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A New Method For Estimating And Projecting Vehicle Miles Of Travel

Linkages To Landscape Change And Ozone Impacts To Northern Forests

Brian Stone, William Obermann, and Stephanie Snyder

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1. INTRODUCTION

Could our driving habits be impacting our forests? In recent years, sprawling residential and commercial development has become a serious environmental concern. Sprawl creates communities that are dependent upon vehicles because many residential areas are too far from school, work, and shopping for people to walk. Changing land use and development patterns have fueled a dramatic increase in the number of miles we drive (Frank *et al*. 2000, Newman and Kenworthy 1989).

Since the passage of the original Clean Air Act in 1963, ambient air quality in the United States has improved significantly. Between 1970 and 2000, aggregate emissions of the six criteria air pollutants regulated by the U.S. Environmental Protection Agency (USEPA) decreased by about 29 percent nationally (USEPA 2001). It is important to note, however, that this aggregate statistic masks significant negative trends that are specific to particular regions and landscape types. Although urbanized regions have generally improved, many rural areas of the country have continued to decline in air quality, particularly with regard to tropospheric ozone formation and transport. Since 1997, rural areas have recorded higher ozone levels than urbanized regions, with 14 national parks exceeding the national health-based standard for ozone in 1999 (USEPA 2001). In the eastern half of the country, rural ozone levels increased by 6 percent over the 1990s (USEPA 2000).

A deterioration in rural air quality significantly threatens not only human health but also the health and productivity of forest ecosystems. Ozone is one component of air pollution that is especially damaging to some types of forest vegetation. A number of studies have associated ozone with a range of detrimental forest effects, including foliar injury, reduced growth productivity, and physiological abnormalities (Chappelka *et al*. 1996, Hogsett *et al*. 1997, Phillips *et al*. 1997). In recent years, rising ozone levels within rural areas have been linked to greater forest susceptibility to disease and a reduction in commercial timber production. The USEPA (2001) estimates that ozone pollution is responsible for over $500 million in commercial forestry and agricultural losses annually in the United States. In light of the strong correlation between ozone formation and ambient temperature, changes in regional and global climates may substantially accelerate these losses over the coming decades.

Much of the growth in rural ozone concentrations can be attributed to a national increase in the emissions of nitrogen oxides (NOx), one of two primary precursors to ozone formation. Between 1970 and 2000, emissions of NOx increased by almost 20 percent nationally, with the bulk of this increase produced by vehicles (USEPA 2001). The substantial rise in NOx emissions may be explained, in large part, by changing land use patterns that have fueled a dramatic increase in vehicle travel. As urbanized regions have continued to decentralize rapidly over the past three decades, national vehicle miles of travel (VMT) have increased by over 140 percent (USEPA 2001). As illustrated by a large number of empirical studies on land use and travel behavior, the national trend toward lower density development patterns has contributed to a significant increase in per capita vehicle travel (e.g., Frank *et al*. 2000, Newman and Kenworthy 1989). Due to the potential for ozone and its precursors to be transported hundreds of miles from the point of origin, rising vehicle emissions within sprawling metropolitan regions can threaten both urban and rural forested areas through a combination of locally produced and transported ozone. If we continue to live in sprawling, dispersed communities and drive more miles in our daily lives, we may be placing our forest resources at risk.

About The Authors:

Brian Stone is an Assistant Professor with the Department of Urban and Regional Planning, University of Wisconsin-Madison, 925 Bascom Mall/Old Music Hall, Madison, WI 53706; e-mail: bjstone@wisc.edu.

William Obermann is Air Quality Planner, Denver, CO.

Stephanie Snyder is an Operations Research Analyst with the USDA Forest Service, North Central Research Station, 1992 Folwell Avenue, St. Paul, MN 55108.

2. PROJECT OVERVIEW

Understanding how land use change affects forest health vis-à-vis increased travel requires an interdisciplinary, multiphase approach. The purpose of this report is to determine how to begin explicitly constructing and testing the linkages between land use, demographics, and VMT. Once these relationships are established, they will form the foundation for analyzing how land use change projections can be used to estimate future levels of VMT, ozone production, and ultimately forest health.

Although scientists have a basic understanding of how ozone pollution ultimately affects forest resources, they know little about how to link that understanding to demographic trends and land use conditions. Without this understanding, it is difficult to determine how changes in land use or development patterns and policies may ultimately affect air quality and forest health. By relating land use and demographic conditions to travel behavior, VMT levels can span that information gap.

The USEPA has developed a suite of models that can be used to estimate vehicle emissions *factors* for the ozone precursor pollutants such as NOx. To generate precursor emissions levels themselves, these emissions factors must be combined with estimates of VMT. Once ozone precursor emissions have been estimated, they can be entered into coupled atmosphere-chemistry models to predict ozone concentration patterns and trends across defined regions. From there, impacts to forest ecosystems can be evaluated. Making this link, however, requires very detailed estimates of when and where VMT values are and will be generated. Our challenge, then, was to determine a way to generate VMT estimates that account for current and future demographics and land use conditions that could be used as input to emissions processing models. Based upon a review of the literature, we determined that new techniques were needed to estimate and predict levels of VMT data that accurately reflect the demographic trends and land use conditions of a region.

This report consists of two parts. In the first part, VMT estimates were developed for the three-State region of Michigan, Minnesota, and Wisconsin based upon current demographic and land use conditions (fig. 1). This project was designed to develop estimates of vehicle travel at the 1-km^2 resolution that may be used as input to mobile emissions models. The final product allocates the 1-km^2 VMT values on an hourly basis through a 24-hour period, as required by the mobile emissions models. These VMT estimates are intended to provide a stronger link between land use patterns, ozone formation, and remote forest effects. In the second phase of this research, a method was developed for estimating VMT based upon future demographic and land use conditions. Both phases were pilot studies meant to illustrate capabilities for estimating and predicting VMT. In practice, VMT estimates are needed across a broader spatial extent than our three-State study area to fully evaluate the effects of ozone on regional forest vegetation.

3. SOURCES OF DATA

The VMT values used in this study represent both residential and commercial traffic summarized from the most comprehensive and complete data sources available. Residential VMT represents trips that started or ended at individual households and are personal in nature (e.g., trips to work, the store, for recreation) and is generally quantified through household surveys. Commercial traffic is typically surveyed at interstate weigh stations, at the workplace, or at border crossings. Therefore, it is typical to have two different surveys that must be merged to represent a region's traffic: one in residential VMT and the other in commercial VMT. The data sources for residential and commercial VMT used for this project are described in more detail below.

3.1 Residential VMT Data

The estimates of residential VMT were developed from the 1995 Nationwide Personal Transportation Survey (NPTS), a national longitudinal household survey sponsored by the Federal Highway Administration, Bureau of Transportation Statistics, Federal Transit Administration, and National Highway Traffic Safety Administration. It provides detailed and comprehensive information to assist transportation planners in statewide, regional, or national research. It is administered every 5 to 8 years; previous surveys include the 1969, 1977, 1983, and 1990 NPTS. The particular strength of the 1995 NPTS for this study is its uniform application throughout the three-State study region. Because each survey household in Minnesota, Wisconsin, and Michigan was chosen with the same sampling technique and issued the same questionnaire, the results provide a uniform foundation for developing VMT estimates.

