Emissions Benefits of Land Use Planning Strategies

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16. Abstract

The USDOT Federal Highway Administration sponsored a study of the methods currently employed to quantify mobile source emissions benefits from land use changes. The study contains reviews of 46 relevant literature items; 10 case studies from around the country describing applied methods; state-of-the-practice and advanced practice methods; and recommendations for future technical and procedural improvements.

The Research Team found that a variety of studies and applications have been performed by a relatively few number of researchers and Metropolitan Planning Organizations (MPOs). Rather than pursuing this work as part of a conformity determination, many of these exercises have been accomplished as part of a community "visioning" process undertaken by local governments. The research that has been done has identified relationships between vehicle miles of travel, trip frequency, trip length, and mode choice. Also, a number of problems with the research have been noted, including consistency in data development, availability of data, subjectivity in measurement, shortcomings in existing modeling techniques, difficulty in assigning causation, and cross-correlation between independent variables.

The paper concludes with recommendations and ideas for future research to improve land use, travel demand and emissions models; and support pathways of the dissemination of information among end-user communities. Appendices and the accompanying CD-ROM contain data resources, case studies, and a summary of elasticity applications.

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1. Executive Summary of Project

1.1 Executive Summary

Background. Research and applied practice have attempted to define the nature of land use and travel behavior for several decades. Seminal figures in planning, architecture, human health, engineering, and environmental fields have each placed their imprint on the understanding of how human living environments shape the actions of people within those environments, as well as measuring the consequences of human-environment interactions on both parties.

Since the 1970 and 1990 amendments to the federal Clean Air Act of 1963, an increasing number of studies have suggested that land use can also indirectly influence emissions of airborne pollutants. These pollutants are largely produced through the use of internal combustion engines operated in private automobiles and trucks, among other point and area sources. The theories have a similar origin, suggesting that land use patterns influence trip making frequency, trip lengths, choice of what mode of transportation to take, and so forth. A wide variety of approaches and technical strengths are exhibited in this body of literature, but the overwhelming majority of conclusions cite that land use patterns do (1) influence the trip making behavior of individuals; and (2) when measured, these travel changes in turn influence emissions from private automobiles and trucks when measured over a broad area.

To understand the past research and current practice, the Federal Highway Administration sponsored a research project that would address the following objectives:

- Critically review existing literature and research on the topic of land use, travel behavior, and emission interactions;
- Conduct a series of interviews and case studies with acknowledged experts and practitioners that are currently conducting or supporting work in the area of quantifying the effects of land use on emissions; and
- Outline the *state-of-the-practice*[1] and recommend improvements and research that can aid practitioners in the future.

The report findings were oriented towards practitioners that are or might be conducting land use-emissions studies.

Key Findings. Fifty literature items were critically reviewed as part of this project, although more items were rejected after an initial review indicated that they did not discuss quantifiable results. The literature generally recognized the importance of *density*, *diversity*, and *design* elements (the "three D's" according to several authors) on trip-making behavior and therefore emissions. Researchers were able to develop *elasticities* to describe these effects, which ranged from near-zero to 0.35. Typical values ranged from 0.03 to 0.10. Although all of these figures imply that the relationship between land use characteristics and travel are relatively inelastic, they still indicate a responsiveness to change.

[1] Note: The first occurrence of any term contained in the glossary (Section 6.0) of this report is shown in *italicized* text. Holding the "control" key down while left-clicking with the mouse will advance the paper to the appropriate definition in the glossary.

Many researchers acknowledged problems with data collection/availability, cross-correlation of key variables, objectivity in measurement, and boundary effects.

In addition to the critical review of the literature, the Research Team interviewed a number of researchers, private agencies, USEPA staff, and *metropolitan planning organizations*. The Research Team used the results of these interviews and case studies to establish the state-of-the-practice methodology for conducting quantifiable analyses of land use changes and their impacts to mobile source emissions. This process generally follows a four- or five-step process, the number of steps depending on the need/desire to disaggregate emissions into small subareas:

1. Develop inventories of land use and transportation infrastructure according to modeling needs;
2. Create a baseline (or "trend") scenario describing how future land uses might look if existing policies remain unchanged, and develop one or more alternative scenarios;
3. Input land use and transportation information for all alternatives into a travel demand model or other gravity-based tool;
4. Extract vehicle miles of travel by transportation facility, vehicular speeds, and other information required to estimate emission factors into an emission factor model (*e.g.*, MOBILE or EMFAC); and
5. If the objective of the study includes examining emissions benefits conferred to subareas, disaggregate emissions into individual grid cells or other small units of geography. This can be done by some travel demand models (e.g., TransCAD™ by Caliper Corporation) and emissions packages such as MODELS3 and CALINE.

More advanced applications make use of sophisticated land use models, integrated land use-transportation models, modified travel demand modeling techniques, or dispersion modeling to refine impacts on small areas and populations. Only two of the 11 case studies applied the results of their testing to attempt to receive an emissions reduction credit in a conformity or state implementation plan (SIP). In the Atlantic Steel case, while the project was shown as a transportation control measure (TCM) in the Georgia SIP, the State of Georgia elected not to take emissions credits for the project. All cases were either "visionary" exercises to study quality of life issues undertaken by MPOs and local governments, or were generated by a proposed large development that might affect the air quality standing in a transportation conformity maintenance area.

Recommended Improvements. The Research Team proposed a number of improvements to state-of-the-practice methods as well as ways to increase the dissemination of information and promote good practice in this area. Providing consistent document guidelines; establishing a central clearinghouse for case studies and guidance; and specific modeling improvements are recommended.

Appendices provide information about data resources, specific elasticity values, brief summaries of all case studies, and the critical review of literature stored in a MS-Access© database on CD-ROM. This CD-ROM also includes the final report and papers/reports that were available to the Research Team during the course of this study.

1.2 Project Contact Information

The following people are considered contacts for more information about this report, its purpose, and its contents.

1.2.1 Federal Highway Administration

Cecilia Ho, Team Leader, Transportation Conformity
Federal Highway Administration
HEPN-10, Room 3240
400 7th Street, SW
Washington, DC 20590
(202) 366-9862 Cecilia.Ho@fhwa.dot.gov

1.2.2 The Louis Berger Group, Inc.

Kenneth Hess, AICP, General Manager
The Louis Berger Group, Inc.
100 Halsted Street
East Orange, New Jersey 07018
(973) 678-1960x553 khess@louisberger.com

J. Scott Lane, AICP, Transportation Planning Manager
The Louis Berger Group, Inc.
1513 Walnut Street, Suite 250
Cary, North Carolina 27511
(919) 467-3885x14 slane@louisberger.com

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2. Background and Purpose of Project

2.1 Project Need

During the last three decades, a renewed interest has been growing in the effects that urban form has on the travel behavior of residents and workers. Agencies typically responsible for effecting research into or applications of this subject include Metropolitan Planning Organizations (MPOs); state departments of transportation (DOTs); state and federal agencies responsible for setting or enforcing air quality standards; transit operators and researchers; environmental advocacy organizations; and a cross-section of citizens concerned about traffic congestion, *sustainable living* arrangements, human health, and various aspects of the environment. A considerable amount of research has been directed towards this topic from all of these disciplines, with each research item imparting its own "spin" on technical methods, hypotheses, input information, and conclusions.

The focus of this synthesis work is on the specific, quantifiable relationship between urban form and pollutant emissions from mobile sources. While research has been conducted prior to 1990, that year marks a major departure point for research into this topic since it was also the year that major amendments were made to the Clean Air Act. These amendments closely tied the results of emissions forecasts to both projects and programs (transportation plans, programming documents, and transportation projects) and served to catalyze additional research into air emissions and *transportation conformity*. Partially as a result, the pace and quality of research into this subarea of the urban form/emissions topic increased substantially during the last 10 years. During nearly the same time period, research has been conducted on qualifying and quantifying the relationship between urban form and on-road emissions of so-called greenhouse gasses (mainly carbon dioxide and methane). It is important to recognize the distinction between these two major fields of domestic study: greenhouse gases are not regulated in the United States, but the criteria pollutants described in the Clean Air Act and its 1990 amendment (CAA and CAAA90, respectively) are regulated through the transportation conformity process and other mechanisms. For the purposes of this project, the typically area-based urban form-greenhouse gas relationship was secondary to the quantification of emissions of regulated, mobile source criteria pollutants, and therefore is not generally discussed in this study. The criteria pollutants created in significant quantities by mobile sources – and therefore most relevant to this project – are particulate matter, nitrogen dioxide, ozone, and carbon monoxide.

The principle purpose of this report is to provide information on past and current attempts at quantifying emissions benefits from changes in land use strategies to identify state-of-the-practice methods that can be applied by *end-user communities* and refined through applied and theoretical research. Several products were produced that are expected to be of use to both application-oriented staff (e.g., MPOs) and researchers:

- A basic, two-stage framework for articulating how land use and development patterns can affect mobile source emissions;
- A comprehensive literature review of a variety of research papers on the topics of urban form, travel behavior, and mobile source emissions;
- A critical review of research and applied methods from across the country, including public agencies, private entities, and research institutions; and

- A number of tools that end-user communities and researchers can use to conduct and apply investigations into land use and emissions benefits, notably sections on recommended methods, elasticities/threshold values, and suggestions for additional research.

2.2 Project Description

This project consisted of four efforts, each of which is briefly summarized below. FHWA staff reviewed interim deliverables during the project.

- *Task 1*: Conduct Literature Search. The Research Team reviewed 46 research papers and reports that examined the relationships between land use, travel behavior, and emissions. These were summarized according to a consistent template and evaluation criteria applied by the Research Team. The resulting detailed bibliography was subsequently integrated into a vertically-searchable database and word processor formats. An initial evaluation of these methods was also provided in Technical Report #1.
- *Task 2*: Analysis of State-of-the-Practice Methods. The Research Team conducted interviews of several agencies, and developed 11 detailed case studies of situations where an agency had quantified the emissions changes from potential land use alterations. Each case study is comprised of the context of the analysis, a brief summary, and a detailed description of the method(s) used by the agency conducting the analysis.
- *Task 3*: Directions for Further Research. Based upon evidence from case studies, interviews and professional experiences, the Research Team identified a number of areas that could be further developed from a theoretical, educational, or application standpoint. These future improvements are viewed from the vantage of the practical needs of the end-user communities.
- *Task 4*: Reporting. The Research Team developed a draft report for FHWA. Upon review of this draft, comments were received from both FHWA and EPA. These comments were incorporated into a final project report.

3. Review of Literature and Existing Practice

The first task of the study was to collect, review and summarize relevant literature that has been produced regarding land use and emissions benefits. The Research Team did not limit the literature search solely to those items that contained information documenting a process that went from land use change to travel behavior change to mobile source emissions change; rather, literature that helped describe either of the two primary linkages (land use to travel behavior or travel behavior to mobile source emissions) was considered valuable for the purposes of this study.

The following sections describe the sources, review methods, and findings from these studies.

3.1 Literature Review Sources

The project work plan identified numerous potential sources of literature for the detailed bibliography exercise. These resources initially included all of the following:

- Transportation Research Information Services (TRIS);
- International Transport Research Documentation (ITRD);
- Victoria Transport Policy Institute (VTPI);
- The Brookings Institution;
- American Planning Association/American Institute of Certified Planners (APA/AICP);
- American Association of State Highway Officials (AASHTO);
- Association of Metropolitan Planning Organizations (AMPO);
- American Public Transportation Association (APTA); and
- Universities with strong backgrounds in transportation planning and land use interactions.

In all, 46 papers were reviewed for this project. Once each technical paper or report was obtained, citations shown in these reports were added to the candidate list of literature items. By repeating this procedure with each new literature item and list of references, the Research Team was able to compile a thorough database of research papers dealing with the topics of emissions and travel behavior changes resulting from land use strategies. The Research Team was able to chart its progress by noting how many duplicate citations that they encountered with each new, additional research paper. Although a compilation of literature items was provided to FHWA early in the life of the study, the Research Team continued to add to its database as new literature items were discovered throughout the course of this project. In all, 46 literature items were critically reviewed, evaluated and summarized according to the procedure described in the next two sections.

During the course of the literature review, there were four distinct research tracks identified. Each track is characterized by different hypotheses, and, to some degree, by the technical capacity of the agencies conducting the study.

Health and Human Environment. The general premise of this research consists of attempts to relate the built environment to human health. A typical hypothesis of this strain of research examined the effects that higher density, mixed-use developments had on the propensity of people to walk more than would be the case in a low-density, homogenous suburban environment.

Lower body weight, decreased incidence of cardiopulmonary disorders, and other health benefits were typically cited as the dependent variables in these studies.

Transit-Oriented Development. As the name suggests, transit-oriented development is focused on encouraging people to make more use of transit through compatible neighborhood designs, typically centered on commuter or light rail terminals. A typical area of exploration for this type of research is to determine a minimum threshold of housing units/acre above which mode share significantly tilts toward the use of transportation other than single occupant, private automobiles.

New Urbanist Design. The New Urbanism is a term often used by those in the architecture and urban land planning fields to describe ways of accommodating mixed-use and pedestrian-friendly activities in close proximity. The Congress of New Urbanism (CNU) states in a section of their charter:

> *Many activities of daily living should occur within walking distance, allowing independence to those who do not drive, especially the elderly and the young. Interconnected networks of streets should be designed to encourage walking, reduce the number and length of automobile trips, and conserve energy. (CNU, 2004, website: www.cnu.org)*

This is done by assuming common building designs, relaxing restrictive zoning standards, changing street setback standards, requiring rear lot vehicle access, and adapting street cross-sections to slow vehicular traffic while accommodating pedestrian and bicycle travel. Often, these community designs call to older, pre-World War II neighborhoods that were situated on rectilinear street systems and serviced (initially) by a trolley or other transit system. These studies typically attempt to compare two or more neighborhoods with different design features.

