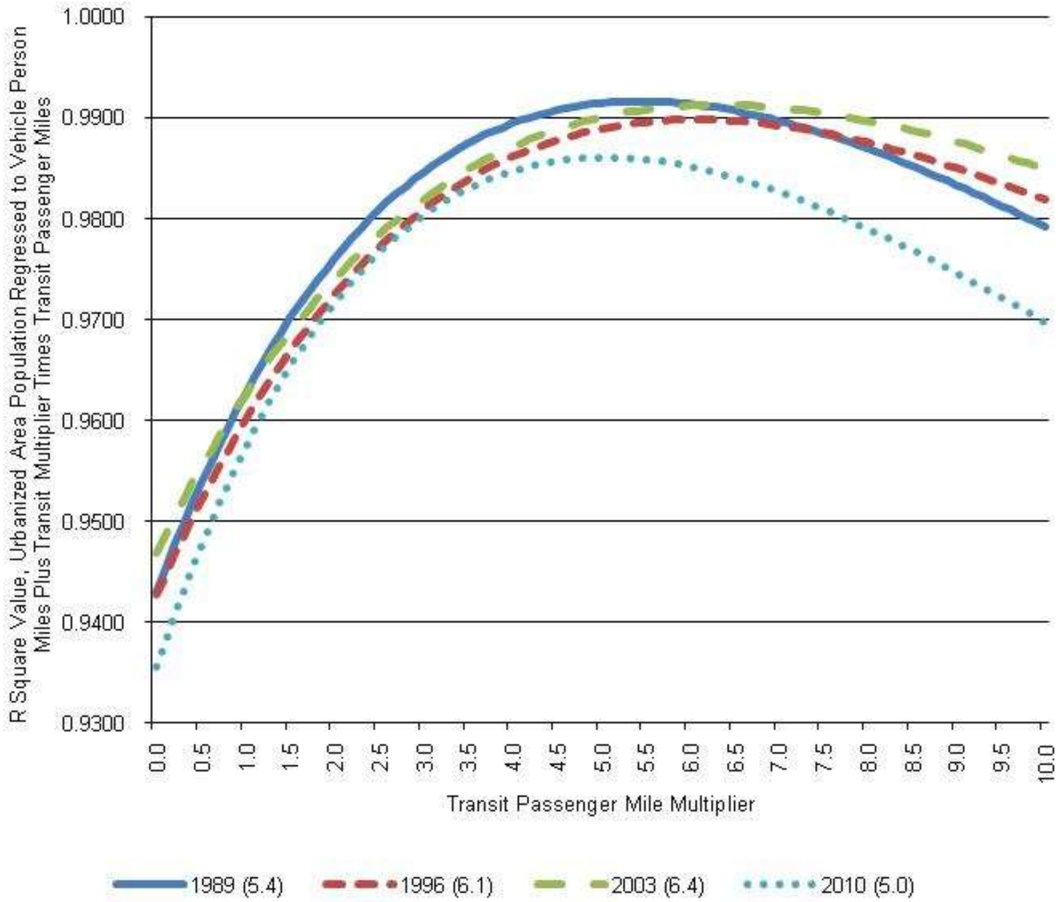
The data results for all six relationships are presented on Table 3 for four illustrative years separated by equal time periods: 1989, 1996, 2003, 2010. The six results in rows 1 through 6 are for r^2 when the "land-use multiplier" is 1.0 and the six results in rows 7 through 12 are for r^2 when the "land-use multiplier" is at its maximized r^2 value. A t statistic is also reported to determine whether the slopes of the regression lines are statistically different from zero, that is, that they are not random. The slopes of the regression lines for hypothesis 1, person miles of travel to population, and hypothesis 2, person miles of travel to land, have high t test values indicating that they are different from zero values. The t tests for hypotheses 3 through 6 do not show the same strong difference from zero as hypotheses 1 and 2, although several have values that can be interpreted as statistically significant; and in three cases they are negative values indicating a negative relationship, which is not consistent with the hypotheses.