The 1995 NPTS data represent a household travel survey administered from May 1995 to July 1996 to gather information on personal travel characteristics. It is the most recent data wave for which complete data are available. Over 42,000 households maintained travel diaries throughout the year for single 24-hour periods.[1] Individual households were randomly selected, but the selection process was stratified by region of the country, size of the metropolitan area, and presence or absence of a subway system. Each selected household was asked to participate in the survey by recording its travel characteristics for one 24-hour period. In addition to the vehicle miles of travel and trip start time variables used for this project, the NPTS also records the purpose of the trip, the mode of transportation used, the number of vehicles per household, and various other characteristics of personal travel.[2] Information recorded on the origin, destination, mode, travel time, and distance of each trip taken may be used to estimate daily household vehicle travel. As a household survey, the NPTS permits individual trips to be associated directly with a discrete set of demographic and land use characteristics tied to the residential census tract, providing an empirical basis for associating land use and travel behavior while controlling for

Figure 1.—Map of project study area

[1] Note: Results from the most recent wave of the NPTS, the National Housing Transportation Survey of 2001, are scheduled for release in 2004. However, because this wave of the NPTS lacks a transferability component, our research will employ the 1995 NPTS in deriving vehicle travel estimates.

[2] Further documentation on the 1995 Nationwide Personal Transportation Survey can be found in the "User's Guide for the Public Use Data Files, 1995 Nationwide Personal Transportation Survey," October 1997, FHWA Publication Number FHWA-PL-98-002. The user's guide and other documentation are also available at: http://www-cta.ornl.gov/npts/1995/doc/index.shtml (valid as of 06/2004).

important demographic influences, such as income and vehicle ownership.[3]

The NPTS provides a comprehensive and reliable basis for measuring vehicle travel across a multistate study region. Unlike national averages or State data obtained through State-specific surveys, the NPTS provides a uniform set of travel observations obtained across the full array of land use types. In addition, such empirical observations provide a more reliable basis for modeling the interaction between land use and travel behavior than theoretically based gravity or discrete choice models of travel decisionmaking. However, the NPTS does not provide complete geographic coverage within each State. In response to this limitation, researchers from the Oak Ridge National Laboratory have developed a “transferability component” to facilitate the accurate estimation of vehicle travel within any census tract in the United States. This component, which was used in this study, is detailed in section 4.1.1.

3.2 Commercial VMT Data

Commercial traffic makes up approximately 20 percent of the VMT in the U.S. and must be estimated separately from residential VMT. The most comprehensive and uniform data set available for commercial truck traffic in the region is collected through the Freight Analysis Framework (FAF), administered by the Freight Management Section of the Office of Operations, Federal Highway Administration.[4] The FAF was developed to help decisionmakers and planners study the relationships between freight flow and infrastructure capacity to determine where future improvements are needed in the interstate system. The FAF provides data and estimates for 1998, 2010, and 2020 volumes of truck traffic on interstates and major highways throughout the United States. These data were compiled using Federal, State, and local sources.

The objective of the FAF effort is to develop strategic policies and plans to upgrade transportation infrastructure as demand grows. Like the residential-based statistics used from the 1995 NPTS, the FAF data are applicable to the entire three-State study region with no need for adjustment between States. In addition, the 1998 counts could be geographically located, which later enabled us to combine residential and commercial VMT into a composite value. For these reasons, the FAF proved to be the most useful commercial data set available for this project.

3.3 Demographic Data

Demographics at the census block group level played a key part in development of the VMT estimates. Census block groups are clusters of census “blocks,” which in their simplest form are city blocks with a relatively even population distribution. Local jurisdictional boundaries, roads, waterways, railways, or other geographic features can also delineate blocks. The primary objective of the census in enumerating demographics at this scale is to capture approximately 1,500 people per block group. But in reality, the population can range from 600 to 3,000 people. Census block groups cannot cross the boundaries of other census tracts, nor can they cross county or State lines. Census tracts are an aggregation of census block groups, so typically two or more block groups exist within one census tract.

For this project, demographic information was obtained from the 1990 and 2000 censuses. Because the 1995 NPTS was administered from 1995 to 1996, demographic information was interpolated from the 1990 and 2000 census data sets. More detail is provided about this interpolation in section 4.1.2.

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[3] It should be noted that, as a household survey, the NPTS associates all household vehicle travel with the land use characteristics of the residential census zone. As a result of this survey design, vehicle trips passing through a particular census zone, but not originating in the zone, are not included in the zone-based VMT estimates, but are rather associated with the zone of origin. Thus, trips neither originating nor terminating in the study region as a whole are not captured in the VMT analysis.

[4] Web site accessible at: http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm (valid as of 06/2004).

4. METHODS

4.1 Estimating Block Group Residential VMT

As described in section 3, results from the 1995 Nationwide Personal Transportation Survey (NPTS) were used to estimate residential VMT at the census block group level. As initially conceived, the NPTS would provide information on both the distance of household vehicle travel and the precise location of each survey household. This would permit household VMT to be statistically associated with demographic variables that are linked to the survey block groups and are known to be strongly related to vehicle travel. For example, vehicle ownership, income, and household size each have been associated with VMT in the literature. The creation of a predictive VMT model would permit the accurate projection of VMT of nonsurveyed households based on demographic data. However, in response to growing confidentiality concerns, the Federal Highway Administration no longer releases precise locational information for NPTS survey respondents. As a result, we were provided with a set of VMT rates developed by the Oak Ridge National Laboratory, an NPTS subcontractor with access to the full range of data. As described in the next section, these VMT rates were used to develop VMT estimates for every census block group within the three-State study region.

4.1.1 The Oak Ridge National Laboratory Transferability Study (Reuscher et al*. 2001)*

The Oak Ridge transferability study used the 1995 NPTS to develop VMT per household *rates.* The rates describe how much VMT is typical for households assigned to 11 different demographic clusters. The Oak Ridge National Laboratory performed this analysis so that transportation planners could tie or "transfer" the results of the NPTS to specific census tracts and therefore geographically locate VMT. In addition, this method does not violate any confidentiality standards.

Developed in 2001, the Oak Ridge transferability component identifies 11 clusters of demographically similar census tracts and derives for each a unique vehicle travel rate based on four demographic characteristics measured at the tract level: income, employment rate (ratio of number of jobs to number of residents over the age of 16), vehicle ownership, and urban-rural community classification (Reuscher *et al*. 2001). Identified in the transportation literature as significant predictors of vehicle travel (e.g., Frank and Pivo 1994, Holtzclaw 1994, TRB 1995), these demographic and land use characteristics are used to group census tracts hypothesized to share similar travel patterns.

As detailed in figure 2, demographically similar census tracts are clustered in three steps. In the first step, census tracts characterized by very high or very low mean incomes are combined into separate clusters. This initial step reflects the strong association observed between levels of income and vehicle travel behavior. In the second step, the remaining census tracts are clustered by community class designation, an urban-rural classification scheme that consists of five community types differentiated by population density and spatial proximity to urban centers. In order of population density and regional location, the classes are urban, suburban, second city, town, and rural community types.[5] In the final step, each community cluster is subdivided into three subclusters corresponding to high, medium, and low levels of income, employment, and vehicle ownership. Weighted averages of these three demographic variables are used in the final clustering process.