Travel Demand Modeling. The fourth research track is that of achieving improvements to travel demand modeling methods. Most often, these studies focus on the generation of trips and mode choice, and are enhanced by the presence of statistically robust travel behavior surveys, or diaries. Using these surveys allows considerably more control over some of the variables that cross-correlate with other common independent variables that plague the other three tracks of research, particularly household income and auto ownership. On very rare occasions a metropolitan planning organization responsible for conducting travel behavior surveys develops a regular schedule for surveying. The resulting historical profile of travel behavior would be one of the single largest improvements to the land use-travel behavior linkage, since a historical comparison would be able to make a much stronger statement about cause-and-effect relationships than the cross-sectional studies that have dominated the field on this subject.

Synthesis Studies. Although not described as a separate category, a fifth literature area has emerged which seeks to synthesize and explain a broad cross-section of past research. Notable are the following three works:

Apogee/Haigler Bailly, 1998, *The Effects of Urban Form on Travel and Emissions: A Review and Synthesis of the Literature.* This was an unpublished draft completed for the Environmental Protection Agency. The authors concluded that while there had been sufficiently robust research to determine and quantify effects on travel behavior from land use strategies, elasticities should be avoided in favor of setting thresholds where these changes are likely to occur. This synthesis comes the closest in terms of content and function to the current critical review of the literature, but many of the highest-quality studies have occurred after its release.

Reid Ewing and Robert Cervero, 2001, *Travel and the Built Environment – Synthesis.* This report picks up where the Apogee/Haigler-Bailly work leaves off by proposing elasticities for the effects of land use strategies on travel behavior. To do this, the authors compiled past research that had significantly (probability less than or equal to 0.05 of systematic error) proven relationships between certain land use strategies and trip frequencies, trip lengths, mode split and VMT. These elasticities were additive, and hence could be combined to form a composite measure from multiple strategies.

Kuzmyak, J. Richard; Pratt, Richard H.; Douglas, Bruce G.; Spielberg, Frank, 2003, *Land Use and Site Design – Chapter 15 of TCRP Report 95, Traveler Response to Transportation System Changes*. This work supports the land use strategy/travel behavior models noted earlier, particularly the effects of density on lowered vehicle miles of travel. The report does note that these effects do not occur in a vacuum and that other, supporting characteristics are important to the overall results. Another chapter (Chapter 17 of *TCRP Report 95*) will be released in 2004 that discusses transit-oriented development in a similar manner, but was not available for review at the time of this writing.

3.2 Literature Database Record Layout and Format

The project workplan expressly called for a database management system to store all of literature items, based on the recognition that sorting and assimilating information from many studies gathered over a period of months would make the task of distilling their contents problematic. Another reason for creating a database as opposed to a more traditional "flat-file" format in a word processor was that each literature item was to be rated on various factors that described the item's usefulness to the project goals. The Research Team described each literature item based upon rating factors using a one-to-five scale with one being the lowest utility and five being the highest (the score was left blank where the variable did not apply to the particular literature item). These variables described the research's handling of internal/external factors influencing outcomes; the validity of the research approach; how transferable the research is to other areas; if and how the research handled air quality/emissions; and the data requirements for the methodology. (See Appendix B for a complete description of the variables and assessments.)

By scoring each paper, it was possible to prioritize each research effort by various areas of emphasis. Although no attempt was made to assess inter-rater reliability (the degree to which two or more reviewers may interpret the same information differently), each paper was reviewed twice by different people to add validity to the reviews. The scores were averaged and commentary merged to form a single record of the review. The complete record layout is shown in Exhibit 3-1. The results of this work culminated in a detailed, critical review of the literature as called for in the project work plan.

Exhibit 3-1. Literature Record Layout.

Field Identification	Description of Field
Title	Title of the article
Date of Publication	Date of accepted publication
Type of Work	Case study; synthesis; research
Author(s)	Principal and secondary authors
Author Contact Information	Address, telephone, email address of principal (first-listed) author. Where contact information was incomplete but readily available from another source, this was used instead.
Input Geography	Geographic units used in analysis
Data Inputs	Data inputs used in analysis
Output Geography	Geographic units for output
Data Outputs	Data outputs presented in analysis
Exogenous/Endogenous Variables	Measurement on 0-5 scale. *(See description in Appendix B for details on the definitions of each measure.)*
Validity	
Portability	
Air Quality	
Data Needs	
Cost-Benefit	
Description of Project	Commentary on contents and conclusions in the article.

3.3 Case Studies

The case studies provide a window on the state-of-the-practice with respect to modeling the effect of land use changes on travel and emissions. The case studies show some patterns in driving forces that motivated the studies and analytical methods used to carry them out. The cases are drawn from medium to large urban areas and the techniques are meaningful as guideposts on how to estimate the types of travel and emission changes that might occur if certain land use policies are implemented within a metropolitan area. Interestingly, it is not only governments which have embarked upon these studies: the private sector is a lead partner in two of the 11 cases.

Originally, the Research Team hypothesized that the motivator for all of these studies would be an attempt to comply with the regulatory framework imposed by the Clean Air Act Amendments of 1990. As information was collected, it became clear that there were at least two motivators for undertaking this type of work. First, the regional planning organizations generally embarked upon comparative studies linking land use and transportation in the quest of more livable communities. The *regional scale* case studies are essentially visionary attempts at quantifying propositions to improve livability or quality of life. When livability is the motivator, emissions, transit use, and congested travel serve as measures of the livability of a community. Second, the private sector has been motivated by the desire to do well by doing good. Their focus has been at the sub-regional or corridor level of scale. These studies are more likely to be undertaken in order to work within the regulatory framework of the Clean Air Act.

The Case Study Selection Matrix Exhibit 3-2 is intended to assist the reader in selecting the case study most useful in a specific situation. Each case study evaluation criterion is discussed briefly below.

Scale - is the scale for which the analysis was performed. This factor is intended to give end-users some indication of whether or not this particular case study matches the scale of analysis in which they are interested. There are case studies at three scales: site specific, corridor, and regional level. Note that there is some upward overlap between the scales so that a site scale analysis may include elements of corridor or regional analyses.

Level of Practice - is an indicator of how the case study compares to the others in its application of tools. The level of practice is characterized as fair, good, and best. It should be noted here that no individual method is automatically acceptable in any future application, and that the goals of these case studies may influence the choice of approach in other, future applications.

Credit Received – indicates whether or not the project sponsor received formal emissions credit in either a state implementation plan or from the congestion mitigation air quality program.

Key Player - shows the driving party of the case study. While the key player may not have done most of the work, they are the entity that is creating the desire to move forward with the study.

Exhibit 3-2 Case Study Summary Matrix

Scale	Level of Practice	Credit Received	Key Player	Strengths	Case Study Name
Site	Fair	TCM in GA SIP (no emissions credit taken)	Private Sector	Proved Lower Emissions Over Conventional Development	Atlantic Steel (Atlanta, GA)
Region	Good	None	MPO	Technically Strong	Baltimore Metropolitan Council
Region	Better	None	MPO	Technically Strong, Land Use Model	DRCOG (Denver, CO)
Region	Fair	None	MPO	Model for Entry-Level Practice	Mid-Region Council of Governments (Albuquerque, NM)
Region	Good	None	MPO	Evaluates Multiple Land and Transportation Plans	Lane COG (Eugene, Or)
Corridor	Fair	None	MPO	Recognized and Mitigated Local VMT Increases	MUMPO (Charlotte, NC)
Region	Good	None	MPO	Public Participation, Land Use Planning	SACOG (Sacramento, CA)
Region	Good	Conformity	MPO	Done through LRTP Conformity Process	SANDAG (San Diego, CA)
Region	Good	None	MPO	Public Participation, Land Use Planning	Tri-County Planning Commission (Lansing, MI)
Site	Fair	SIP/CMAQ	Private Sector	Proved Lower Emissions Over Conventional Development	Woodlands Town Center (Houston-Galveston, TX)

From the technical perspective the case studies fit into three categories that we have labeled fair practice, good practice, and better practice. We have explicitly avoided the term best practice for two reasons. First, no case study exemplified all the characteristics of what the Research Team would call best practice and second the state-of-the-practice is rapidly changing. Compounding factors in our decision not to define a 'best practice' include the resource intensity required at all levels of the practice, and the difficulty of transferring current methods from area to area.

Better Practice includes a number of features not found in the lower levels. First, it is the technically most advanced level of practice. It normally includes from three to five land use scenarios and as many transportation plans. It also includes both a formal (computerized) land use model and an advanced travel demand model. In addition to the technical models the stakeholder component of the land use and transportation planning process is very strong. Often there are a number of committees for stakeholders that are very involved in the evaluating land use and transportation. In addition the stakeholder involvement processes work at multiple governmental levels (*e.g.*, regional, county, and town). Unfortunately, the very comprehensive and customized nature of the better processes makes them difficult to transfer from region to region.

Good Practice represents a good working level. Normally, three or four land-use and transportation plans are analyzed in tandem with a strong stakeholder process that drives the land use component. The land use components are often developed by expert panels or as a result of a number of facilitated meetings. The travel demand models are state-of-the-practice and are appropriate for the region in question, meaning that the region has the resources to maintain the models and data.

Fair Practice almost always arises from special circumstances (*e.g.,* the desire to support a nontraditional TCM). The 'fair' studies are included primarily for illustrative purposes. However, fair practice may also illustrate a way for a smaller region to begin assessing the effects of land use on travel demand and emissions.

In addition to the ratings of practice, the Research Team discovered several areas in which the level of practice could be improved. Several case study contacts indicated difficulties with the emissions factor models. These difficulties included ease of use, difficulty in using outputs at the appropriate level of detail, insensitivity of the emissions models to changes in the transportation system, and incompatible time horizons for the travel models and the emissions models[*].

Another critical need cited by the case study contacts are rigorous tools to estimate the effect of land use policies in the absence of formal land use models. The Research Team also notes the need for more uniform reporting of data and more uniform measures of effectiveness. For example, most case studies reported density increases in terms of a percentage change in a fairly broad region. Common measures of effectiveness could also improve practice. As it is the measures of effectiveness are wholly dependent on local preferences and interests. A consequence of this diversity is that it is difficult to compare results and assess the likelihood of success of a study.

3.4 Significant Findings

The graphic shown in <u>Exhibit 3-3</u> shows the factors that affect trip making and emissions. The first column of the table briefly lists the land use factors that may affect trip making characteristics. The second column of the table summarizes the vehicle operating characteristics that affect emissions. Some, but not all, of the vehicle operating characteristics are influenced by land use features. A more detailed discussion of the relationship between land use features and vehicle operating characteristics is provided below in Section 3.4.2.

Stage one begins when an actual or proposed change to an element of land use occurs. This change can be characterized at a regional scale for large area development patterns of jobs, housing, or shopping; or a *local scale* land use change can be described in terms of changes to landscaping and architectural design features of buildings, street layout, or how the buildings are oriented to the street in a neighborhood or community. Various authors have postulated that narrower street widths, grid patterns, building faces closer to the street, mixtures of land uses, density of land uses, availability and quality of transit services, and many other variables affect the propensity of making mode changes and/or decreasing the frequency or duration of trips.

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[*] This comment came from the Sacramento case and may apply only to EMFAC. MOBILE 6.2 allows a time horizon to 2050 although vehicle turnover stops around 2025 when MOBILE's entire fleet is on the same technology tier.

Exhibit 3-3. Two-Stage Process of Land Use and Emissions

Land Use
- Density
  - Neighborhood
  - Region
- Mixing/Proximity
  - Neighborhood
  - Region
- Design Elements

Vehicle Miles of Travel
- Mode
- Trip Length
- Trip Frequency

Operating Conditions
- Ambient Temperature
- Vehicle Speed
- Road Grade/Slope
- Acceleration/Deceleration
  - Number
  - Magnitude
- Percent Cold Start

Fleet Mix
- Passenger
- Heavy-Duty Diesel
- High Emitter Vehicles

Emissions
- Total Emissions
  - Carbon Monoxide
  - Oxides of Nitrogen
  - Volatile Organic Compounds
  - Fine Particulates (2.5micron)
- Emissions from Subareas
- Duration
- Affected Population

STAGE ONE:
Land Use Change Triggers One Or More Changes in Travel Behavior

STAGE TWO:
Travel Behavior Change Triggers One or More Changes in Emissions

Stage two begins after the trip making effects of the land use change are quantified in terms of travel mode, trip length, trip frequency, vehicle speed, acceleration events, and percentage of cold start. Exhibit 3-3 shows several operating characteristics that are not affected directly by changes in land use: ambient air temperature, high emitter vehicles, and slope. The travel characteristics discussed here are most often purported to be affected by land use changes.

During the literature review and analysis, it became clear that a substantial and growing body of work exists that attempts to describe the first of the two linkages shown in Exhibit 3-3, the link between land use alterations and one or more aspects of travel behavior. It is less common to see research carry forward to the second linkage, that of travel behavior changes to mobile source emissions. Before relating the findings of the literature review to the two key linkages it is important first to briefly consider some of the possible relationships that link land use, travel behavior and emissions at regional and community scales, as identified in the literature.