Figure 1 shows the pattern of change in the r^2 of Hypothesis (1), the relationship of person miles of travel to the "land-use multiplier," for the same four illustrative years: 1989, 1996, 2003, 2010. The top of each arc represents the maximum r^2 value and may be interpreted as the "land-use multiplier" value, that is, the number of automobile person miles of travel replaced by each passenger mile of transit travel. In 1989 the value is 5.4 miles of automobile person travel are replaced by each mile of transit passenger travel, in 1996 the value is 6.1, in 2003 the value is 6.4, and in 2010 the value is 5.0.

Table 3: Coefficients of Determination for Hypotheses 1 through 6, Illustrative Years

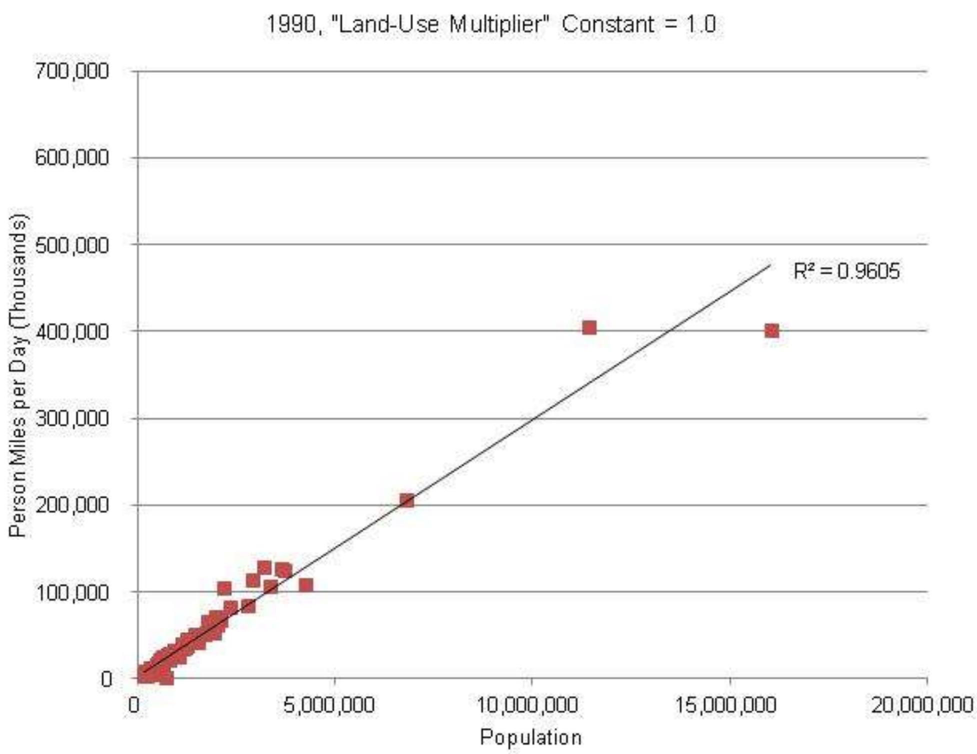
Row	Hypothesis	X	Y	Measure	1989	1996	2003	2010
R squares for Direct Addition of Motor Vehicle Person Miles and Transit Passenger Miles								
1	(1) Land-Use Multiplier = 1.0	Population	Total Person Miles	r^2	0.9627	0.9601	0.9626	0.9574
				t	55.4371	53.2946	59.6196	56.5769
2	(2) Land-Use Multiplier = 1.0	Land Area	Total Person Miles	r^2	0.8844	0.9033	0.8355	0.8835
				t	30.1741	33.2080	26.4717	32.8180
3	(3) Land-Use Multiplier = 1.0	Density	Total Person Miles	r^2	0.3627	0.3495	0.3046	0.2596
				t	8.2294	7.9624	7.7752	7.0556
4	(4) Land-Use Multiplier = 1.0	Population	Person Miles per Capita	r^2	0.0018	0.0158	0.0060	0.0307
				t	-0.4613	-1.3753	-0.9130	-2.1214
5	(5) Land-Use Multiplier = 1.0	Land Area	Person Miles per Capita	r^2	0.0096	0.0003	0.0000	0.0060
				t	1.0728	0.1814	0.0027	-0.9260
6	(6) Land-Use Multiplier = 1.0	Density	Person Miles per Capita	r^2	0.1129	0.1703	0.0640	0.2638
				t	3.8909	-4.9218	-3.0712	-7.1327
R squares for Addition of Motor Vehicle Person Miles and Transit Passenger Miles Times the R square Maximizing Constant								
Population/Person Mile Land-Use Multiplier					5.4	6.1	6.4	5.0
7	(1) Land-Use Multiplier = Value at Maximum r^2	Population	Total Person Miles	r^2	0.9917	0.9898	0.9913	0.9861
				t	118.9253	107.1992	125.5023	100.3069
8	(2) Land-Use Multiplier = Value at Maximum r^2	Land Area	Total Person Miles	r^2	0.8717	0.8838	0.8243	0.8594
				t	28.4360	29.9647	25.4413	29.4571
9	(3) Land-Use Multiplier = Value at Maximum r^2	Density	Total Person Miles	r^2	0.3486	0.3390	0.2830	0.2488
				t	7.9799	7.7789	7.3805	6.8583
10	(4) Land-Use Multiplier = Value at Maximum r^2	Population	Person Miles per Capita	r^2	0.0316	0.0066	0.0112	0.0022
				t	1.9695	0.8842	1.2528	-0.5604
11	(5) Land-Use Multiplier = Value at Maximum r^2	Land Area	Person Miles per Capita	r^2	0.0919	0.0446	0.0296	0.0018
				t	3.4707	2.3457	2.0513	0.5098
12	(6) Land-Use Multiplier = Value at Maximum r^2	Density	Person Miles per Capita	r^2	0.0246	0.0575	0.0131	0.1831
				t	-1.7314	-2.6825	-1.3519	-5.6409