Once the various clusters have been formed, an average rate of vehicle trip generation and vehicle miles of travel is calculated based on the travel behavior of the NPTS respondents in each cluster. This average rate serves as a unique vehicle travel

[5] This classification scheme was developed by the Claritas Corporation.

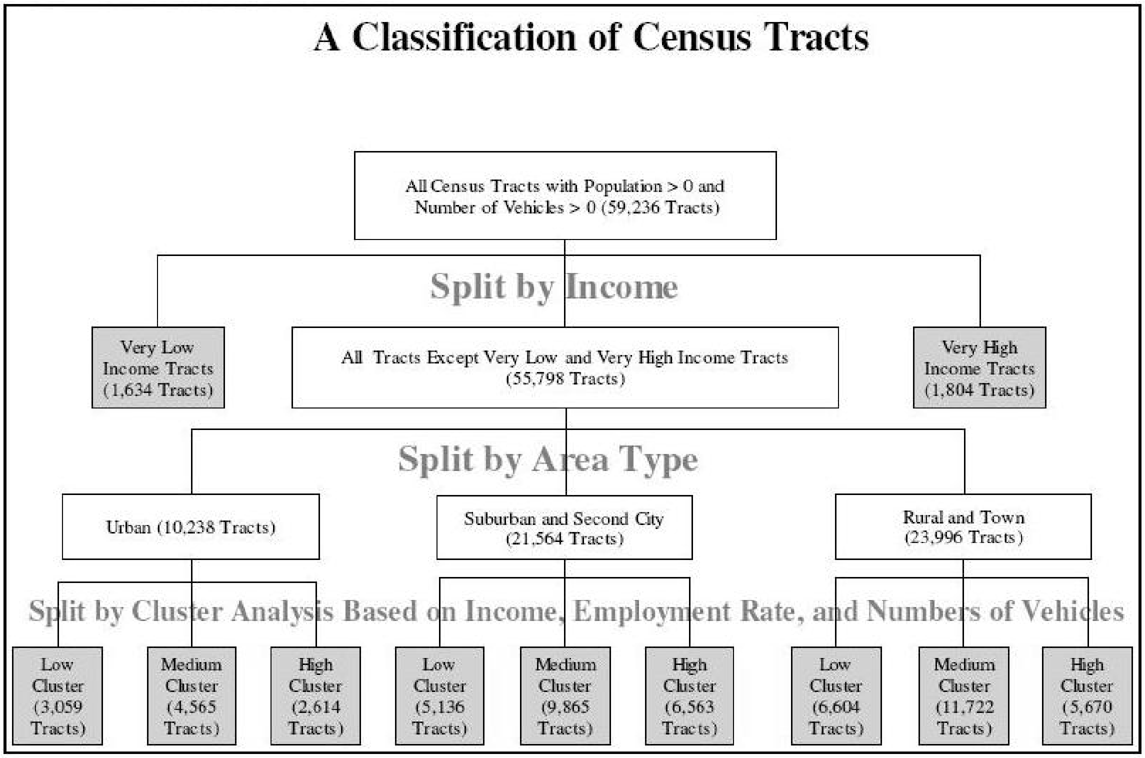


Figure 2.—Oak Ridge National Laboratory cluster analysis using census tract demographics.

factor that may be multiplied by the number of households found in any cluster census tract to derive an estimate of total daily vehicle miles of travel. In short, the transferability method derives 11 unique VMT factors that can be used to estimate daily vehicle travel in any census tract in the country. By multiplying the appropriate VMT factor by the household population of any tract, a reliable estimate of daily tract-level VMT may be derived, regardless of a particular tract's inclusion in the NPTS. This tract-level estimate is then aggregated to a uniform grid for incorporation into mobile emissions models.

To validate the cluster VMT rates, the estimated rates were compared to observed rates of VMT in four metropolitan regions included in the NPTS but withheld from the initial regression modeling (to ensure statistical validity). The clustering method was found to predict actual VMT within a 2- to 5-percent margin of error.

4.1.2 Deriving 1995 Census Tract Household Estimates

As noted above, total daily census tract VMT may be estimated by multiplying the number of households located in a particular tract by the associated VMT rate. Having assigned rates to each tract in the study region, our next step was to determine the number of tract households. The Census Bureau does not estimate the number of households for 1995, the year for which the VMT rates were generated from the NPTS. As a result, census data from the years 1990 and 2000 were used to interpolate a year 1995 estimate of tract households. Because the boundaries of some tracts shifted between the 1990 and 2000 censuses, we adopted the year 2000 census geography for the analysis.

4.1.3 Reconciling 1990 and 2000 Census Tracts and estimating VMT Rates

Because the VMT rates were derived based on 1990 census tract boundaries, these rates had to be spatially adjusted to match the tract household numbers tied to the census 2000 tract boundaries. Although the boundaries for most census tracts between 1990 and 2000 remained unchanged, a proportion of these areas were modified to accommodate significant population changes. Most commonly, a single 1990 tract was split to form two or more census 2000 tracts as tract population grew. In these instances, VMT rates needed to be adjusted to account for this modification. Once adjusted, the new household VMT rates could then be used with the 1995 household estimates to derive tract VMT estimates for the year 1995.

The www.census.gov Web site provides a 1990 census tract relationship file to adjust the 1990 census tracts to match the 2000 boundaries.[6] For this analysis, it was only important to know how the area of the tract had changed between the two censuses and to reflect that change accordingly in the VMT per household rate. The relationship file specifies the percentage of the 1990 tract areas within the 2000 tracts (i.e., 100 percent if the boundary has not changed, less if it has). The VMT per household rates from the Oak Ridge transferability study were tied to the 1990 tracts and then weighted according to how they were represented within the 2000 tract boundaries. For example, if a 2000 tract boundary included portions of two 1990 tracts, the VMT rate for both 1990 tracts was weighted to develop a composite 2000 VMT per household rate, as detailed in table 1 below.

4.1.4 Disaggregating to the Block Group Level

The final step in the residential VMT calculation was to disaggregate the census tract VMT estimates to the block group level. This step was performed to achieve a higher data resolution, a resolution more compatible with the 1-km^2 dimension often used for ozone modeling studies. Because tract boundaries are delineated to capture homogeneous demographic characteristics, moving from the tract to the block group should not introduce significant statistical bias. In addition, because the statistic is a per household *rate*, it can be applied at either the tract or block group level. In this project, the rate derived at the tract level was simply applied to each block group within that tract. For example, if a given tract contained four block groups, the same tract-level VMT rate was multiplied by the household estimate for each block group in the tract.

4.2 Assigning Commercial VMT to Near-Interstate Block Groups

To develop a more accurate estimate of VMT at the block group level, commercial VMT was also calculated for block groups located near interstate highways. Interstate volumes were used because of the nature of data collection through the Freight

Table 1.—Example of 2000 VMT per household rate determination

2000 tract ID*	1990 tract ID	Percent area of 1990 tract inside 2000 tract	1990 VMT per household rate	Weighted VMT (column D x column C)	2000 VMT per household rate (sum of column E)
A	B	C	D	E	F
0001.00	9,501.00	45	20.25	9.11	19.83
0001.00	9,502.00	55	19.51	10.72	19.83

* The 0001.00 year 2000 tract is one tract, but repeated in the format of this table since two different 1990 tracts compose its area.