Other syntheses, notably including those by Steiner (1994) and Southworth (2000), were also included and are valuable in developing expected results from various land use strategies, as well as highlighting consistent themes and shortcomings in methodology.

Bulleted italics denote the significant findings in the discussion below. In most cases the significant findings come from the literature review although some findings are taken from either interviews or case studies.

3.4.1 First Linkage: Land Use Strategies and Travel Behavior

As previously mentioned, a large body of research has been devoted to examining changes in land use and the effect that those changes may have on travel behavior. Often, secondary effects resulting from land use strategies, such as noting the improvement to human health from more walking or reducing air pollution levels in an urban area that adopts growth management policies, are mentioned only in a qualitative fashion. Exhibit 3-4 and the following discussion comprises a summary of the main consensus of the research that was reviewed as a part of this project.

Development Density

- *Higher density is associated with lower per capita regional VMT and higher congestion.*
- *Higher density may increase trip rates.*
- *Higher density seems to be an indicator for other factors that either facilitate greater mode stronger mode splits or discourage automobile use.*
- *At least one regional model uses density and land use as a factor in trip generation and mode choice.*

The most frequent area of study in both the research (literature) and applications that were studied for this report dealt with increasing densities in certain areas of a region. The terms "density", "proximity", and "intensity" are often used interchangeably. The studies did not typically deal with the policy decisions that would have to be undertaken to achieve the higher densities, an important omission since this policy discussion may represent a stronger argument for a realistic "cap" on the densities of those areas receiving additional growth than the physical capacity of a land area to add new development. For example a study of programs involving the sale or transfer of development rights might have indicated how the transfer of growth opportunities might affect the areas receiving growth. Instead, development caps were manufactured from the physical and/or zoning constraints on growth, which neglects the difficulties of convincing existing residents that increased development densities is good for the community. Nearly all studies assumed that regional growth remained constant in both the trendline and alternative land use scenarios, with sub-areas of the region increasing or decreasing in development density.

Trip Frequency

- *Higher density seems to facilitate shorter trip lengths.*
- *Heterogeneous land uses, and higher density seem to increase trip frequency.*

Trip frequencies refer to the number of trips made during a given model run or time period. Often, these frequencies are not separated by mode or trip type, a shortcoming that could be addressed fairly easily if the output is generated from a travel demand model. Land use scenarios that incorporate density changes may actually have the counter-productive effect of producing more and longer trips in those areas that are designated as receiving places for higher intensity land uses. Hence, measuring the effects of increasing development at a regional level may be masking serious and offsetting increases in trips and emissions at a local scale. Some studies have suggested that these increases in trip frequencies are (1) due to the increased accessibility offered by creating nearby opportunities for shopping and recreation; and (2) that these new trips in denser, more mixed-use, or more pedestrian- or transit-friendly environments are being made by means other than private automobile. The very thing that may be making some communities effective at reducing auto trips –

ease of alternative mode trips like walking – may also make these effects difficult to quantify since travel behavior surveys are somewhat notorious for under-representing some short trips or trips made by walking. The literature is not conclusive on the effect that urban design alone may have on the number of trips taken. Independent variables tend to be highly cross-correlated with land use mixing, making independent conclusions difficult.

Exhibit 3-4. Common Research Conclusions On Land Use and Travel Behavior

<table>
<tr><th>Travel Behavior</th><th>Densification</th><th>Land Use Mix</th><th>Urban Design Features</th></tr>
<tr><td>Vehicle Miles of Travel</td><td>• Higher densities are associated with lower regional VMT
• Higher densities are also associated with higher congestion.</td><td>• Heterogeneous land use shortens trip lengths</td><td>• Neotraditional design features and street layouts are weakly correlated with VMT.</td></tr>
<tr><td>Trip Frequency</td><td colspan="2">• Higher densities and the increased mixing of land uses may increase trips rates
• Mode split may partially compensate for higher trip rates.
• Delineating these effects more difficult because travel behavior surveys tend to under-report short trips and walk trips.</td><td>• The literature is inconclusive regarding the effect of urban design on trip frequency.</td></tr>
<tr><td>Trip Lengths</td><td colspan="2">• Shorter trip lengths is the major factor in regional VMT reduction.
• Regional reductions may be partly offset by longer trips in the immediate area.</td><td>• The literature is inconclusive regarding the relationship between design features and trip length</td></tr>
<tr><td>Mode Choice</td><td>• As density increases,transit, biking, and walking increase as a share of total trips.
• Quality of transit service is very important in determining transit mode share.</td><td>• Mixed land uses facilitate walking and biking.
• Mixed land uses have a weak effect on transit use.</td><td>• Neotraditional urban designs facilitate walking, bicycling, and transit.</td></tr>
</table>

Trip Lengths

- *Network connectivity plays a role in determining trip length.*
- *From the case studies it seems that much of the travel effect associated with land use changes is not effectively captured in standard regional travel demand models.*

While not conclusive, the literature suggests that higher densities increase the average trip lengths in the local vicinity. This is due not only to the number of transportation system users increasing in some areas, but also because the presence of higher traffic congestion levels will force more circuitous trips to reach a destination in the shortest possible time. However, the literature also suggests that more of the total trips use modes other than the single occupant automobile. Recent studies have also focused on trips that originate from or destined for the workplace as they relate to the character of that workplace in terms of development densities and complimentary, proximate land uses. Generally speaking, the literature that deals with changes to trip lengths as a result of urban design features is poorly represented and inconclusive as to the degree of its effects in isolation from density and degree of land use mixing.

Mode Choice

- *Density influences mode choice.*
- *Quality of transit service is very important in determining the transit share of trips.*
- *Urban design factors (e.g., neotraditional designs) may facilitate the pedestrian and bicycle modes.*

Higher density developments may promote additional transit usage, but the degree of that shift seems to depend largely on the quality of the transit service in the geographic area. Biking and walking trips also increase as density increases. Private auto usage drops, although this may be partially a result of increased parking prices and congestion levels. Mixing complimentary land uses has been observed to facilitate increased walking and biking trips in a number of studies, particularly at work locations. The effects of the "attraction" end of trips has recently been recognized by a number of researchers as having just as significant an effect on mode choice as the home or "production" end of the trip. As with the other metrics listed here, the issue of design's influence on mode choice has been very difficult for the research community to disentangle from other features of the built environment. There has been some demonstration that walk-, bike-, and transit-friendly design features enhance the effectiveness of attracting people to these alternative modes of travel.

3.4.2 Second Linkage: Changes in Travel Behavior and Emissions

Establishing the linkage between travel characteristics or behavior and mobile source emissions is, superficially at least, a more approachable problem than describing the connection between land use and travel behavior. This statement is true for at least two reasons: (1) the commonly accepted assumption that reductions in vehicle miles of travel, less reliance on private automobiles, and reductions in trip length and frequency translate simply into emissions benefits; and (2) the almost universally-accepted emissions factor model, MOBILE.

The first rationale, that trip behavior modifications that reduce the dependency on the private automobile immediately and simply translate into emissions reductions, is virtually unchallenged in the literature. However, the magnitude of the change is the subject of significant debate. Although probably true, there is very little investigation of this assumption to be found in the literature. In one hypothetical example, mode shifts away from private automobile usage and onto mass transit must be at least partially offset by the increase in emissions from greater mass transit usage (assuming that the mode shift is sufficient to warrant additional service by bus). Another argument against this assumption would involve the effect that narrow, grid-based streets have on travel behavior and thus emissions. While a grid-system allows for easier land accessibility than some other network configurations, the grid implies that there is a lot of accelerating and decelerating at each intersection. Since the MOBILE model only crudely accounts for the effects of acceleration/deceleration through user-supplied vehicle speed values, there is some doubt that the reduction in vehicle trips partially attributable to grid-based street systems in some studies are achieving all of the emissions reduction benefits that are claimed. Additional research into this topic using portable emission monitoring equipment (PEMS) would be required to formally establish the cost of driving in grid-based street systems as opposed to curvilinear and cul-de-sac systems. There have been some studies of the effects of certain "traffic calming" practices on vehicle speeds that adding stop signs or speed humps has little effect on link (as opposed to spot) speeds, implying that vehicles are accelerating after exiting a traffic calming device.

The widespread (and regulated) practice of using the MOBILE model as an emissions factor generator has established familiar input variables that powerfully affect the outcomes of emissions calculations: average link travel speeds, ambient air temperature, and vehicle fleet mix and age are the most recognized. Essentially, once the analyst or researcher has translated whatever land use effect might be under study into terms that the MOBILE model recognizes as inputs, then the remainder of the task is fairly straightforward: run the emissions factor model and apply the results to the vehicle miles of travel for various vehicle types. In a regional analysis this step is applied for the travel demand for all the land uses evaluated. There are embedded elasticity-based formulations of emissions within some spreadsheet, GIS, and stand-alone software packages. However, these elasticity-based models are generally deemed not suitable for transportation conformity purposes since, as this study indicates in later sections, the variability of the trip-making behavior resulting from land use strategies is generally too great to take such a simplified approach. Because of the well-established nature of travel demand models and the regulatory stature of the MOBILE model across the country (the corollary in California is the EMFAC model), it can be expected that a number of metropolitan planning organizations have been or are currently engaged in analyses that take advantage of these two tools. This assumption was verified during Task 2.0 of this project engagement.

The first issue is the shortfall, or difficulty, in translating land use strategies into emissions calculations. First, there are some connections between land use and travel behavior shown in Exhibit 3-3 that are either counter-intuitive (e.g., land use strategies affecting ambient air temperatures or grade) or have not been explored in detail. For example, no known research has attempted to calculate the long-term changes in vehicle mix or age that may result from various land use changes, possibly because there is no clear, intuitive hypothesis that can be formulated (and possibly because longitudinal studies are inherently more expensive to undertake, as previously stated). The number of hours that vehicles in an area operate in a cold start mode, or number of trips that begin in cold start or hot soak modes, may also vary with different land use strategies, as may acceleration and deceleration patterns.

A second issue deals with the level of detail of the analysis. For simply computing the amount of emissions that are emitted into the air as a result of a specific change in land use strategies, the scenario whereby land use data are fed into a travel demand model which then provides speeds and VMT for a mobile emissions model may suffice for regional conformity applications. However, some researchers have attempted to calculate the exposure of various populations to unhealthful pollution levels. In order to undertake this procedure, an understanding of photochemical dispersion is required. These models require considerable additional data above and beyond aggregate emission modeling. The data is usually temporal and three-dimensional in nature, and contains information about wind speeds, air temperatures, sunlight, and pollutant concentrations. It may be supposed that acquiring and applying this level of data is well beyond the reach of all end-user communities except those partaking in dedicated research efforts or state air quality agencies conducting analyses associated with the development of State Implementation Plans (SIPs). In terms of transportation conformity, these small-area studies are often termed "hot-spot" analyses but are not temporally dimensioned.

3.4.3 Research Literature Issues and Limitations.

The previous discussion of land use effects implies some limitations to the existing literature. The following discussion deals specifically with the most common limitations to the research items that were reviewed for this project.

Cross-Correlation. Numerous studies have cited the tendency (usually in other studies) to leave uncontrolled variables that may exhibit strong cross-correlation to the independent variables being examined. This is particularly true for sociodemographic variables like income, household composition, head-of-household characteristics, and car ownership. Although not as often recognized as a flaw in the research, uncontrolled operational characteristics such as parking pricing or other impediments to choosing a certain mode of travel appear to have a similar confounding role. The implication for the results of these studies is profound, and bring into question the validity of the results unless external or cross-correlated variables are dealt with explicitly in the study methodology.

Although not as frequently mentioned in the literature as the previous issues, there is an inherent synergy between some independent variables. In essence, this is the opposing face of the cross-correlation problem. Individually, a change in land use density or mixing may be insufficient to trigger a change in travel behavior, but collectively the results may be quite different. Hence, the attempt to isolate individual elements of land use strategies may be serving as an accomplice in masking these synergistic effects.

Objectivity in Measurement. Studies have cited the difficulty of devising a consistent, objective metric for assessing urban design features. While the primary goal of these metrics is to capture the sense that walking and bicycling are safe and productive means of travel, the variety of design features that can impart this sense of acceptability may be too great to adequately capture over a large geographic area. This has also hampered efforts to operationalize the effects of urban design in trip generation or mode choice modules of travel demand models. Most studies have instead focused on comparing two or more communities that have different urban forms. However, following this strategy limits the statistical robustness of the effort, and introduces greater potential for cross-correlation to other, uncontrolled variables.

Data Availability/Reliability. The paucity of data, especially at large scales (small units of geography), has often hampered the ability of researchers to adequately populate independent variables, particularly those relating to urban design features. The lack of time series data for a specific study area has implied that almost all of the empirical studies described are limited to a "snapshot" of how one or more study areas are behaving. One of the few exceptions is a Swedish study (Vilhelmson, 1999) comparing the travel behaviors of differently-sized towns and cities. Local scale studies utilizing temporally-stratified data could not be located to be a part of the literature review. Another, related problem is that of travel surveys under-counting secondary trips and walk trips. The implications of this problem are two-fold: first, some types of studies that ideally involve large data sets, data that does not come "pre-packaged" in the correct format or scale, or longitudinal data sets are seldom undertaken. The lack of longitudinal data particularly implies that many studies cannot confidently determine causality. The second result of this issue is apparent as researchers attempt to use surrogate variables in place of hard-to-get data items, usually without much discussion of the appropriateness of using the surrogate variables.