Figure 1: r^2 Values for Urbanized Area Population Regressed to Transit Passenger Miles Times a Constant Shown on the Horizontal Axis Plus Automobile Person Miles.



Figures 2 and 3 show example regression lines for Hypothesis (1) with a "land-use multiplier" value of 1.0 compared to the "land-use multiplier" value that achieves the maximum r^2 value. The regressions are for data from 1990 and 2002. In each case it is visually apparent that the increase in the constant value in the equation which represents the "land-use multiplier" creates a significantly better linear fit for the data.

Figure 2: First Regression Line Comparison Example Using 1990 Data, Constant Value Set at 1.0 and Constant Value Set at 6.2 Where Maximum R^2 Was Achieved



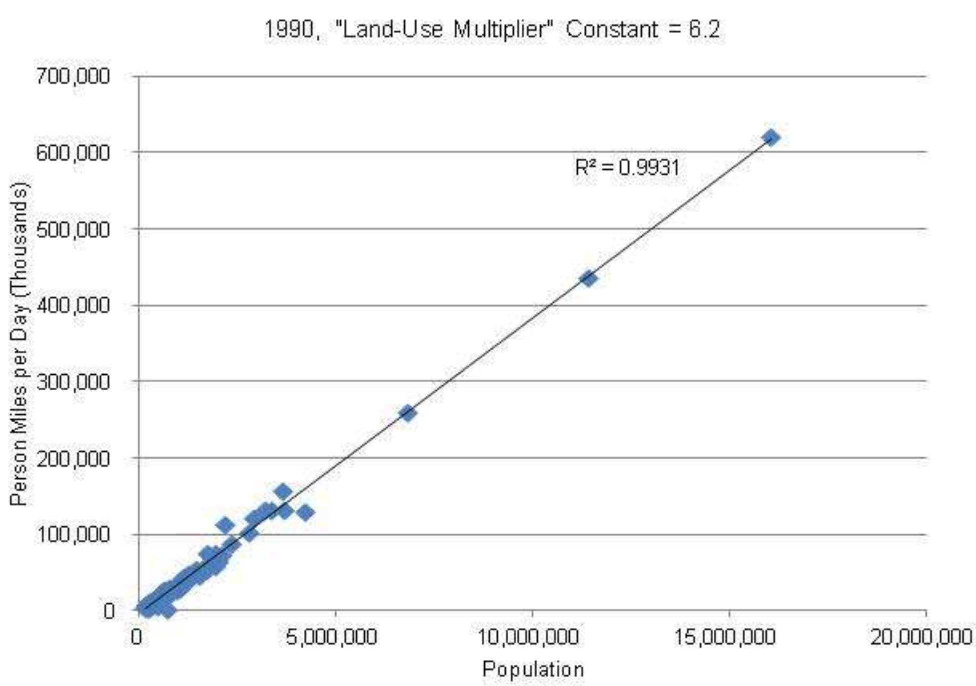
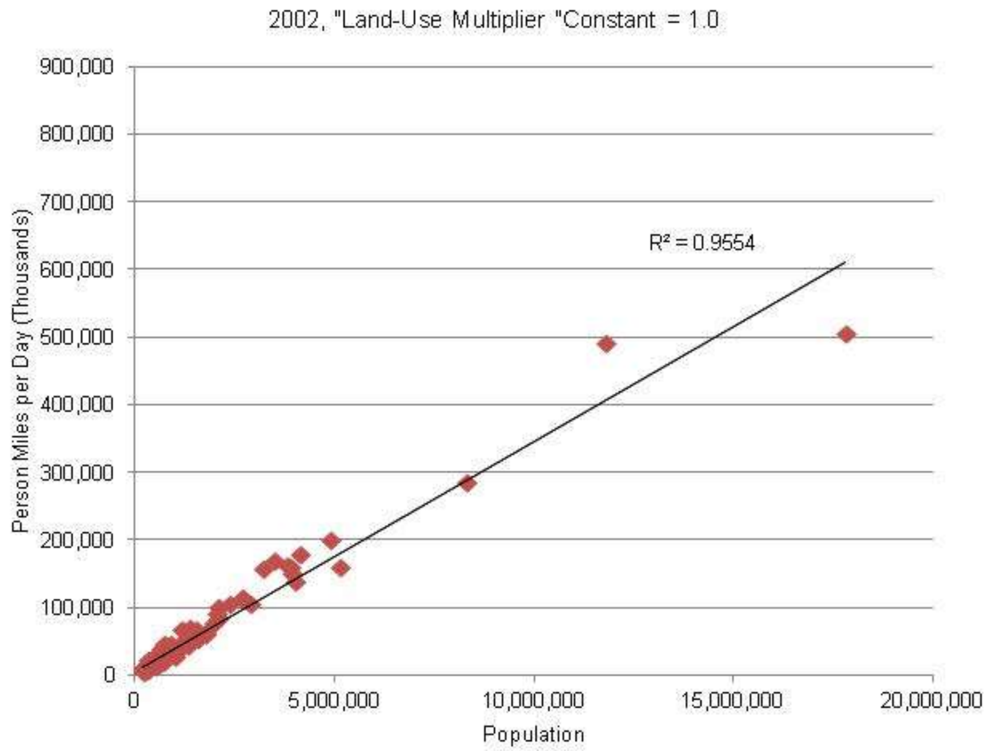


Figure 3: Second Regression Line Comparison Example Using 2005 Data, Constant Value Set at 1.0 and Constant Value Set at 6.8 Where Maximum R^2 Was Achieved