[6] *The 1990 census tract relationship file can be accessed at: http://www.census.gov/geo/www/relate/rel_tract.html (valid as of 06/2004).*

Analysis Framework (FAF), which served as the data source for the commercial VMT (see section 3.2). The primary source of information for the FAF is data collected at weigh stations and major destinations. Although the FAF allocates commercial truck traffic to State and county highways, these allocations were modeled from the data collected along interstates. As depicted in figure 3, the truck traffic flow is reported between major exits and interchanges.

The FAF provides one data source that can be used for all three States to determine *where* commercial traffic volumes are located. Other State commercial traffic data sources were either not readily available, not spatially explicit, or not consistent among the States in terms of how the data were collected and processed. For these reasons, the FAF was the preferred source of commercial data.

The FAF digital line files and the 2000 block group boundaries were used in a GIS to identify those block groups bordering interstate highways. Once these near-interstate block groups were selected, the FAF segment lengths were calculated. A ratio was then developed reflecting the portion of the interstate segment (bounded by two exits or interchanges) within a specific block group. The truck traffic for the original FAF segment was then multiplied by this ratio to determine the appropriate volume of truck traffic for each block group. Figure 4 shows an example of this ratio technique. Block group 1 contains a ratio of 0.56, or 56 percent of the FAF interstate segment within its boundaries. Therefore, the commercial truck traffic count for this FAF segment was multiplied by 56 percent and assigned to block group 1. The remaining 44 percent of the count was assigned to block group 2.

In sum, two values were derived for each block group bordering an interstate highway: one for residential VMT (derived from the Oak Ridge transferability study and the 1995 NPTS) and another for the commercial VMT calculation (derived from the FAF). These two values were combined to produce a composite VMT of commercial and residential vehicle mileage. Note that data are not currently collected that would allow measurement of non-interstate commercial traffic volumes across a multistate region.

4.3 Allocation of VMT by Time of Day

Because ozone formation is sensitive to the solar cycle, the daily VMT estimates were next allocated to a 24-hour schedule. To do so, we used the day trip file from

Figure 3.—Distribution of the Freight Analysis Framework. Commercial truck traffic counts along I-94, I-43, and I-894 west of Milwaukee, WI. The darker lines represent the interstate; the gray lines represent State or county roads in the FAF network.

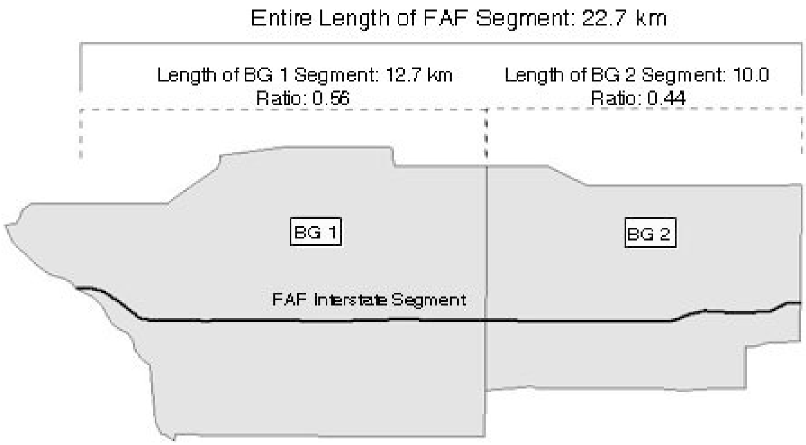


Figure 4.—Example of method used to assign FAF commercial truck traffic counts to near-interstate block groups.

1995 NPTS that contained information on what time trips started during the 1995 survey.[7] It should be noted that 1995 NPTS trip start times were used for both the commercial and residential VMT. As described above, commercial VMT estimates were developed for near-interstate block groups. These block groups were a small fraction of the total block groups for the entire study area. In addition, even in the near-interstate block groups, the residential portion of VMT was the majority portion in the composite VMT estimates. Finally, no suitable data were available for commercial trip start times in the study region.[8] For these reasons, the residential breakdown in trip start time from the 1995 NPTS was used for the composite VMT (residential + commercial) values. The volume of trip start times by time of day for the study region is expressed in table 2.

Table 2.—Percentage of trip start times by time of day (Developed from the 1995 NPTS day trip variable STRTTIME)

Hour	Total trips	Percent of total
0	55	0.52
1	35	0.22
2	22	0.14
3	14	0.09
4	46	0.29
5	136	0.86
6	425	2.70
7	868	5.51
8	759	4.82
9	752	4.78
10	931	5.91
11	1,043	6.63
12	1,199	7.62
13	1,011	6.42
14	1,119	7.11
15	1,357	8.62
16	1,264	8.03
17	1,341	8.52
18	1,023	6.50
19	734	4.66
20	688	4.37
21	447	2.84
22	255	1.62
23	189	1.20
Total	15,713	100

[7] *The variable in the 1995 NPTS data set that contains the start time of the trip in the day file is coded "STRTTIME."*

[8] *Hallenbeck, Mark,* et al. *1997. "Vehicle Volume Distributions by Classifications." FHWA Publication Number FHWA-PL-97-025. This study developed a percentage breakdown of commercial traffic over a 24-hour period. However, the information was developed from surveys at weigh stations throughout the Nation and the authors strongly recommended* against *applying the information at regional or statewide scales.*

4.4 Development of 1-km^2 Grid

Having estimated VMT at the block group level and allocated these estimates to a 24-hour schedule, we spatially distributed VMT to a 1-km^2 grid. The first step in developing the final grid was to divide the block group VMT by the block group area in square kilometers. This produced an estimate of VMT/ km^2 at the block group level.

Next, the VMT/km^2 value was converted into a raster grid at the 100 x 100 meter scale (or an area of 10,000 m^2). A raster grid is a file containing values in fixed units of area distributed over an X and Y coordinate system. Each value is represented as a “pixel,” much like the pixels used in digital photographs. Each pixel is a color in the grid, which represents a distinct VMT value. The size of these pixels represents the resolution of the grid and can be controlled by the user. We needed VMT estimates at the 1,000 x 1,000 meter resolution to meet the requirements for a concurrent ozone modeling study at the 1-km^2 resolution. However, our investigation showed that the area of many urban block groups is smaller than 1 km^2. Therefore, a 100 x 100 meter resolution was selected to represent the distribution of VMT more accurately. Figure 5 shows the difference in resolution between the two grid sizes. Note how the 100 x 100 meter grid represents block group VMT much more accurately than the 1,000 x 1,000 meter grid.

As figure 5 shows, if the 1 km x 1 km raster grid on the right was used to develop the final grid, much of the fine-scale resolution of urban block groups would have been lost. Instead, the finer 100 x 100 meter resolution on the left captured all of the block groups. The VMT values were then aggregated into the final 1-km^2 resolution grid.

Figure 5.—Representation of VMT at different grid resolutions.