Boundary and Edge Effects. Some studies of urban design acknowledge that major freeways or other physical barriers may exert a halo effect on the rest of the area being studied.

These portions of a community may have a very different set of urban design and travel characteristics that distort the results for the study area. Edge effects may also be present, in which adjacent communities with different (for example, more car-oriented) characteristics are dampening the effects of urban design for the area under study. The most straightforward solution for either issue is to utilize smaller study areas, but this approach dramatically increases the overhead required to collect and manipulate data.

Land use strategies that have been considered as having an effect on travel behavior and environmental quality generally assume one of two forms: a regional scale, policy-oriented directive on controlling growth at the margins of existing, developed areas; or a microscopic focus on individual communities stressing features of the built environment including buildings, streets, sidewalks, and streetscaping.

At a regional level, additional mixing of land uses, densification (more dwelling units or square feet of employment space per unit of land area), or more closely aligning employment opportunities with residential developments are typical categories of strategies. The general hypothesis is that by bringing common origins and destinations closer together, trip lengths are reduced and the opportunities for alternative (to single occupant, privately-owned vehicles) modes of transportation are enhanced. In practice, this has been difficult to prove or disprove since a number of other factors often play a significant role in trip-making decisions. These include the availability of various modes of travel, climate, and perceptions of personal safety. Many of these confounding factors take place at a much smaller scale than a regional initiative is likely to capture.

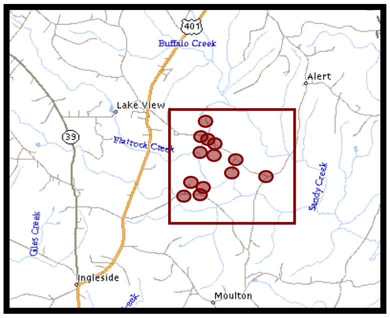
At this smaller geographic scale, researchers have supported the concept that specific design elements in the built environment affect the type and quantity of travel undertaken by residents, and in some cases, workers. Features that are commonly supposed to alter travel behavior include the presence or absence of sidewalks; spacing and setbacks of buildings; proximity of complimentary uses such as shopping opportunities near homes; streetscaping and traffic delineation; and the street layout. The metrics of street layouts include *connectivity* (number of intersections in a given area; see Exhibit 3-5, number of curved segments, number of cul-de-sacs, and block lengths. There are reliability concerns at this level of input as well, and various researchers have expressed concerns about consistency and objectivity in measuring accessibility and urban design features.

A second concern relates to *edge and boundary effects*, or how one cell (or other analysis unit of geography) affects other cells. An example of this is when a pedestrian-friendly older neighborhood is bounded by one or more adjacent, newer neighborhoods that are automobile dependent. The boundaries between the different land use types are neither impervious, linear, nor sharp. The effects of different land uses tend to 'bleed' across the boundaries. Few studies attempted to measure the size and strength of the cross boundary effects.

Studies that accounted for edge and boundary effects often used rectilinear overlay grids to define consistent manageable cells and to evaluate the interaction between adjacent cells. The strength of the interaction was often assumed to be proportional to the shared length at the cell boundary. Using this viewpoint adjacent cells with similar characteristics tend to reinforce one another while adjacent cells with dissimilar characteristics tend to have weaker effects. One difficulty with the 'gridiron' model is how to estimate the effect where four cells come together at their vertices. Because the shared boundary length is zero this model would assume that the interaction between any two cells that touch only at their corners is minimal, or even zero. The traditional way of overcoming edge effects is to use have very small units of geography. The difficulty of collecting data increases as the size of the individual study unit (e.g., traffic analysis zone) shrinks, making this solution difficult to apply for a large study area. An interesting side note to this discussion is that at least one researcher has pointed out that hexagonal input units of geography would provide equal edges all the way around a cell's perimeter thus eliminating many of the difficulties associated with grid systems

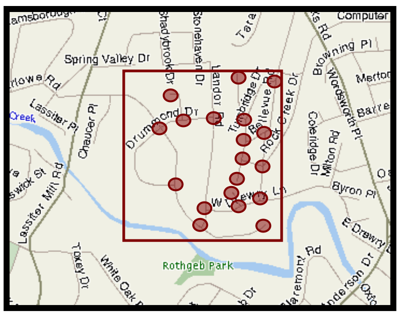
Both regional and local scale analyses have faced significant problems in overcoming data shortfalls and inconsistent or subjective measurements of input data. The research did not reveal any attempts to establish forward or backward links between land use strategies and changes in vehicle fleet composition, percent grade, percent cold starts, ambient air temperature, or patterns of acceleration and deceleration. Most of these omissions are understandable since addressing them would have required making assumptions that are both not intuitive and difficult to test about long-term vehicle ownership trends or changes in the physical space of a study area. However, a significant research topic worth exploring deals with the number of cold starts that occur in various local scale studies of built environments. One of the few papers to deal with this specific research variant (Frank, et al, 2000) found that employment densities are inversely related to trip generation (cold and hot soak), travel time, and distance traveled. One hypothesis from such research would be that closer proximity to compatible uses might cause more trip chaining and hence fewer cold starts, leading to lower overall emissions. This situation is generally not accounted for in four-step travel demand models, but may be better addressed in tour-based models (see also Section 5.2.2).

Exhibit 3-5. Connectivity and Measures of Connectivity



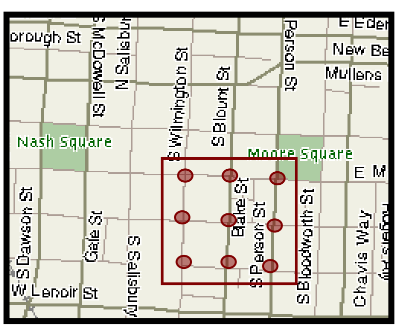
Example #1. Rural Network.

This rural study area shown within the study area depicted by the red frame has a low level of connectivity. (CI = 16 Links divided by 13 Nodes = 1.23)



Example #2. Fringe or Suburban Network.

In this example, connectivity is compromised by the bounding water feature and patterns of modern suburban development trends (curvilinear streets and cul-de-sacs). This gives an beta index of approximately 1.4. (CI = 26 Links divided by 16 Nodes = 1.37)



Example #3. Urban or Central Business District Network.

For this section of a downtown, the connectivity index for the area in the red box is very high (2.67 connectivity index). Indeed, a connectivity index this high is very close to the theoretical maximum of 3.0 achieved with a four-node, grid-based network. (CI = 24 Links divided by 9 Nodes = 2.67)

Background. It is often desirable to consider not only the capacity of facilities to carry traffic, but also the number of alternative paths that can be used to get from one location to another. Termed connectivity, this is an important feature of any transportation system for a number of reasons:

- Street systems with greater degrees of connectivity offer greater possibilities for rerouting traffic during a temporary closing of one or more links in the system;
- Higher connectivity implies a more robust transportation system, one that is able to provide users with greater degrees of freedom in making travel choices during periods of heavy traffic and accommodating trip chaining (making brief stops at different places during a trip);
- Greater connectivity typically equates to a greater capacity for moving and distributing traffic, and potentially reducing congestion levels; and
- Areas with more connectivity have better access to land, with implications for the diversity and intensity of potential developments in those areas.

Application. There are a number of ways that the degree of connectivity can be measured in a transportation network, including density of streets (links) or intersections (vertices) within a given geographic space. One of the easiest methods to understand and apply is the beta index: simply divide the number of links by the number of intersections plus cul-de-sacs (which are collectively called "nodes").

The higher the ratio of links to nodes, the better connected is the overall network in a study area. The theoretical maximum value is 3.0; however, in any larger network (more than 32 nodes) it can be demonstrated that this maximum value rapidly converges to 2.3. "Good" connectivity can be said to occur in street systems where the connectivity index (CI) is between 1.4 and 1.8. In order to put this ratio into a context that is more easily understood, examples are shown at left.

When calculating the beta index, it is important to count those links (streets) that go from the last node outward. Hence, the selection of the study area boundary is critical when calculating the CI. Averaging the results by shifting the red "frame" around slightly in the examples on this page is a good practice to ensure that a representative CI is chosen for the area.

Other Measures of Connectivity. No one measure of connectivity is necessarily a "perfect" indicator. The size of the study area or distance between nodes is not considered in the calculations for the beta index. However, some measures of connectivity can be weighted by the study area size so as to describe the impact of distance on the traveler.

Other indices include: gamma (difference between actual and maximum number of link connections); alpha (incorporating the cyclomatic number, or the number of "loops" in a network); and the Shimbel, or dispersion, index (which does incorporate distance between nodes). A simple and potentially useful index that measures how well a place is connected to the area around it has been proposed by Criterion Planners and Engineers. A cordon line is first drawn around the study area. Then the average distance between street intersections at the cordon indicates how well the area is connected to the "outside world."

Lowe and Moryadas, *The Geography of Movement*. (Washington, DC: Houghton-Mifflin Co.), 1975. pp. 78-109.

Criterion Planners and Engineers, INDEX PlanBuilder® Indicator Dictionary. April, 2004. (website: http://www.crit.com/index.html).

4. Critical Analysis: State-of-the-Practice Methods

In order to develop profiles of state-of-the-practice methods and potential advancements, the literature review and detailed bibliography that resulted were supplemented by the development of 11 case studies that centered on recent or ongoing studies being conducted at metropolitan planning organizations around the country. The main product generated from this effort was a 1-2 page summary of the context, application and possible improvements relevant to each case study shown in Appendix C (Case Study Summaries). The case studies are summarized in a table in Appendix C that describes the content and application of all the case studies, allowing a quick reference for those persons interested in finding a case with specific characteristics.

4.1 Evaluation Methodology

Several categories of agencies were identified at the outset of this study that might produce either direct information on the current practice of land use/emissions testing, or produce additional contacts. The major categories of agencies are:

Metropolitan Planning Organizations (MPOs). MPOs are responsible for conducting transportation conformity analysis and reporting according to federal law. They are also the primary agency responsible for considering the combined effects of transportation strategies over large, multi-jurisdictional areas, although parts of this responsibility may be shared. Regardless, the MPO is fully responsible under the provisions of *23 CFR Part 450* for transportation plans, programs, and projects, and in nonattainment and maintenance areas the provisions of *40 CFR Parts 51 and 93* to execute analyses and make a determination of the transportation conformity of its long-range transportation plan and transportation improvement program.

State/Federal Air Agencies. State environmental departments were not surveyed as a part of this study due to the fact these agencies have not traditionally taken a lead role in executing land use studies. It is recognized that these same agencies do assume a more significant review role for transportation conformity, and a direct role in evaluating TCMs for inclusion in the SIP.

Every regional office of the Environmental Protection Agency (EPA) was contacted during the course of the study. EPA staff were asked if they knew of any MPO, research agency, or state air quality agency that were conducting applied or theoretical research into the developing quantitative forecasts of emissions benefits from land use strategies. The EPA Regional Offices were also asked if any of these agencies had been a part of trying to get land use strategies included as a control measure in a State Implementation Plan (SIP). The Research Team discovered that in at least two instances, the Atlantic Steel and Woodlands case studies in this report, land use measures had been included in state SIPs (although the Atlantic Steel case did not take credit for emissions reductions). The discussions with EPA Regional Office staff were successful in identifying candidates for the case studies discussed in this report.

Exhibit 4-1A (Map). Location of Initial Agency Contacts.

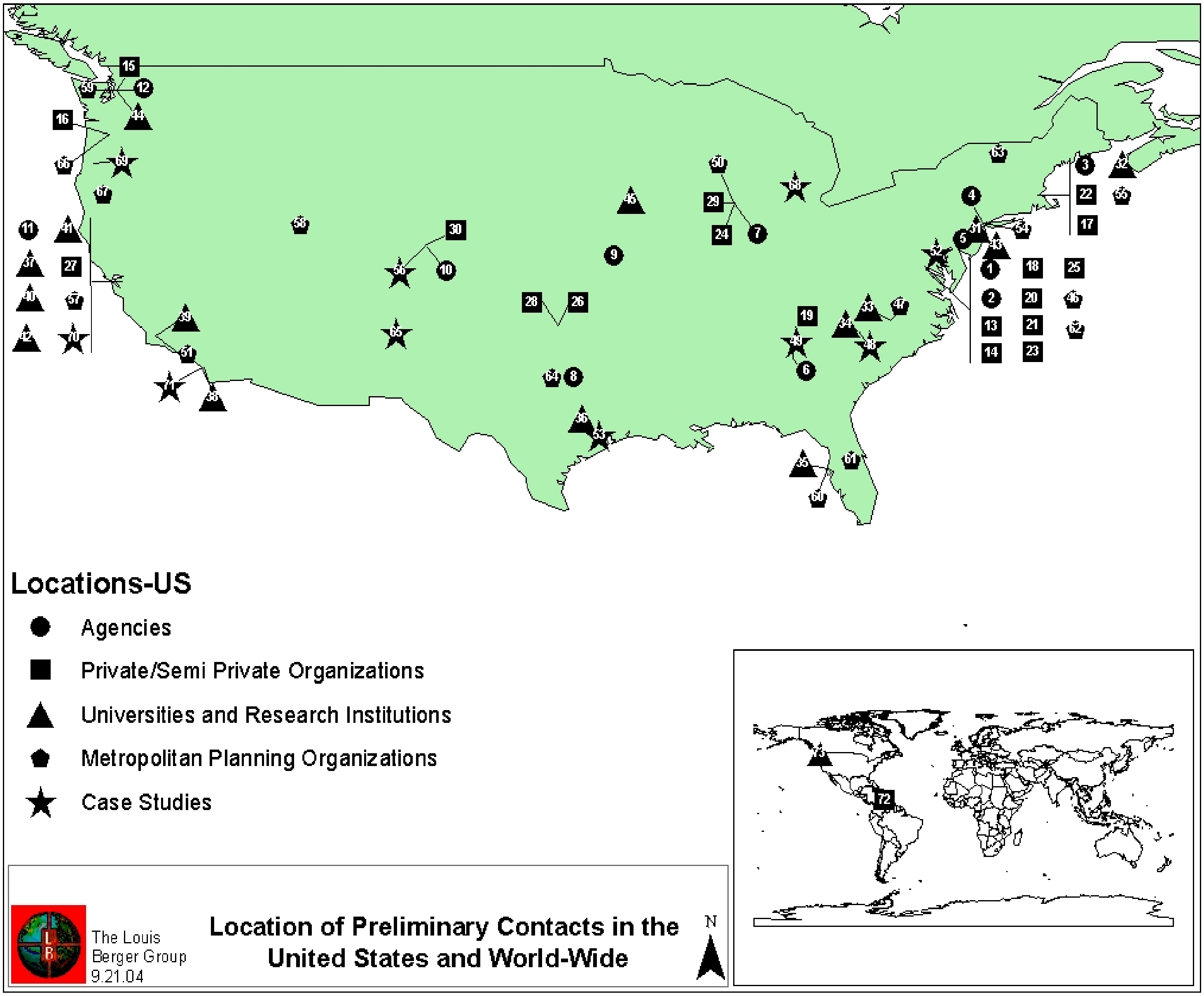


Exhibit 4-1B (Table). Initial Agency Contacts.