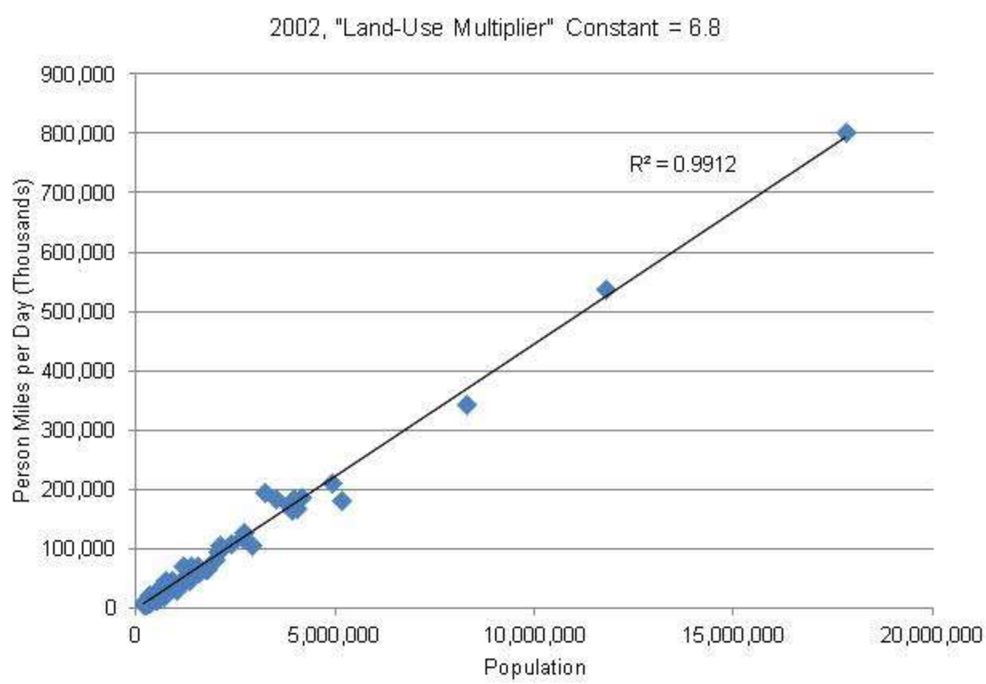


Table 4 reports the "land-use multiplier" value for each year from 1989 through 2010 (highway travel data are not yet published for 2009). The coefficients of determination for Hypothesis (1) are shown for direct substitution of automobile travel for transit travel with a constant of 1.0. The r^2 values show a very strong relationship of population to miles of travel and the slopes of the regressions are shown to differ significantly from zero by the high t test values. The "land-use multiplier" value at which r^2 maximizes are shown and are considerably higher than 1.0 indicating that one mile of transit passenger travel substitutes for substantially more than one mile of automobile person miles of travel; anywhere from 5.0 miles to 7.5 miles of automobile travel being replaces by a single mile of transit travel.

Table 4: Results for Tests for 1989 Through 2010 Showing Coefficients of Determination with Transit Ridership Directly Substituting for Automobile Travel (Constant = 1.0) and At The "Land-Use Multiplier" Value (Constant = from 5.0 to 7.5)

Year	Constant Set at 1.0			Constant Set at Maximum Coefficient of Determination		
	Constant Value	Coefficient of Determination (r^2)	t Test Value	Constant Value at Maximum r^2	Coefficient of Determination (r^2)	t Test Value
1989	1.0	0.9627	55.4371	5.4	0.9917	118.9253
1990	1.0	0.9604	54.1904	6.2	0.9931	132.0765
1991	1.0	0.9629	56.0555	6.4	0.9945	148.5070
1992	1.0	0.9596	54.5097	6.5	0.9925	128.2440
1993	1.0	0.9564	51.1542	7.5	0.9921	124.5125
1994	1.0	0.9515	48.9307	7.3	0.9899	109.3418
1995	1.0	0.9493	47.8163	7.2	0.9892	105.8413
1996	1.0	0.9601	53.2946	6.1	0.9898	107.1992
1997	1.0	0.9432	44.4389	7.4	0.9868	94.2874
1998	1.0	0.9446	45.0303	7.1	0.9838	84.8812
1999	1.0	0.9447	45.0796	6.8	0.9845	86.8500
2000	1.0	0.9445	44.7990	6.6	0.9835	83.9192
2001	1.0	0.9485	46.6283	6.3	0.9846	86.9148
2002	1.0	0.9554	53.5648	6.8	0.9912	123.1595
2003	1.0	0.9626	59.6196	6.4	0.9913	125.5023
2004	1.0	0.9548	53.7694	6.6	0.9871	102.4043
2005	1.0	0.9594	57.2845	6.5	0.9885	109.5315
2006	1.0	0.9565	62.6609	5.6	0.9881	107.8520
2007	1.0	0.9630	60.8018	5.4	0.9877	106.8810
2008	1.0	0.9606	58.8350	5.5	0.9872	104.5720
2010(a)	1.0	0.9574	56.5769	5.0	0.9861	100.3069

(a) Highway data are not yet available for 2009.

These results are consistent with other studies defining the value of the "land-use multiplier" reported on Table 1. The average value of the 13 "land-use multiplier" calculations on Table 1 was 6.17 and the average value of the 21 years reported in this paper is 6.41. These results are presented, along with the results of previous research, on Table 5 and graphically in Figure 4. As described earlier, results have been converted to person miles of automobile travel if the original study reported vehicle miles of automobile travel.