5. RESULTS

The following sections display examples of the 1-km^2 VMT grid in urban and rural regions throughout the study area. These graphics provide a general overview of the VMT distribution throughout the study region. In addition, they show how VMT varies with intensity of land use. Generally, VMT values are highest within urban areas, but are also concentrated along major interstate corridors.

5.1 Distribution of VMT in Urban Areas

The following maps represent the 1-km^2 VMT grid in several urban areas throughout the study region. Figures 6, 7, and 8 detail the Detroit, Michigan; Milwaukee, Wisconsin; and Minneapolis/St. Paul, Minnesota regions, respectively. In each of these examples, darker shades of grey are indicate higher levels of VMT. Note the clustering of VMT in the downtown areas and along major interstates.

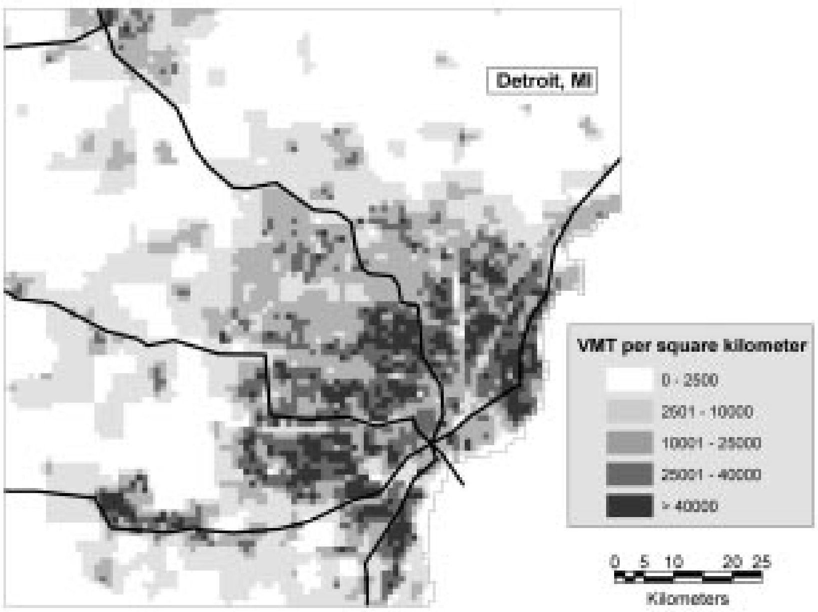


Figure 6.—1-km^2 VMT grid for the Detroit metropolitan area.

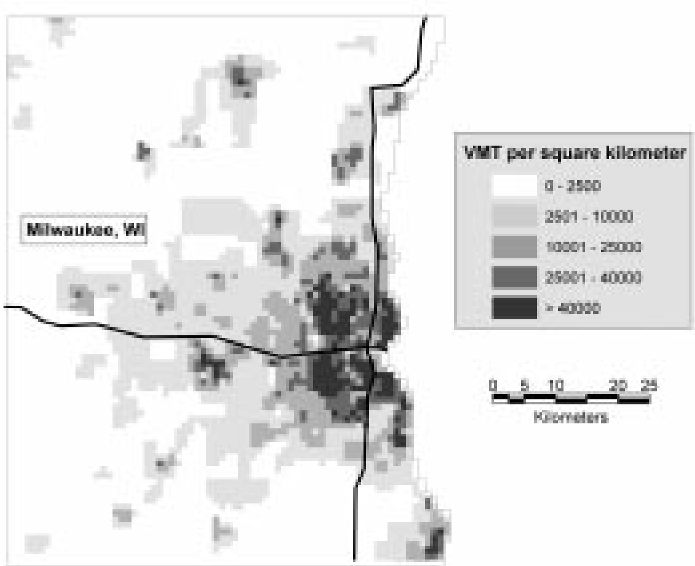
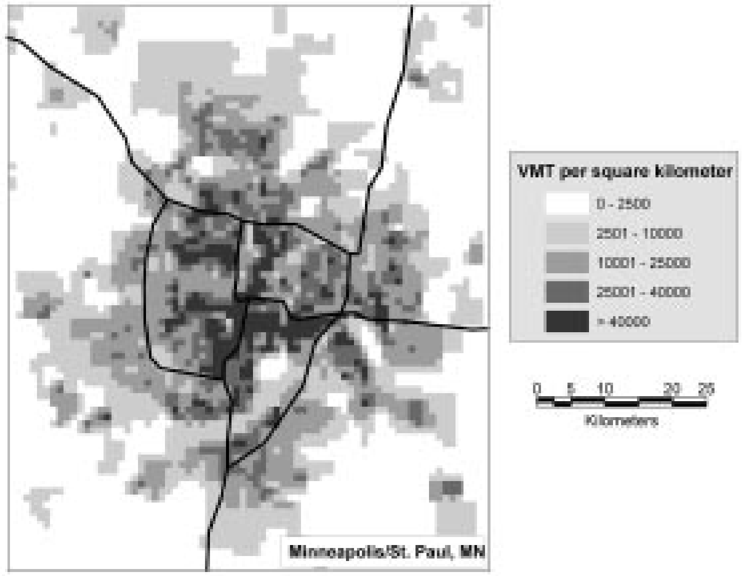


Figure 7.—1-km^2 VMT grid for the Milwaukee metropolitan area.

Figure 8.—1-km^2 VMT grid for the Minneapolis/St. Paul metropolitan area.



5.2 Distribution of VMT in Rural Areas

Figure 9 shows the 1-km^2 VMT grid in Wausau, Wisconsin, a rural section of the study area. In the large rural sections of the study area, like this example, the 1-km^2 VMT values are small in comparison to those in the urban areas. This is primarily due to the smaller number of households per block group in these areas, which was a central component in deriving the VMT estimates (see section 4.1). Hence, the grid shades are much lighter representing lower VMT rates than those found within urban areas.

Figure 9.—1-km^2 VMT grid for Wausau and surrounding rural area.

6. PHASE II—PREDICTING VMT UNDER FUTURE CONDITIONS

The second phase of this report details a method to forecast travel behavior. Specifically, this section of the report outlines a method to predict VMT at the census tract or block group. These results may then be disaggregated to a square kilometer grid and 24-hour schedule, using the methods outlined in the previous section, and then input into regional mobile emissions models. With the ability to forecast VMT, researchers can determine the impacts of future land use scenarios on regional air quality, particularly ozone.

It is important to emphasize that the intent of this research is to measure the sensitivity of regional air quality and remote forest ecosystem health to a set of predetermined land use characteristics rather than to precisely forecast how land use will change across the Midwestern United States over time. Subject to a diverse array of market-based, regulatory, and socio-political forces, regional land use change is a highly complex phenomenon that has been forecasted with only limited success over time scales extending beyond a decade or so. Rather than attempt to predict regional landscape change 25 to 50 years into the future, this work seeks to assess how a range of potential development scenarios would influence vehicle travel patterns, emissions, and ozone formation in future years. Specifically, the methodology presented herein may be employed to forecast the regional air quality implications of a "business as usual" scenario, through which historical land use trends continue into the future, and a set of "smart growth" planning scenarios, through which new development achieves a higher level of compactness, connectivity, pedestrian and transit orientation, and a diverse mix of land uses, among other design objectives. By evaluating the air quality and forest effects of alternative land use scenarios, we may compare the potential benefits of a land use design-oriented ozone management program to those of other control strategies.