Map No.	Organization Name*	Map No.	Organization Name*
1	EPA Clean Air Act Advisory Committee	37	UC-Irvine, Institute of Transportation Studies
3	EPA Region 1	38	UCL A, Institute of Transportation Studies
2	Office of Policy and Economic Innovation	39	UC-Davis, Dept of Environ. Science and Policy
4	EPA Region 2	40	San Jose State U, Mineta Transportation Institute
5	EPA Region 3	41	San Francisco League of Conservation Voters
6	EPA Region 4	42	Natural Resources Defense Council
7	EPA Region 5	43	University of Washington, (UrbanSim)
8	EPA Region 6	44	Iowa State University
9	EPA Region 7	45	Association of Metropolitan Planning Org.
10	EPA Region 8	46	Capital Area Metropolitan Planning Org.
11	EPA Region 9	47	Mecklenburg-Union Metropolitan Planning Org.*
12	EPA Region 10	48	Atlanta Regional Commission*
13	AASHTO	49	Chicago Area Transportation Study (CATS)
14	ITE, Transportation Planning Council	50	Southern California Association of Governments
15	Global Telematics	51	Baltimore Metropolitan Council*
16	Land Use, Transportation, and Air Quality (LUTRAQ)	52	Houston-Galveston Area Council*
17	Caliper Corporation (TransCAD)	53	New York Metropolitan Transportation Council
18	Smart Growth Network/Sustainable Communities Netwo	54	Boston Metropolitan Planning Org.*
19	Center for Transportation Analysis	55	Denver Regional Council of Governments*
20	The Brookings Institute, Center on Urban and Metro	56	Metropolitan Transportation Commission
21	American Public Transit Association	57	Wasatch Front Regional Council
22	Lincoln Institute of Land Policy	58	Puget Sound Regional Council
23	National Transportation Library	59	Hillsborough County Metropolitan Planning Org.
24	Travelmatters.org (Center for Neighborhood Tech)	60	Metroplan Orlando
25	The Assoc of State and Local Air Quality Agencies	61	Metropolitan Washington Council of Governments
26	Central Regional Air Planning Association	62	Chittenden County Metropolitan Planning Org.
27	The California Air Pollution Control Officers Ass.	63	North Central Texas Council of Governments
28	Central States Air Resource Agency	64	Mid-Region Council of Governments
29	Conservation Design Forum	65	Portland Metro
30	Rutgers University, Voorhees	66	Rogue Valley COG
31	MIT - Center for Transportation and Logistics	67	CommunityViz (Scenario360 software)
32	UNC-CH - Department of City and Regional Planning	68	Tri-County Planning Commission (Lansing MI)*
33	UNC-Charlotte	69	Lane Council Of Governments (Eugene, OR)*
34	USF - Center for Urban Transportation Research	70	Sacramento Area Council of Governmnets (SACOG)*
35	Texas A&M University - Texas Transportation Inst	71	San Diego Association of Governments (SANDAG)*
36	UC-Berkley, Institute of Transportation Studies	72	TRANUS (Modelistica Systems and Planning)
		73	Victoria Transport Policy Institute

**Note: Areas where case studies were performed are denoted by an (*).*

Research Institutions. These agencies were thought to be involved in the land use/emissions topic in at least two important ways: (1) assisting MPOs with technical problem-solving or data collection, management, or analysis; and (2) conducting independent research on specific, related issues.

Private, Quasi-Private, and Non-Profit Organizations. Although not a lead agent in conducting analysis, organizations that sold software for travel demand modeling, emissions analysis, and land use modeling were considered during this study. Quasi-private and non-profit or advocacy groups occasionally take a lead role in analysis, but more often provide the impetus for getting such studies programmed by other agencies, notably MPOs. The Research Team generally used these contacts to identify other agencies directly involved in the quantification of emissions benefits from land use strategies. The figure and table shown in Exhibits 4-1A and B provide a listing of those areas that were on the initial contact list and the physical locations of each. Although many agencies were deemed suitable for contacting for this research, some of the agencies were either not contacted after a second consideration of their potential contribution, or the agency was contacted but did not offer information that contributed to the objectives of this study.

4.2 Evaluation Criteria

One of the objectives of this study is to determine state-of-the-practice methods for quantifying the emissions benefits from land use planning strategies, it was necessary to define those aspects of various strategies that make them better or worse for future applications of end-user communities. A technical brief was developed that created categories of evaluation measures and tentative benchmarks that were used in the evaluation of the methods reviewed in the case studies. Exhibit 4-2 highlights the evaluation criteria that were used to assess various methods quantifying emissions benefits of land use strategies. Not shown are benchmarks developed for each evaluation criterion. Since these benchmarks were derived from published literature, they were deemed to be flexible and were used only as approximate guides during the course of the evaluation of various methods that were reviewed during the case studies.

The Research Team recognized that while the majority of efforts being undertaken concern regional scale assessments of large shifts to future land development, there were also relevant studies being conducted that consider the emissions benefits of local scale (neighborhood or community) analysis as well as some studies that went a step further and undertook dispersion modeling, potentially useful for small area or “hot-spot” analysis. For these two types or variants of study, the Research Team proposed adding or modifying a few of the evaluation measures to better accommodate the specific differences between them and the more common regional scale analyses.

4.3 Evaluation Results

The Research Team selected ten case studies from medium to large cities that had done prior work or were in the process of conducting studies evaluating the effect of land use policies on emissions. The case studies cover a range of complexity and technical difficulty. Based on the case studies the state-of-the-practice for this effort is to evaluate multiple set land uses and multiple transportation plans. Common practice appears to be to evaluate between two and five land use patterns along with several transportation scenarios. Seven of the eleven case studies in Appendix E evaluated either three or four land use scenarios. To some extent the transportation scenarios are adjusted to the land use pattern. For example, Lane COG varied the availability of express bus service depending upon the land use scenario being evaluated. The highest level of practice is found in those methodologies that include land use variables in trip generation and mode choice and use formal land use models to develop alternative development scenarios (sometimes termed “alternative futures”).

Some local planners cited the desire of decision-makers to improve quality of life or to preserve open space. Others cited state planning regulations. The case studies also pointed out several things that would make this type of effort easier for them and others. These include more longitudinal data that establish effect of land use

Exhibit 4-2. Evaluation Criteria for State-of-the-Practice Models for Quantifying the Emissions Benefits of Land Use Strategies.

Criteria	Description
Portability	Does this method use data sources and models that are widely available to practitioners across the United States? This is a composite measure assessing both availability of datasets and use of standard computing equipment.
Data Requirements	A composite index describing detailed data input requirements or extensive manipulation of large data sets (e.g., post-processing of model outputs to get inputs for other models) to obtain reliable results.
Quantification	Does the method directly output criteria pollutant emissions in terms of tons or kilograms per time period, or is a secondary calculation/process required to reach these results?
Ease of Use	A composite index measure describing (a) the number of models required to be linked together to obtain reliable results; (b) special computing requirements; and (c) availability of interfaces, scripts or other scenario and data management tools.
Model Validity	A composite index measuring the validity of the results from the model or method.

(Additional Criteria for Local Scale Analyses)

Criteria	Description
Field Data Collection	Many neighborhood-level analyses require additional field data collection efforts on such items as design characteristics or street configurations. This measure complements the Tier One measure for Data Requirements.
Objectivity of Metrics	Do the metrics objectively assess accessibility and/or neighborhood form? In other words, will two analysts assess the same variable in the same way?

(Additional/Modified Criteria for Dispersion Modeling)

Criteria	Description
Need for Meteorological Data	Dispersion models typically require considerable additional data on wind speed/direction, humidity, ambient air temperatures, mixing conditions, sunlight, and so forth to conduct project-level, small area, or hot-spot analyses. *This measure supplements the measure for Data Requirements for this type of effort.*
Quantification	Does the method directly output criteria pollutant emissions in terms of tons or kilograms per time period, or is a secondary calculation required to reach these results? *This measure replaces the Quantification criterion.*

policies; better user interfaces for emission models[2]; travel models that are more sensitive to land use variables; simpler land use models that can predict the result of proposed land use policies; longer time horizons on regulatory emission models; and the need for accepted methodologies to evaluate the emission effects of land use changes.

Based on the case studies the Research Team believes it is feasible for many metropolitan planning organizations to evaluate multiple land use patterns. Making this effort will require dedicating both time and financial resources for a period of six months to two years for each application, depending on the complexity of the effort and the degree to which pre-existing models and data are already available to carry out the analyses.

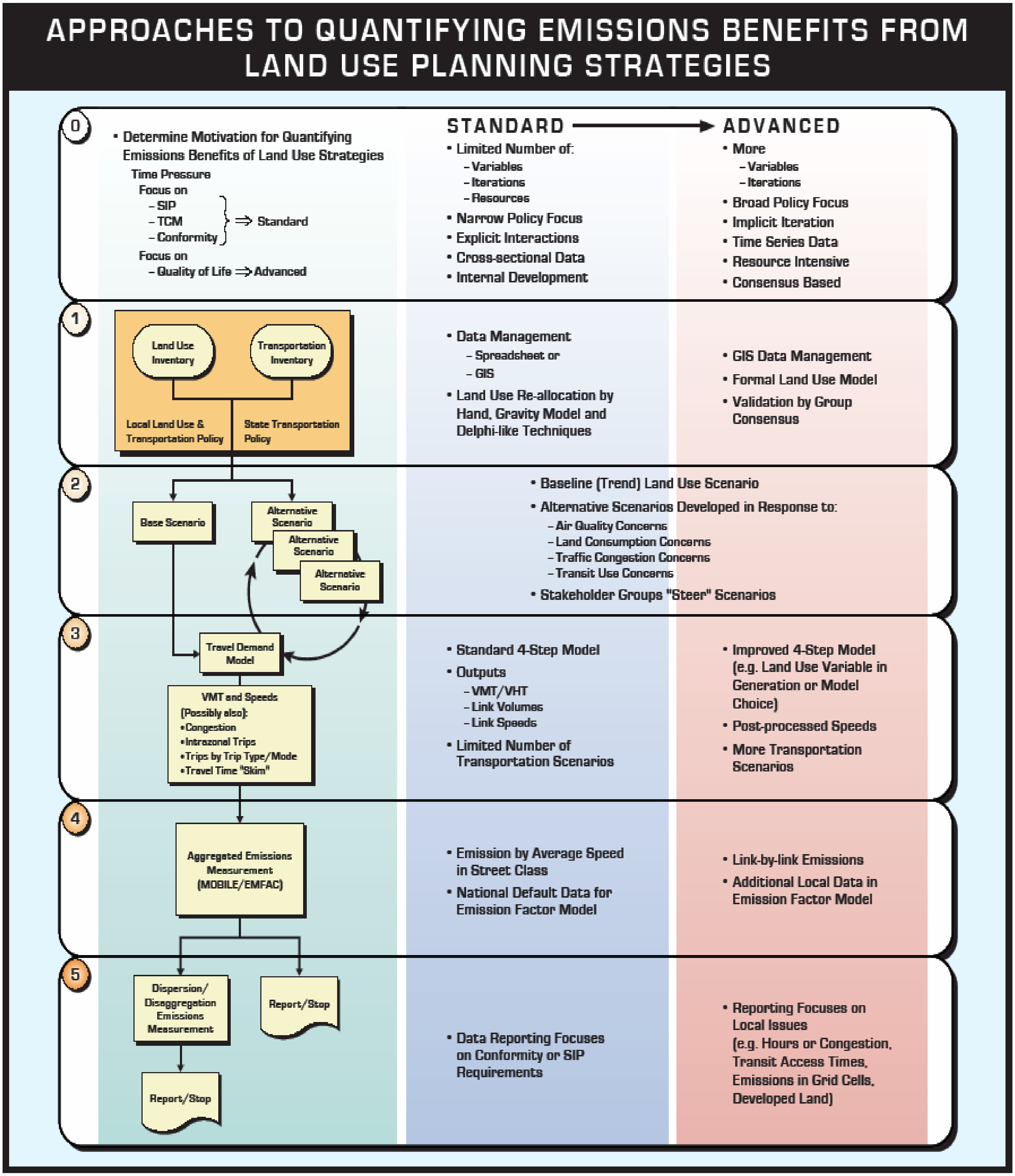
4.4 Summary: State-of-the-Practice Methods for Predicting Mobile Source Emissions Changes from Land Use Alterations

Based upon the critical review of the literature, interviews and case studies described in this report, the Research Team compiled descriptions of both standard (state-of-the-practice) methods and advanced methods being undertaken to quantify the emissions benefits realized from land use strategies. The advanced method presents a number of refinements to the standard practice. These differences include: broader focus, more alternatives studied, more stakeholder involvement, more advanced land use and/or transportation models, and additional data collection efforts.