Table 5: "Land-Use Multiplier" Values Calculated for Hypothesis (1) Compared to Results from Other Studies

Year of Study or Data	Auto Vehicle Miles of Travel Reduction per Transit Passenger Mile (a)	Auto Person Miles of Travel Reduction per Transit Passenger Mile (* Calculated from VMT Data)	Source
2010	---	5.0	This Report
2009	---	1.3 to 6.3	New York MTA, reported in APTA Working Group, 2009,
2009	4.0	* 6.4	Litman, 2009
2008	---	5.5	This Report
2007	1.9	3.1	Bailey, Mokhtarian, and Little, 2007.
2007	---	5.4	This Report
2006	---	5.6	This Report
2005	---	6.5	This Report
2004	---	6.6	This Report
2003	---	6.4	This Report
2002	---	6.8	This Report
2001	---	6.3	This Report
2000	---	6.6	This Report
1999	---	6.8	This Report
1998	---	7.1	This Report
1997	---	7.4	This Report
1996	---	6.1	This Report
1995	---	7.2	This Report
1994	1.4 to 9.0	* 2.2 to 14.4	Holtzclaw, 1995.
1994	---	7.3	This Report
1993	---	7.5	This Report
1992	---	6.5	This Report
1991	4.0 to 8.0	* 6.4 to 12.8	Holtzclaw, 1995.
1991	---	6.4	This Report
1990	---	6.2	This Report
1990	4.4	* 7.0	MTC/RAFT 2010 Project, reported in Holtzclaw, 1995.
1989	---	5.4	This Report
1980	2.9	* 4.6	Newman and Kenworthy, reported in Holtzclaw, 1995.
1980	---	3.5	Newman. and Kenworthy, 1992
1980	3.6	* 5.8	Newman and Kenworthy, reported in Holtzclaw, 1995.
1980	4.0	* 6.4	Pushkarev and Zupan, 1980.

(a) Studies with amounts shown in this column reported their results in vehicle miles of travel, which are converted with a standard multiplier of average automobile vehicle occupancy to a person mile value shown in the next column.

Table 6 groups the calculated "land-use multipliers" from this paper and other categories into ranges. Only one study found a "land-use multiplier" value less than 2.0, three found values between 2.0 and 4.0, 7 found values between 4.0 and 6.0, 21 found values between 6.0 and 8.0, and only two found values greater than 8.0.

Figure 4: "Land-Use Multiplier" Values Calculated for Hypothesis (1)
Compared to Results from Other Studies