What follows in this section is a general overview of a methodology to associate land use change with vehicle miles of travel at the regional scale.

6.1 Oak Ridge National Laboratory NPTS Transferability Study

As detailed in the first phase of the report, reliable VMT estimates at the census tract level may be derived from the Nationwide Personal Transportation Survey (NPTS). Although the transferability component provides a useful tool for estimating census tract VMT in the present, this method has not been used to forecast VMT in the future. We propose using the NPTS transferability component for this purpose by deriving estimates of tract-level income, employment rate, vehicle ownership, and community type for future years, and then by reassigning census tracts to one of the eleven transferability VMT clusters based on projected changes in a tract's demographic profile over time.[9]

The NPTS transferability component may be employed to estimate VMT in future time periods through three primary steps. In the first step, a set of demographic variables found to be significant predictors of vehicle travel are projected to a future time period. A number of forecasting methods may be used in this step, including linear trend extrapolation or one of a number of available land use and transportation modeling software packages. We recommend that linear trend extrapolation be employed to develop a "business as usual" development scenario, and that an additional "smart growth" scenario be developed in response to desired changes in housing densities by community type.

In the second step, census tracts are reassigned to one of eleven transferability VMT clusters in response to projected levels of income, employment rates, vehicle ownership, and urban-rural class in a future time period. The third and final step entails estimating future daily VMT at the census tract or

[9] *While the first section of this report developed present year estimates of both residential and commercial travel for census zones bordering interstate highway corridors, there are insufficient data to project commercial vehicle travel estimates.*

block group level by multiplying the projected number of census zone households by the appropriate cluster VMT rate. Once derived, these projected VMT estimates may be spatially and temporally disaggregated for incorporation into vehicle emissions models.

The remainder of this report examines these land use forecasting, cluster assignment, and VMT computation steps in detail.

7. FORECASTING LAND USE

In the first step of the method, we will forecast future tract demographics in response to two scenarios: a "business as usual" scenario and a "smart growth planning" scenario. The business as usual scenario will be based on the assumption that tract-level rates of change in housing population, household income, vehicle ownership, and tract employment rates will continue at historical rates. Through the estimation of a series of tract-level linear regression models, we will extrapolate future values of these variables to the target years of 2025 and 2050 based on data from the 1970, 1980, 1990, and 2000 U.S. censuses. These trend extrapolations will provide a generalized forecast of future conditions based on past rates of growth or decline in four land use/demographic variables linked to travel behavior.

For the smart growth planning scenario, business as usual projections will be modified based on a set of assumptions pertaining to the adoption of growth management policies designed to enhance population and employment densities, while providing incentives for pedestrian and transit usage combined with disincentives for automobile travel. A set of adjustment factors, derived from a comprehensive literature review, would be developed to reflect the adoption of various smart growth planning policies in each census tract of the multistate study region. The package of policies adopted within each tract would be responsive to the tract's base year urban-rural classification, target year population and employment rate projections, and proximity to existing and planned transit and/or major roadway infrastructure. The following methodology may be used to forecast VMT responsive to either scenario.

7.1 Projecting Census Tract Demographic Variables

The first step in our method requires that tract-level income, employment rates, and vehicle ownership be projected to future years. Although there are many land use forecasting techniques for developing such projections, the complexity and expense of applying these methods across a multistate region is prohibitive. Given the availability of tract-level estimates of these four variables at discrete points in time (i.e., from the U.S. census conducted every 10 years), we recommend that future values of these four predictor variables be derived through simple linear trend extrapolation. Specifically, tract-level estimates of income, employment rates, vehicle ownership, and household population from the 1970, 1980, 1990, and 2000 decennial censuses may be used to develop a set of trend extrapolations to a future target year. These future values may then be employed to reassign each tract to a VMT cluster, which can be used—in concert with the household population forecast—to estimate tract-level VMT.

An important obstacle to developing such trend extrapolations concerns the changing geography of census tracts over time. Because census tract boundaries shift over time in response to population gain or loss, demographic estimates from past surveys must be adjusted to match the boundaries of the year 2000 census. As illustrated in table 3, an income estimate from 1990 can be adjusted to match the census 2000 tract geography based on the percentage of the tract area maintained in both years. Refer to section 4.1.3 for additional information on the relationship file.

Table 3.—Adjusting historical census demographics with the relationship file

2000 tract ID*	1990 tract ID	Percent area of 1990 tract inside 2000 tract	1990 Income	Weighted income (column D x column C)	2000 income (sum of column E)
A	B	C	D	E	F
0001.00	9501.00	45	$100,000	$45,000	$86,250
0001.00	9502.00	55	$75,000	$41,250	$86,250

* The census 2000 tract 0001.00 is composed of two census 1990 tracts.

Once these boundaries are adjusted, future values of any census attribute can be extrapolated to a target year through the derivation of a simple linear regression model. It should be noted that the reliability of this model diminishes in proportion to the length of the planning horizon (i.e., projections for the year 2050 would be less reliable than projections for the year 2025).

7.2 Deriving the Urban-Rural Classification for Future Years

In addition to the demographic attributes of income, employment rate, and vehicle ownership, the urban-rural classification is also essential to predicting household VMT. To derive the community type designation of a census tract in a future time period, a surrogate measure of population density known as “contextual density” must be derived. Contextual density accounts for both the population of a spatial zone and the density of all surrounding zones. Developed by the Claritas Corporation, contextual density is computed from two criteria: 1) the population density of a 4-square mile grid cell, and 2) the proximity of the grid cell to a major urban center. Rather than simply use grid cell density to develop community classifications, Claritas reasoned that there are fundamental differences between a small city outside of a metropolitan region and a suburb of a large city, even if both communities have the same population density. For this reason, a five-class scheme was developed to distinguish gradations of urbanization. As discussed above, these classes consist of the urban, suburban, second city, town, and rural community types.

To classify a spatial zone, Claritas first measures the population of a 4-square mile grid cell, as well as the population of all bordering grid cells. As illustrated in figure 10, the contextual density for the center grid cell is derived by summing the population of all nine cells and dividing by the total area of 36 square miles (persons per square mile of center cell is presented in parentheses; other cell values are numbers of residents). These contextual grid cell densities are then ranked from 0 to 99 to create density centiles (fig. 11). Based on observations from around the country, Claritas has designated rural areas as having a contextual density centile value of 19 or less. This ranking indicates that these rural areas have contextual densities less than that of 80 percent of all other cells. Grid cells (and encompassed census tracts) found to have a density centile between 20 and 39 are classified as “town,” while density centiles greater than 79 are classified as “urban.” Grid cells with a centile density of between 40 and 79 are classified as either “second city” or “suburban,” depending upon the cell’s proximity to an urban grid cell.

4989	5375	4702
5400	**5812 (1261)**	4500
5405	5320	3903

Figure 10.—Contextual density—population counts of 4-square mile grid cells.

85	87	83
88	**91**	81
89	88	75

Figure 11.—Centiles of contextual density.

Following the classification of geographic grid cells throughout the country, census tracts are classified based on their representation within a particular grid cell. The outcome of this process designates each census tract as urban, suburban, second city, town, or rural. Table 4 presents a set of descriptive statistics on the census tracts included within each of the urban-rural classes for the base year of 1995.