As diagrammed in Exhibit 4-3, the differences between standard and advanced methods start with the initial purpose of the study. The regulatory requirements of transportation conformity have created a *de facto* minimum standard of practice in this type of application. Where the project sponsor is focused on quantifying emissions for transportation conformity (*i.e.*, regulatory) purposes, the methodology generally emphasizes components of standard, not enhanced, practice. Regions with more complicated issues add elements of the advanced practice depending upon their abilities and schedules. In a regulatory context time is often more important than either cost or performance as long as performance is adequate. In a non-regulatory context time is less important so the project manager can use additional time to gain better performance. The use of geographic information systems and gravity-based travel demand algorithms (either through a dedicated travel demand model or through an integrated land use-transportation model) are well-established and common to both standard and advanced practices. The basic steps for quantifying emissions benefits from land use changes are described on the following pages. It should be noted that in no instance was every advancement applied in a single case study; some advancements were present in several studies.

[2] There are two issues relating to MOBILE's user interface. First, MOBILE still operates as a command line or batch file interface, no longer state-of-the-practice for production software. Second, the analyst must do a considerable amount of reformatting inputs and outputs before using MOBILE and before moving to the next analytical step.

Exhibit 4-3. Approaches to Quantifying Emissions Benefits from Land Use Strategies



Pre-Analysis (Step "0" in Exhibit 4-3). The context within which the analysis will take place determines the goals and objectives of the study. These objectives, in combination with other factors such as available time, data, and financial resources; expertise; and the availability of pre-existing travel demand and land use models, drive the decisions about the tools and approach to be taken to quantify emissions benefits from land use strategies. The most important differentiating aspect of these studies is if the goal is to quantify the effects from community-scale, design-oriented causes or if the purpose is to look at regional-scale shifts of land use from one place to another. Both types of studies typically address density and mixing of land uses, but only the former considers the effects of design elements on mode split, trip frequency, and trip length.

Inventory of Land Use and Transportation Elements (Step 1). The prevalence of geographic information system (GIS) technology within state and local governments has greatly enabled the development, management, manipulation, and distribution of databases of land use types, environmental constraints on development and public infrastructure (e.g., transportation, schools, water/sewer). Again depending on the goals of the study, some or all of this information may be required for an analysis of land use and emissions. When design issues are under consideration, a fourth dataset is usually required that describes the specific characteristics of the proposed, existing, or surrounding communities that are to be studied.

Exhibit 4-4 provides examples of each of these data sets; but is not intended to be all-inclusive since literally dozens of variables have been used in various studies of land use and emissions benefits. The relevance of the first three columns of data types is oriented towards the constraints and inducements for growth; for example, areas that are environmentally sensitive or are expected to be served by public infrastructure. The fourth column in Exhibit 4-4 represents the general categories of information that are typically assessed for community-scale, design-oriented studies. The design category of data is critical in that it typically must be collected "in the field" since this information is seldom recorded in municipal databases and some of it is

Exhibit 4-4. Categories of Data Collection

Land Use	Infrastructure	Environmental	Design Features
Slopes	Roads (by capacity or type)	Protected Habitat	Building Architecture
Existing Development	Transit	Floodplains	Street Layout
Historic Structures or Districts	Public Water and Sewer	Valuable Open Space or Recreational Areas	Landscape Architecture
Zoning Classification	Sidewalks	Wetlands	Street Design
Soils/Hydrology	Schools	Water Features	Edge Features

difficult to gather even from good-quality, digital aerial photographs. The implication for any community-scaled analysis is that there is usually a substantially greater amount of time and money required for data collection compared to regional-scale studies. Although not completely overcoming this problem, researchers that have undertaken design-based efforts have relied on (inexpensive) intern labor or sharply controlling the size of the study area(s) to offset the data collection requirements. The second implication of data constraints on design-based studies is that these studies are nearly impossible to conduct for a time-series analysis since historical data records are not kept for detailed design features (this is a difficult problem faced in regional studies as well, but not to the same degree). Without historical data, understanding a cause-and-effect relationship between design elements and travel behavior/emissions is extremely problematic. Additional information is required for the travel demand and emissions models, which are explained in subsequent steps.

Development of Land Use Scenarios (Step 2). The second step of the modeling process for quantifying the emissions benefits from land use strategies involves the creation of the land use scenarios that will be tested. This should involve one baseline case developed from expectations of past trends continuing into the future. This is not a "Do Nothing" case; rather, the baseline case assumes similar growth rates, growth patterns, policies, and infrastructure development for the study area in similar quantities and at a similar pace as seen in the past. The MPO draws the infrastructure improvements from the long-range transportation plan which in turn is developed from proposals put forward by MPO members. Population and employment growth, location, and type are derived from existing projections, comprehensive plans, small area land use plans, U.S. Census, and state demographers. Since the baseline scenario is seen as the most probable future for an area, as well as being represented in documents that help guide economic growth, the baseline forecast of land use and transportation information is usually adopted by a policy board such as a metropolitan planning organization (MPO) or Council of Governments (COG). Transportation conformity rules stipulate that a transportation conformity analysis must include the "latest available data." It is important that there be no subsequent forecasts of planning data made by, or for the MPO. It also seems advisable for the MPO to verify the accuracy of land use forecasts as part of the planning process.

Once the baseline case has been adopted, one or more alternative land use scenarios are developed. The alternatives may have greater densities of development; more provisions for transit, bicycling or walking modes of travel; more diversity of complementary land uses in close proximity; or a design that facilitates trip-making by a means other than private automobile. Typically, shifting growth in housing and employment from one area to another is a "zero-sum game" with respect to the entire study area. There should be no net loss or gain of people or jobs between the alternative scenarios and baseline scenarios. Market forces that cause large numbers of people or jobs to relocate to other regions are generally assumed to be beyond the scope of these studies and beyond the ability of state and local governments to control. However, the changes in land use represented by each alternative future typically represents some policy directive, such as better balancing of jobs and housing (diversity) or a proposed zoning practice incorporating design-based codes.

While large, well-funded planning organizations often use formal land use models these tools are not often accessible to smaller MPOs. Two less costly tools available to these MPOs are the expert panel and the Delphi techniques.

The expert panel process is a structured, face-to-face interview or facilitated meeting involving local experts on land-use and growth. The panel can be structured as a facilitated work session that allows for full interaction between the various experts. Likely candidates for the expert panel include, but are not limited to, school officials, utility providers, real estate professionals, environmental groups, parks and recreation professionals. The purpose of the panel is to elicit the group's best opinion about the amount and location of growth in the region.

The Delphi technique is similar to an expert panel with two key differences. First, the panel members do not meet face-to-face and, ideally, should be anonymous to one another. Second, the process is iterative with panel members responding to a number of questionnaires intended to converge on the 'most likely' future.

Travel Demand Modeling (Step 3). A complete discussion of travel demand modeling is beyond the scope of this research. There are numerous documents providing guidance on each step of the travel demand modeling process. The Research Team recognizes that there is significant variability between urban areas regarding the level of effort and detail used in their modeling effort. While there are efforts to apply new methods or more precise model formulations to predicting travel, four-step models are the current state-of-the-practice and will be the focus of this discussion.

The traditional four-step modeling paradigm processes land use (or socio-economic) data and transportation network data through four related, but separate, sub-models to arrive at an estimate of travel that is generally expressed in terms of person trips, vehicle trips, and vehicle miles of travel. In addition to these performance measures travel models can provide estimates of mode split, travel under congested conditions, travel speed, and intrazonal travel. While there is no regulatory requirement to 'post-process' model network speeds, the analyst should not use the travel model's estimate of speed for three reasons. First, many travel models are at least partially validated by adjusting link speeds to shift traffic from place to place; in other terms, travel demand models are calibrated to link volumes, not link speeds. Second, the link speed actually represents the difficulty of moving (impedance) along that link of the network. Third, the network information encoded in travel demand model networks has traditionally been inadequate to accurately estimate link speeds. For example, delays incurred as a result of signal delays, recurring congestion, and accidents are seldom reflected in travel demand models. Some limitations can be partially overcome by using either a link type volume-to-speed lookup table or a link type post-processor to estimate realistic travel speeds.

Most trip generation modules use cross-classification models that estimate trips based on two or more dimensions of a trip generation matrix. Commonly used variables include household size, automobile ownership, and household income. Some cities, for example Baltimore, Maryland, have experimented with adding land use variables to their trip generation modules. The Research Team believes that this is feasible and good practice, but that it requires a substantial additional effort and resources to locally collect additional land use and travel behavior data.

Trip distribution most often uses a version of the *gravity model* to distribute trips between origin and destination zones based on the size of the attraction and the perceived travel time between the two points. A key point in the trip distribution process is that the gravity model should be iterated using congested travel times until travel times do not change between trip distribution and trip assignment. *40 CFR Part 93.122(b)(1)(iv)* and *(v)* and a number of other documents strongly encourage iterating between the gravity model and trip assignment. Of interest is the suggestion from the Denver Regional Council of Governments (DRCOG) that modelers should carefully consider their techniques for balancing productions with attractions. DRCOG staff believe that by balancing to productions for home-based trip types that modelers may be losing some of the effect of land use strategies. One alternative is to modify the trip generation equations to respect linkages between several different land use types for both the origin and destination ends of each internal trip within the model.

For mode choice the current state-of-the-practice is the multinomial logit model. These models assign trips to modes based on the availability of that mode in both origin and destination zones and the relative utility of that mode to other modes. It seems likely that to fully account for land use effects in travel demand models that both walking and bicycling modes should be included as well as various transit modes, and that the mode choice model should include a term accounting for either land use or local network design. A note of caution is that it is difficult to effectively evaluate the effect of land use changes on transportation without a predictive mode choice sub-model, and many existing travel demand models in use today have deterministic mode choice sub-models.

The current state-of-practice in trip assignment is to use a capacity sensitive assignment algorithm. There are a number of assignment options that meet this criteria including equilibrium assignment, stochastic equilibrium assignment, and incremental assignment methods. The Research Team believes that capacity sensitive algorithms will remain the standard for some time to come.

The next step of the process is estimating emissions based on travel and speed. As discussed earlier, link speeds should be post-processed based on link characteristics. The state-of-the-practice is to estimate an average speed by facility type and estimate emissions based on that speed and the motor vehicle fleet characteristics associated with a given facility type. The reason for the aggregation is the excessive computing time that would be entailed for estimating emissions for each network link.

Aggregated Emissions Measurement (Step 4). In a conformity analysis, or other regulatory analysis, the emission factors will be calculated based upon the most recent EPA-approved mobile source emissions model (MOBILE6.2[*] as of this writing) and the AP-42 guidance for determining emission factors. An emission factor is a quantitative amount of pollutant emitted by vehicles for every mile the vehicles travel or every hour the vehicles idle. The engine factors that would affect MOBILE6.2 emission estimates include vehicle model, type, age, fuel used, driving patterns, roadway types and conditions (freeway, arterial, collector, local, and ramp), temperature, humidity, technology, and regulations (vehicle emission standards, fuel standards, Inspection and Maintenance programs, etc). With all examined inputs for input engine data, as well as traffic conditions such as traffic speed, cold/hot start percentages, and others, the emission factors will be estimated as output of MOBILE6.2. It is important to note here that VMT and speeds, by facility type, represent the key data inputs that originate from travel demand models. Travel models are also sources for information on trip origins and destinations which can be used to estimate starts and evaporative emissions. Any effect that can be measured by a travel demand model but is not actuated through one of these two data inputs will not be “sensed” by the emissions model. The roadway emission strength can then be estimated by multiplying VMT and traffic volumes to these emission factors to determine source strength on each of the traffic links within the study region, or, more commonly, on aggregations of VMTs reported by roadway grouping or classification. The link-based method may be more responsive to local scale applications than aggregating to a larger geography, but this largely depends on how the emission factors are assigned to individual links in the travel model network.

[*] The regulatory model for California is the EMFAC/Burden series.

The combined results and sum of air emissions resulting from all analyzed roadway links within the study area will constitute a basis of conformity determination for this region that has regional concern for CO, PM, or ozone and its precursors – VOC and NOx. Regional analysis of these emissions and effects must be assessed and reported in the TIP or long-range transportation plan conformity determination report, depending upon the nature of the exercise.