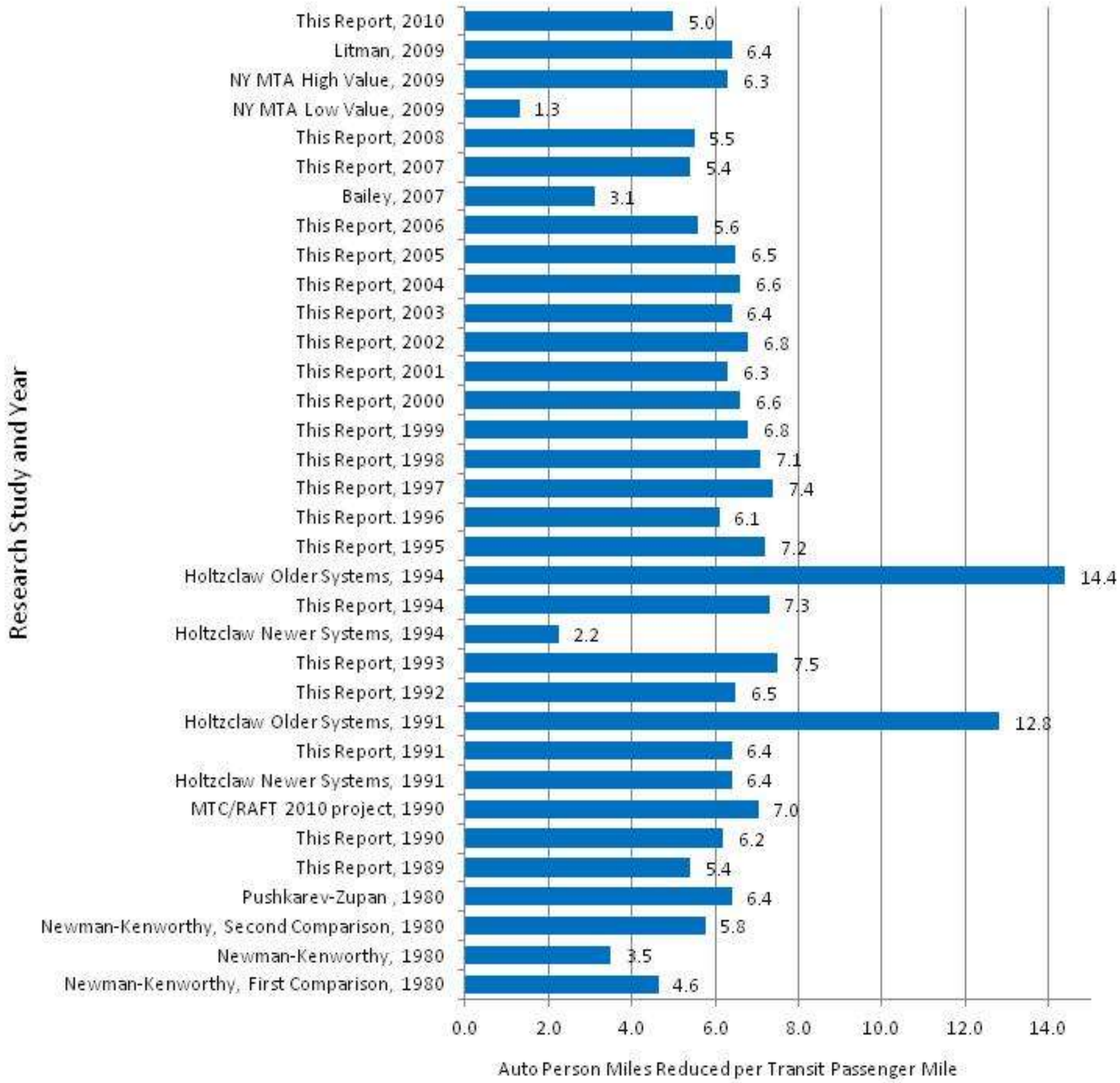


Table 6: "Land-Use Multipliers" Grouped in Ranges

"Land-Use Multiplier" Range Found in Research Studies	
Range in Miles	Number of Studies with Result in Miles Range
Less Than 2.0	1
2.0 to 4.0	3
4.0 to 6.0	7
6.0 to 8.0	21
8.0 or More	2

SUMMARY

Tests using standardized data, reported annually by federal government agencies, confirm the findings in previous research that there is a "land-use multiplier" that is greater than 1.0. A "land-use multiplier" is a measurement of how much automobile travel, measured in person miles, is replaced by a single passenger mile of transit travel. Researchers have measured "land-use multipliers" as low 2.2 and as high as 14.4. The purpose of this paper is to confirm and measure the "land-use multiplier" using publicly available data in a manner that can be easily replicated and repeated over time.

The test is based on the principal of time budget theory that when measured using adequately sized population groups, the average amount of time people spend daily on specific activities, in this case travel, does not vary over time or location. A large number of time use surveys indicate that people travel about 70 minutes a day, they do so in different places and have done so over long periods of time. This phenomenon is tested for by using United States urbanized area data from 1989 through 2010. The assumption is made that average travel speed is the same in these areas. If the speed and the same amount of time is devoted to travel, than the aggregate amount of travel is a function of population size. Regressions are run of the amount of vehicular travel, automobile person miles and transit passenger miles, compared to population. Very high coefficients of determination are obtained which are found to have slopes significantly different from zero.

If, however, transit travel disproportionately replaces automobile travel, the coefficients of determination should increase in value if a constant called the "land-use multiplier" is added to the regression equation as a multiplier of transit passenger miles to account for the loss of automobile miles. This procedure is followed and the coefficients of determination are found to increase. The coefficients maximize, reach their highest value, when the "land-use multiplier" is between 5.0 and 7.5 in the 21 replications of the test.

This is an important confirmation of other research. It means that a simple comparison of transit and automobiles costs and benefits is not a valid comparison of their impact. The reduction in air pollutant and greenhouse gas emissions and the reduction of energy use associated with the replacement of automobile travel with transit travel are seriously underestimated using a direct substitution comparison. According to these data the estimated savings from direct comparisons are a small fraction of the actual savings. Further research concerning the "land-use multiplier" that would improve the application of the concept would be very beneficial to transit benefit/cost analysis.

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