To derive these community type designations for future years, the population density of each tract is projected to a target year in the same manner as the other demographic measures. The grid cells are then reclassified based on future trends in population density and the potential emergence of new urban centers. As described in the next section, these modified community type designations may then be used to reassign each census tract to a VMT cluster.

Table 4.—Nationwise descriptive statistics for the 1995 Claritas urban-rural classes

	Selected demographics by urban-rural classifications				
Demographic	**Rural**	**Town**	**Second city**	**Suburb**	**Urban**
Total households	18,016,688	17,875,435	13,849,764	24,520,613	17,684,910
Pct of total households	20	19	15	27	19
Population center density	11.7	42.0	60.3	85.5	92.1
Grid cell density	10.3	29.3	55.3	63.3	89.1
Median HH income	25,316	32,207	30,384	40,046	30,434
Median householder age	49.0	47.0	45.7	45.9	46.1
Pct HHdr age 15-34	22.8	25.9	30.5	27.6	29.3
Pct HHdr 65+	24.6	21.8	22.0	19.2	22.1
Pct HHdr white	90.0	88.9	81.0	81.5	58.4
Pct HHdr black	6.1	6.0	11.6	8.8	21.6
Pct HHdr American Indian	1.2	0.5	0.4	0.3	0.3
Pct HHdr Asian	0.2	0.8	1.7	2.8	4.9
Pct HHdr Hispanic	2.3	3.7	5.2	6.5	14.7
Pct pop foreign born	1.6	3.2	5.7	8.4	18.8
Pct 1 person HH	20.7	21.6	27.4	23.0	31.5
Pct 4+ person HH	28.1	27.2	23.4	26.6	24.1
Pct married couple HH	64.6	61.3	50.4	57.0	40.4
Pct HHs with children	39.2	38.6	33.9	36.1	31.6
Pct married couple HHs w/children	31.6	30.3	23.8	27.6	19.1
Pct HHs single parent	7.6	8.3	10.0	8.5	12.6
Pct HHs with female HHdr	8.8	10.0	12.4	11.0	16.2
Pct own	78.3	71.6	58.1	66.4	44.1
Pct rent	21.7	28.4	41.9	33.6	55.9
Average units in structure (weighted by HH)	1.4	2.8	5.7	6.2	13.3
Pct structure SFDU	74.6	72.6	63.7	68.4	42.8
Pct structures 1 detached	73.4	68.9	58.0	61.6	34.0
Pct structures 1 attached	1.2	3.7	5.7	6.8	8.8
Pct structures 20+ units	0.5	2.3	7.2	8.2	21.5
Pct HHs in condo	0.3	2.2	4.5	6.9	7.0
Median years of stay in unit	9.5	7.8	7.1	8.1	8.1
Pct HHs moved in <= 5 years	40.8	49.3	54.3	51.5	49.7
Pct HHs move in 20+ years	21.6	17.5	17.0	17.2	18.5
Pct with college degree	11.3	18.8	22.3	25.9	22.8
Pct white collar occ.	42.8	55.4	59.1	65.4	60.4
Pct managerial/professional occ.	18.0	25.0	26.6	30.3	27.3
Pct blue collar occ.	38.1	30.6	26.0	23.4	25.1
Pct farm occ.	7.2	2.2	1.4	1.0	0.9
Pct in agricultural ind.	9.5	3.4	2.1	1.4	1.1
Pct in manufacturing ind.	21.6	19.6	15.9	15.9	15.0

Abbreviations and Notes:

HH = Household
HHdr = Householder
Occ = Occupations, based on employed persons age 16 and over
Ind = Industry, based on employed persons age 16 and over
SFDU = Single family dwelling unit
Average units in structure = Weight-averaged number of units in structure weighted by households
College degree = Pct population age 25 and over with BA or advanced degree

Data represent weight-averaged values for block groups weighted by households.

8. ASSIGNING CENSUS TRACTS TO VMT CLUSTERS IN FUTURE YEARS

After projecting census tract income, employment rates, and vehicle ownership, and assigning a new urban-rural classification for a target future year, we reassign each tract to a VMT cluster. For census tracts that are not expected to change significantly between the base year of 1995 and a target future year, the cluster designation is also unlikely to change, resulting in the assignment of the same base year VMT rate. However, under a business as usual scenario, tracts that have grown significantly across one or more of the four demographic measures in past decades will be projected to continue these trends in future years. Likewise, community types projected to increase in density under the smart growth scenario (e.g., the suburban classification) will be assigned a higher number of housing units in future years, regardless of past trends. Therefore, as a result of projected demographic change, many tracts will "migrate" from one cluster to another. For example, an increase in the population density of a tract designated as a "town" in the base year of 1995 (as a result of continuing historical trends or simulating a change in planning policy) could result in its reclassification as a "second city" in some future year. Were such a transition to take place, the census tract would be reassigned from a town cluster to a second city cluster and, as a result, would be associated with a new VMT rate.

The assignment of tracts to VMT clusters in future time periods requires two basic steps. First, the average levels of income, employment rate, vehicle ownership, and urban-rural classification associated with each of the base year VMT clusters must be determined. This step requires that a full set of 1995 demographics be interpolated from the 1990 and 2000 censuses. Second, each tract must be reassigned to a cluster based on the pairings of target year income, employment rate, vehicle ownership, and urban-rural classification with the 11 VMT cluster variable ranges. The following discussion explores these steps in more detail.

8.1 Deriving VMT Cluster Characteristics

To assign a VMT rate to census tracts in future years, we must determine the mean income level, employment rate, vehicle ownership, and urban-rural classification of each VMT cluster. As briefly noted above, every census tract in the country was assigned to one of eleven clusters based on the relative distribution of these four variables. The clustering steps are explored in more detail in the following sections; please refer to figure 2 for a graphical illustration of this process.

8.1.1 Clustering by High and Low Income

The first step in the clustering method is to develop cutoffs for outliers in the data set based on household median income. All census tracts that have a median income less than $12,000 are separated from the rest and designated as "very low income" tracts. These tracts form their own cluster. Similarly, tracts with a median income of more than $75,000 are separated from the rest and designated as "very high income" tracts. These tracts also form their own cluster. As illustrated in the "split by income" tier of figure 2, this step yields three groups of income data: less than $12,000, greater than $75,000, and a large set of intermediate income tracts. The second step in the clustering process is to stratify these intermediate income tracts by urban-rural classification.

8.1.2 Clustering by Urban-Rural Classification

As discussed above, Claritas developed five community type designations for the 1995 NPTS. A preliminary analysis of travel behavior within these urban-rural classes suggested that residents in suburban areas and second cities manifest similar vehicle travel patterns. Likewise, the travel behavior of residents in tracts classified as rural or town was also found to be similar, suggesting that little statistical value resulted from differentiating these tract groupings for an analysis of vehicle travel. As a result, researchers at the Oak Ridge National Laboratory combined these groups into just three clusters of census tracts: urban, suburban-second city, and town-rural. Thus, in the second step of the transferability study clustering process, every census tract in the Nation was assigned to one of three community type designations. The number of urban, suburban-second city, and rural-town tracts is presented in table 5.