Disaggregated Emissions Measurement (Step 5). Often, it is desirable to consider the local scale dispersion effects of a land use change. As noted elsewhere, localized density increases may reflect positively in a regional land use scenario, but increases in local VMT may actually worsen both congestion and air quality in the vicinity of the density increase. In this case, the MOBILE model procedure described above may not be completely adequate[3]. Furthermore, the location of receptors may be moved closer to the edge of the roadway by suggesting a more New Urbanist set of design codes. This particular downside of enhanced design attributes has not been explored in the literature review conducted for this project. The CALROADS suite of dispersion models and one alternative model are described below that typically accommodate dispersion analysis.

CAL3QHC. This is a model derived from the original CALINE3 model with additional queuing and hot spot calculations. Both CALINE3 and CAL3QHC model are designed to determine air pollution concentrations at receptors downwind of emission sources by using a steady-state Gaussian dispersion. CAL3QHC estimates total air pollutant concentrations (CO or PM) near highways and arterial streets due to emissions from both free-flow moving and idling vehicles, as well as the length of queues formed idling vehicles at signalized intersections. While this model takes into account the expected emissions, roadway geometry, and meteorology, the model also reflects the fact that land use characterization also plays an important role in air dispersion modeling. These land use factors will affect the meteorological conditions processing to define air dispersion situation such as urban or rural conditions, wind direction, as well as surface roughness length (which is the measure of height of obstacles in the study area) against wind flow. This land use effect on downwind dispersion, known as washing, is a function of various land uses such as water surface, forest, swamp, cultivated land, grassland, suburban, urban, or center city land use types. CAL3QHC is a simple model for Tier 1 analysis in most areas without traffic congestion. Compared to other models, it provides conservative (highest prediction of concentrations) results.

CAL3QHCR. CAL3QHCR is an enhanced version of CAL3QHC. It is capable of processing up to a year of meteorological, vehicle emissions, traffic volume, and signalization data for each hour of the week in one run using the same basic dispersion algorithms from CAL3QHC. Daily or seasonal runs can also be made. Output from the model consists of calculated running eight-hour and one-hour averaged CO or 24-hour and annual block averaged PM-10 concentrations. CAL3QHCR is a much more robust and complicated model that can be used for areas with traffic congestion and potential to exceed NAAQS. It would usually provide a more realistic prediction of air pollutant concentrations by using hourly meteorological and traffic emission data. The prediction can be as low as 40% of that predicted by CAL3QHC due to the procedural refinements available in CAL3QHCR.

[3] Although it should be noted that at least one travel demand model can report emissions to a fine (1km) grid or to traffic analysis zones using a subroutine that "calls" MOBILE for every grid cell in the overlay.

CALINE4. CALINE4 predicts air concentrations of carbon monoxide (CO) and particulates (PM), as well as concentrations of nitrogen dioxide (NO_2) near roadways - an advanced procedure due to various settling velocities for gases and particles. In addition to roadway and intersections, it can also model parking lots, depressed freeways and canyons. Currently, it is used only in California. CALINE4 can predict various pollutants including NO_2 in addition to CO and PM, and for various facilities such as parking lots, street canyon areas, etc. in addition to areas near roadways and intersections.

BREEZE ROADS (Alternative). BREEZE ROADS can be used to predict the ground-level concentrations of CO, PM, NO_2, VOC, and benzene (not a CAA criteria pollutant, but recognized as an airborne toxin by the model) from the roadways and development. This model has been approved by U.S. EPA and includes the CAL3QHC, CAL3QHCR, and CALINE4 line source dispersion models as well as a traffic algorithm for estimating vehicular queue lengths at signalized intersections. BREEZE ROADS will estimate the total air pollution concentrations from both free-flow moving and idling vehicles. This model incorporates three modules: two for modeling a single hour specific meteorological data condition (as defined in CAL3QHC and CALINE4), and the third for modeling hourly meteorological data and mixing height algorithm (as defined in CAL3QHCR). In addition, the BREEZE ROADS model also incorporates an accounting of NO to NO_2 conversion. This dispersion model can be used in conjunction with emission factor models such as MOBILE or EMFAC. It also includes a fully integrated GIS database.

5.0 Directions for Improvements: Research and Accessibility

The final task undertaken by the Research Team was to recommend directions for further research and assistance to agencies that will be conducting analyses to quantify emissions benefits from land use strategies in the future. These recommendations were based upon the critical reviews of the literature and contacts with end-user communities discussed in this report. The improvements emphasize methods that produce results usable for State Implementation Plans (SIP) and conformity analyses. However, other end-users that are motivated by improving aspects of quality of life (economic, cultural, etc.) bring additional techniques not commonly represented by those agencies wishing to conduct an analysis as part of a conformity determination, particularly in the areas of land use planning and economic development. Therefore, this second group of end-users should be recognized as a partner that can enhance technical practices.

The first section of this chapter discusses the user community profiles, differentiating levels of resources and specific needs of each community of end-users by the tools and methods required to create a credible forecast of emissions changes from alternative land use strategies. The second section of the chapter identifies specific shortcomings of current state-of-the-practice methods and points to improvements that would be beneficial to the quantification of emissions benefits, developing land use strategies, and travel demand modeling. The third and final section discusses how to make training, techniques, and data more accessible to all of the end-user communities.

5.1 User Community Profiles

During the course of research, several different communities of end-users were identified. Understanding these different communities and their needs is a necessary first step to creating a context that allows an accurate assessment of research needs and how to improve the skill sets within the user communities (both of which are discussed in subsequent sections).

Metropolitan Planning Organizations. MPOs are clearly the largest potential community of agencies that have a direct interest in the quantification of emissions benefits from alternative land use strategies. MPOs that are either non-attainment or maintenance for one or more of the NAAQS are responsible for proving that their transportation plans, programs, and projects conform to the intent of their state's SIP. They also participate with the air agencies to develop transportation measures to reduce emissions. Less than half of all MPOs are operated within the same organizational framework as Councils of Government (COGs) which, like the MPO, are frequently engaged in inter-jurisdictional studies of best land use practices, environmental effects of development and related issues. The specific needs of this end-user community include improving skill sets of staff; accommodating study approaches to meet the restrictions imposed by (frequently) small staffs and budgets; and ongoing technology transfers as methodological improvements are made.

State and Local Air Agencies. Usually contained within the state's environmental department, the state air quality or emissions staff works cooperatively with metropolitan planning organizations, state departments of transportation, and private contractors to develop emissions testing methods, review emissions tests, and create state implementation plans and control strategies to reduce emissions. These agencies typically do not lead efforts to apply land use-emissions, but are often involved and interested in such studies when they touch upon SIP development or conformity issues. The needs of this group tend to be more aligned with understanding the theory and methodological strengths of various approaches to quantifying emissions benefits from land use strategies. This would allow a more complete review capability when MPOs and other agencies propose using land use as a means to reduce mobile source emissions.

Regional Air Agencies exist in many areas and play a similar role to that of state air agencies. Their interests are similar to those of the state air agency but their focus tends to be on permitting and enforcement of SIP rules addressing measures to achieve transportation conformity.

Private Sector. Large private developments, such as the Atlantic Steel case study shown in this report, may undergo emissions analyses under certain circumstances (*e.g.*, to get TCM status for some component, to obtain CMAQ funding for a critical piece of infrastructure, or to comply with state or local permitting regulations). These agencies typically want to tout the benefits of their development scenario over another scenario, and want to obtain government permissions and permits required to construct a planned development or project. Therefore, the private sector consulting firms conducting these studies tend to be primarily interested in seeing an adopted set of broadly recognized standards for calculating emissions benefits from proposed developments.

Transit Planning Agencies. This subset of users typically includes those agencies that are assessing or promoting transit-oriented development solutions that complement existing or proposed high-quality transit services, usually rail. Although sometimes their interests in land use/emissions benefits studies are expressed through the appropriate metropolitan planning organization, these agencies are frequently capable of conducting detailed and robust studies using their own resources. The current policy of the Federal Transit Authority not to consider possible changes to ridership forecasts based on land use changes that may result from having increased access to the transit service in New Starts applications has perhaps dampened the market for such studies by transit agencies. Initial feasibility studies are still conducted to help justify some of the benefits of transit development that may be conferred on local, municipal partners. The interest of these agencies is focused on considering the interrelationship between improved transit service and the supporting role that "*smart growth*" and denser, mixed use land patterns can offer to transit station areas. These studies, and the transit agencies' interests, tend towards considering the design features of small (¼-mile and ¾-mile radius circles) study areas and their impacts on mode choice. Increasing the understanding of design effects on travel behavior are desirable, as are the emissions benefits and costs of higher-density living, shopping, and working arrangements.

Federal Agencies. The Environmental Protection Agency (EPA) and USDOT (particularly Federal Highway Administration and Federal Transit Administration) support research in the areas of land use and mobile source emissions, and are often present at interagency consultation meetings to discuss conformity practices undertaken by MPOs. Like state air quality agencies, federal agencies are often placed in a role of reviewer and resource agency to the lead agency conducting a study of land use/mobile emissions, at least when the results of such a study may be cited during a conformity determination process. Further, FHWA and FTA must make independent conformity determinations based in large part upon the information provided to them by the MPO. Hence their interests are also related to understanding the theoretical underpinnings and communicating acceptable best practices to those agencies that wish to undertake such studies.

Advocacy Groups. This community of end-users may include formal, informal, publicly or privately subsidized groups that have a direct or indirect interest in the subject of air quality benefits from land use changes. Part of the interests of the Congress for New Urbanism (CNU), for example, resides in the health benefits to communities that exhibit smart growth patterns of development over traditional, more sprawling patterns of development. Groups like the Sierra Club may have a more direct interest through a role as "watchdog" or motivator for land use studies. Segments of the public may briefly coalesce to support or protest certain proposed developments, plans or programs based on their emissions benefits or costs. Varied in their level of expertise, the primary need of these groups is reliable information that is readily absorbed by people that may never actually conduct any portion of a land use/mobile emissions study. Increasing the level of expertise of these groups is nevertheless important, since the awareness that these groups possess may provide an important long-term influence on the quality and quantity of land use/emissions studies that are conducted.

5.2 Research Needs and Model Improvements

Based upon an understanding of the needs of various end-user communities, discussions with case study participants, and a critical review of past studies and research, the Research Team proposes a three-pronged approach to improving the current state-of-the-practice in quantifying emissions benefits from land use strategies: improving the management of land use and transportation inventories and forecasting; modifications to travel demand models; and modifications to emissions modeling. Each of these is discussed below, with specific recommendations for both research and application improvements under each of the three main headings.

5.2.1 Improvements to Transportation and Land Use Data

Tools for Managing Large Data Sets. For regional-scale studies where large numbers of traffic analysis zones and/or large numbers of attributes are involved, the management of data for multiple scenarios becomes a significant problem. In a number of studies reviewed, the primary tool for manipulating large data sets of zones and zonal attributes was a series of computerized spreadsheets. The Research Team recommends that more emphasis be placed on both optimizing the capabilities of spreadsheets through Visual Basic applications (VBA) and built-in functionality, as well as migrating the data to geographic information system (GIS) platforms. VBA is a programming environment that allows repetitive tasks to be performed quickly, or that allows tasks not normally a part of the feature set of the spreadsheet software. Built-in VBA functions such as pivot tables, application "wizards," and database queries can be of assistance in error-checking and applying control totals to long columns of data. VBA code, once developed, is readily exported to other users conducting similar work; hence, a VBA code library may be useful to the end-user communities that are taking a lead role in conducting such work.

Tools for Forecasting Growth and Development Scenarios. In recent years, there has been a proliferation of GIS-based models that allow the consideration of a number of variables (see Exhibit 4-4, for example) to forecast land use scenarios according to pre-defined policy parameters. In many conformity-based land use/mobile emissions studies, there is an initial assumption that land use will be aggregated or "mixed" according to some supposed concept of reasonableness based on changing past trends through undefined or poorly defined policy actions. If an alternative land use scenario is selected as the preferred alternative, then the lead agency must then embark on developing and assessing policies and programs to effect the presumed land use changes. Beginning with a calibrated land use model that is sensitive to policy and environmental changes as well as past development trends can provide the ability to create a larger number of trial scenarios very quickly and also permits sensitivity testing, indirect impact assessments, community impact assessments, and cost-benefit assessments. These and other reasonableness tests can greatly aid agencies involved in interagency consultation meetings, for example, to have some additional degree of confidence that the postulated land use changes will actually happen if certain policy directives are undertaken by local and state governments. As an added benefit, land use models often integrate with standard travel demand models and GIS packages, allowing faster modeling of multiple scenarios and display of results to decision-makers.

A promising recent development in the area of dynamic land and transportation modeling is the use of *cellular automata*. Popularized by John Conway and his Game of Life[4], the central concept of cellular automation is that each cell in a grid obeys certain rules according to its own (internal) condition as well as to influences of the other cells around it (externalities). A number of land use models are using cellular automation to help predict when a sub-area (cell) becomes "active" or develops. Physical constraints, public infrastructure supply, ownership, and zoning are typical examples of internal properties of each cell; the state and type of development of adjacent cells are considered externalities. Much like Dr. Conway's original Game of Life, the models assess the current state of all cells to determine the state of each cell in the next iteration of the model. Extremely complex interactions and regularized processes can develop from very simple rules applied in this manner. It has been proposed that the application of cellular automation models can help reduce the amount of data required for a model since each iteration builds off of a base case and a simple set of rules to determine each successive iteration. These models also offer the opportunity to test multiple scenarios under different rules very quickly without the manual adjustment of many individual cells (or traffic analysis zones) and the ability to integrate economic and non-economic constraints/incentives fairly easily. There are problems associated with these models, particularly the issue of efficiently calibrating them to known conditions. While this can be accomplished to some degree using *spatial autocorrelation* techniques to relate known or historical conditions to modeled conditions, pinpointing the adjustments required to improve a model's ability to emulate known conditions is made difficult by the complexity of the interactions among so many discrete entities represented by cells and their internal/external variables.[5, 6]

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[4] Gardner, Martin. On cellular automata, self-reproduction, the Garden of Eden and the game 'Life.' Scientific American 224, No. 2 (February, 1971): 112-117.