Table 5.—Number of census tracts by community type cluster

Cluster	Number of 1995 census tracts
Urban	10,238
Suburban-second city	21,564
Rural-town	23,996

8.1.3 Clustering by Demographic Profile

The final step in the clustering process requires that each community type cluster be sub-stratified by similar groupings of income, employment rate, and vehicle ownership. Analysis of the data suggested that three subgroupings per community type cluster would be sufficient to statistically differentiate the data. Within each community type grouping, therefore, census tracts were assigned to a low, medium, or high subgrouping—roughly corresponding to low, medium, and high levels of income, employment rates, and vehicle ownership. This demographic clustering process worked well for tracts characterized by uniform levels of these three variables. For example, for census tracts characterized by low levels of income, employment rates, and vehicle ownership, the development of a "low" cluster was a straightforward process. Many tracts, however, are characterized by a nonuniform distribution of these three demographic variables. For example, a highly urbanized tract might be characterized by high levels of income and employment but low levels of vehicle ownership. In these instances, a statistical clustering algorithm was needed to develop distinct clusters based on a statistical weighting of the demographic attributes. The result of this clustering step is the final set of nine clusters presented in table 6.

Table 6.—1995 transferability study clusters and associated census tracts

Transferability study cluster	Number of 1995 census tracts
Urban high	2,164
Urban medium	4,565
Urban low	3,059
Suburban high	6,563
Suburban medium	9,865
Suburban low	5,136
Rural high	5,670
Rural medium	11,722
Rural low	6,604

8.2 Deriving Transferability Study Cluster VMT Rates

As explored in the first part of this report, cluster VMT rates are based on the vehicle travel behavior patterns of NPTS households captured within the cluster. Representative of demographically similar groupings of households, the clusters are hypothesized to capture households with similar rates of vehicle travel. Thus, the average level of daily VMT by NPTS households is assigned to all households in the cluster, facilitating the development of VMT estimates for households and census zones not included in the NPTS. An independent analysis of non-NPTS household travel rates found the clustering methodology to be a statistically reliable approach to estimating daily household VMT (Reuscher *et al.* 2001).

8.3 Assigning Census Tracts to VMT Clusters in Future Years

The final step in our clustering methodology is to reassign census tracts to new clusters based on the mean values of these variables in future years. To do so, we must quantify the demographic characteristics of each cluster. Although the authors of the Oak Ridge transferability study have not published the exact demographic profile of the 11 clusters, this information can be obtained by interpolating a set of 1995 estimates of tract-level income, employment rates, and vehicle ownership from the 1990 and 2000 censuses. In combination with published information on the cluster designation of each tract, the mean value and range of income, employment rates, and vehicle ownership associated with each cluster are easily derived. This information may then be used to reassign census tracts to the fixed cluster ranges following the development of demographic attributes for a future year. Once each tract has been reassigned to a cluster, the cluster VMT rate may be used to estimate vehicle travel in the future time period.

Table 7 illustrates this process. In the first three columns, the cluster number, description, and average household daily VMT rate is provided. To reassign future year census tracts to a cluster, we must determine the range of income, employment rate, and vehicle ownership associated with each cluster. For the very low and very high income clusters, the employment rate and vehicle ownership variables were not used in cluster development and thus are not needed for the reassignment of census tracts. For all other cluster groupings, the variable ranges of these three variables must be determined for the 1995 base year. As noted above, data from the 1990 and 2000 censuses must be interpolated to derive the 1995 values of income, employment rate, and vehicle ownership.

Once these variable ranges are determined, census tracts may be reassigned to the clusters based on the future year values for income, employment rate, and vehicle ownership. This step can be accomplished through the use of a statistical software package.

Table 7.—Cluster VMT rates and needed demographic profiles

Cluster	Description	VMT rate	Demographic characteristics		
			Income	Employment rate	# of vehicles
1	Very Low Income	20.24	< $12,000	N/A	N/A
2	Urban Low	19.50		TO BE DETERMINED	
3	Urban Middle	36.97		TO BE DETERMINED	
4	Urban High	43.94		TO BE DETERMINED	
5	Suburban Low	41.11		TO BE DETERMINED	
6	Suburban Middle	52.05		TO BE DETERMINED	
7	Suburban High	64.62		TO BE DETERMINED	
8	Rural Low	60.61		TO BE DETERMINED	
9	Rural Middle	67.78		TO BE DETERMINED	
10	Rural High	77.55		TO BE DETERMINED	
11	Very High Income	66.09	> $75,000	N/A	N/A

9. ESTIMATING VMT IN FUTURE YEARS

The final step in the methodology entails estimating future year daily census tract or block group VMT. Having assigned each census tract in the study region to a new cluster, we may derive an estimate of daily vehicle travel by multiplying the projected number of housing units for the target year times the cluster VMT rate. This simple process is illustrated in table 8.

Following the computation of a tract or block level VMT estimate for a future time period, the data may be spatially and temporally disaggregated to a square kilometer grid matrix and a 24-hour daily schedule according to the methodology presented earlier.

Table 8.—Computation of tract total daily VMT

Tract ID	Cluster ID	Cluster VMT rate (daily VMT per household)	Tract household population	Tract total daily VMT
001.00	7	64.62	4,023	259,966
002.00	4	43.94	3,202	140,696

10. CONCLUSION

This report outlines new methods for estimating current VMT and projecting future VMT in the census zone for input into regional vehicle emissions and air chemistry models. To date, data and methods for associating land use and demographic conditions with travel characteristics and ozone production have been missing. With the ability now to makes these linkages, planners and analysts can begin to evaluate how changing land use patterns and demographics may ultimately affect regional air quality and forest resources. Estimating VMT is one of the first steps in evaluating how current and future anthropogenic sources of ozone precursor emissions may impact the health of forest ecosystems.

Our method for generating VMT levels associated with current land use conditions and demographics was demonstrated by developing estimates for the States of Minnesota, Wisconsin, and Michigan. Further, a detailed methodology for predicting VMT levels associated with projected demographics and land use conditions was outlined. Both methods are readily adaptable for estimating VMT for other regions of the country.

By using previous research from the Oak Ridge National Laboratory on vehicle travel characteristics, as well as data from the Claritas Corporation on land use classification at a fine scale, we developed methods to forecast VMT at the census tract or block group level in response to a business as usual or smart growth planning scenario. These methods provide the basis for a landscape change and vehicle travel behavior modeling process that may be used to associate regional land use policies and practices with ground-level ozone formation, transport, and remote forest effects across a multistate region anywhere in the United States.

This land use-based ozone modeling process provides a much-needed empirical basis for incorporating environmental impact projections into the regional land use and transportation planning process and dialogue. This represents a critical step forward in beginning to unravel the influences of landscape change on forest ecosystem health and productivity. In particular, through this approach, we will eventually be able to see how the choices we make concerning where we live, work, recreate, and drive may ultimately affect our regional air quality as well as our vital forest resources.

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Outlines new methods for estimating vehicle miles of travel (VMT) under current demographic and land use conditions and projecting VMT under alternative future conditions. Reports on the role that VMT estimates play in evaluating how changing land use patterns and demographics may ultimately affect regional air quality and forest health.

KEY WORDS: travel patterns, VMT, air quality, ozone.

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