[5] D.P. Ward, A.T. Murray, and S.R. Phinn. An optimized cellular automata approach for sustainable urban development in rapidly urbanizing regions. Department of Geographical Sciences and Planning, University of Queensland, Brisbane, Australia. Proceedings of the 4th International Conference on Geocomputation (1999). *See also (http://www.geovista.psu.edu/sites/geocomp99/Gc99/025/gc_025.htm) for a re-print of this paper.*

[6] There are many available references and demonstrations of both Conway's Game of Life and cellular automation applications. Included on the accompanying CD-ROM are Clarke, *et al*'s seminal 1997 work proposing a modeling construct for the San Francisco Bay area which serves as a good introduction to the topic. The authors also recommend reviewing the SLEUTH model as an example of a refinement of the Clarke urban

In order to hasten the adoption of land use models, greater attention needs to be applied to developing usable, detailed data sets and expanding the expertise of the end-user communities while simultaneously lowering the learning curve required to create and use these models. Creating partnerships between the various end-user communities can often help offset the considerable financial and staff time resources required to create and maintain land use models. One case study participant noted that a greater emphasis on economics-based land use models would be desirable. Many land use models rely solely on past development trends and physical constraints to create future land use scenarios, not market trends.

Creation and Maintenance of Appropriate Data Inventories. Design-based alternative scenarios, as already mentioned, face a particular challenge in field data collection since design aspects of areas are seldom maintained in usable formats. Developing standards for defining mixed use, street layout configurations, street designs, transit service, pedestrian/bicycle amenities and other independent variables would aid local agencies in knowing what information to collect and maintain. Another aspect of this problem is defining and understanding the real effects of adjacent land uses that are not supportive of travel behavior changes on those areas that do exhibit some features that might alter mode splits, travel behavior, or trip lengths. Additional research needs to be conducted to help understand these boundary and edge effects. Similarly, the size and composition of geographic analysis units (e.g., traffic analysis zones) also play into the considerations of how to store and maintain spatial data, requiring additional cooperation between agencies that traditionally may have little pre-project interaction with each other on visionary projects, such as GIS, transportation, and planning departments.

5.2.2 Modifications to Travel Demand Modeling

A number of possible improvements or research topics were revealed speaking to case study participants, as well as during the review of the technical literature from research efforts.

Manipulation of Intrazonal Trips. Those trips in the model that do not reach the edge of their originating zone are called intrazonal trips. It is the stated purpose of many regional and community-scale land use/emissions modeling efforts to maximize intrazonal trips, since this implies that a greater percentage of trips are shorter or are made by walking and bicycling. Typically, some fraction of intrazonal trips are assumed to be walk, bike, and car trips. The percentage of each trip type is sometimes determined by an index created from land use characteristics of the zone. Many travel modeling packages do not assign intrazonal trips to the regional network so additional steps may be needed to estimate the VMT associated with intrazonal trips. Many of the travel interactions necessary to evaluate the effect of land use changes on emissions occur in the intrazonal trips. It is therefore very important to obtain estimates of intrazonal trips for use in transportation conformity, and generally when evaluating the emission effects of land use changes. Very often intrazonal VMT is taken to be some percentage of total VMT that is estimated based on the number of intrazonal trips or is estimated using the number of intrazonal trips multiplied by ½ of the average distance between adjacent zones.

The conformity regulation notes that "Reasonable methods shall be used to estimate nonattainment or maintenance area VMT on off-network roadways within the urban planning area…" Travel modelers have taken three approaches to this task: (1) assuming that local VMT

growth model that uses cellular automation coupled with Monte Carlo simulation as a working land use model that has been tested in several major metropolitan areas (http://www.ncgia.ucsb.edu/projects/gig/project_gig.htm).

is some percentage of total VMT and adding this percentage to the local VMT, (2) treating centroid connector VMT as local VMT, or (3) estimating local VMT by multiplying the number of intrazonal trips by an averaged length such as ½ of the average distance to some number of the nearest zones.

However, a number of factors can influence the number of intrazonal trips: number of productions/attractions occurring within the same zone (mixture of uses), centroid connector speeds, size of the zone and size of adjacent zones (since intrazonal trips are in part determined by the distance to the centroid of one or more neighboring zones), and friction factors applied in the model. Modifying any of these variables will have some affect on the number of intrazonal trips, and the effect may be significant if the study area is small or the change to the variable is applied globally throughout the model. For example, increasing the link speed on centroid connectors increases the number of trips that reach the edge of the zone, thereby decreasing the number of intrazonal trips.

Zone Composition and Size. The size of the traffic analysis zone has traditionally been determined by the amount of development (jobs and housing) within the zone; efforts are made to keep this number fairly consistent across the model, implying that zone areas increase as population and employment densities decrease. Furthermore, it is traditional practice in model development to minimize the number of land uses within a single zone. However, many alternative land use strategies require the mixing of land uses in close proximity to one another, hence conflicting with the homogeneity of zones. Again, the size of the zone will affect the number of intrazonal trips that are made, and potentially cloud any small changes in travel behavior that may occur due to design features of the community. Just as travel models are not calibrated to link speeds, zone boundaries are not selected based on the homogeneity of design features or street layouts. This means that the very zonal structure of travel demand models is ill-suited in many cases for examining the relationship between land use and travel behavior effects that might influence mobile source emissions. Splitting large zones; changing zone boundaries; reconsidering centroid connector placements and speeds; and re-evaluating intrazonal travel times are recommended practice for most applications. Additional research detailing zone modifications that better reflect land use strategies is an identified need.

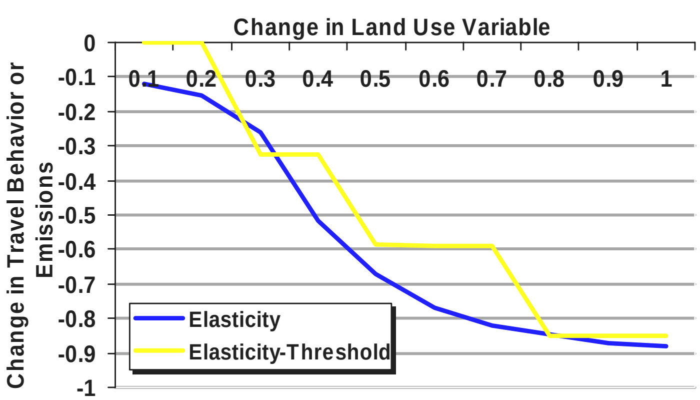
Design Feature Sensitivity. Measuring and assessing the impacts of design values in an existing or proposed community as part of a land use scenario has proved to be a significant topic in the past, since the evaluation of some of these features tend to be subjective. Developing a consistent evaluation method for design features that relates to mode choice and vehicle miles of travel would be a significant contribution to the existing literature. Some studies have focused on this aspect of the land use/travel behavior relationship, but a consistent evaluation method has not emerged. Once a consistent method for measuring the complimentary design features of a community has been established, additional research and case studies that apply the methodology to a variety of communities and settings would greatly enhance the ability of the model to accurately reflect changes to trip generation and mode choice due to community design.

Technical Improvements in Modeling Framework. Bicycle and walk mode modeling is still in a very early stage of development compared to roadway and transit modeling. Calibrating to what is often a very small number of trips made by bicycling or walking; adding network attributes (or a separate network entirely); and developing trip generation/attraction models have generally not been within the resource or capability constraints of many agencies developing travel demand models. However, many of the benefits that accrue to denser, more diverse, and design-friendly communities primarily benefit these modes of travel. It is quite possible, for example, that pursuing a gravity-based formulation for these trips is not as good an approach as considering an activity-based model. A greater understanding of what makes these modes more attractive, how trips are generated, and mode choice decisions would be beneficial to overall travel demand modeling practice. Another approach, already in use in some modeling applications, is the use of a land use index that modifies the trip generation or mode choice sub-models to account for greater numbers of biking and walking trips in those areas that have design or diversity characteristics favorable to those modes of travel. Simplifying and standardizing these indices would be an important improvement to current practice.

Tour-based modeling and activity-based modeling structures are relatively recent additions to the traditional four-step modeling process, which has been substantially unchanged for the past three decades. In tour-based modeling, information is retained about the trip-maker throughout his/her day, meaning that if a person gets to work by bus they are not likely to go home in their personal automobile. The Travel Modeling Improvement Program (TMIP) has allowed great strides to be made in the application of highly disaggregated travel demand modeling. Activity-based modeling makes assumptions about trip-making behavior not on the characteristics of the trips, but on the profile of the trip-maker. This approach inherently offers some advantages to replicating those local scale, land use elements of the decision-making process that current four-step models may overlook.[7] Both modeling techniques are still in a relative stage of infancy, but do show some promise for the application of emissions benefits since they require a more disaggregated dataset and more understanding of the trip-maker.

Travel behavior surveys, usually conducted through a diary format for a random or stratified-random sample of trip-makers, can be improved greatly to help better define the impacts of land use. Seldom are these surveys stratified by land use characteristics. Instead they are stratified (or the sample is expanded for certain stratifications) by income or car ownership. A better accounting of the type of community that each survey respondent resides or works within can greatly enhance the understanding of how community type can influence travel behavior and thus emissions. A second improvement to travel behavior surveys would be scheduling frequent, even annual, survey sampling rather than conducting very large samples at much less frequent periods. This would allow for a better representation of the longitudinal data relationships than is currently the normal practice. A better understanding of the elasticity relationships and critical thresholds that influence travel behavior (and emissions) based on land use changes may be the single most important line of research that

Exhibit 5-1. Elasticity-Only and Elasticity Threshold Relationship



[7] RDC, Inc., *Activity-Based Modeling System for Travel Demand Forecasting*, Sponsored by Metropolitan Washington COG, USDOT, USEPA. September, 1995.

can be pursued in the short-term. Additional cross-sectional and longitudinal studies should be accumulated to help define the elastic relationship between the independent variables of community design, development intensity, and land use diversity to the dependent variables of mode choice, vehicle miles of travel, and trip lengths. The Research Team suggests that elasticities alone cannot adequately explain these relationships; there are thresholds above or below which no significant change in travel behavior occurs and hence no emissions benefits accrue. Hence, these elasticity-based analyses should not be used for conformity purposes, but remain in the realm of a first tier assessment of the potential of a proposed land use strategy to generate emission benefits.

Exhibit 5-1 illustrates an elasticity-only relationship to a land use change and a curve that reflecs both elasticities and thresholds. The implication of the elasticity-threshold curve is that small changes in land use patterns do not produce small results in emissions – they may produce no results whatsoever. Only when a critical threshold or large increment of change is achieved does the actual travel behavior and emissions within a region alter in response. This is especially true at either end of the elastic region of the curves, and can be intuited by considering the case of changing a residential land use from a R-40 (one dwelling unit per 40,000 square feet) to a R-20 designation (one dwelling unit per 20,000 square feet). By itself, this doubling of density is unlikely to achieve any results in mode choice, trip lengths or any other travel behavior likely to impact emissions. Both land designations can still be low-density, suburban neighborhoods reliant on the private auto to reach all destinations. Visually, they would appear very much alike, with both cases characterized by driveways, attached garages, many cul-de-sac streets, and homogeneous land uses. The extreme opposite end of the spectrum may also be true: those communities that are already at a very high development density may not exhibit marked changes in transit use, trip length or other travel behavior variable if density is increased further.

This example also highlights a second issue confronting researchers: many changes in travel behavior and the resulting emissions benefits require changes in multiple variables. A doubling of land use density by itself may be a very small component of realizing travel behavior changes in a community, but if land uses are more diverse, designs in streets and building orientations are more walk-friendly, and high-quality transit service is implemented nearby there is a much better chance of realizing significant travel behavior changes. Many studies have attempted explicitly or implicitly to disentangle the effects of various land and infrastructure changes. The Research Team proposes that the whole land use-travel behavior construct may be considerably greater than the sum of its individual parts. The implication is that land use variables are co-dependent and cannot be isolated during analysis, raising additional questions about the ability of traditional four-step models to "capture" the effects of multiple land use changes.

A better understanding of the land use-travel behavior relationship is the most productive path both to developing a sketch analysis tool for smaller MPOs to conduct feasibility testing for including land use strategies in their long-range plans, and for reviewing agencies to test the reasonableness of proposed changes' potential benefits to air quality. The current understanding of this relationship is presented in Appendix D. Additional research that adopts consistent study methodologies can be used to fill in the gaps in the current understanding of the land use-travel-emissions relationship.

Exhibit 5-2 uses data from the case studies to illustrate the magnitude of the changes that cities have reported in practice. The figure shows the percent of change associated with NOx, mode share, trip length, and vehicle miles of travel. Unfortunately, the case studies did not report the density changes in a manner that is compatible with evaluating the other changes in terms of elasticity. Also notice that the change in VMT is relatively small when compared to the changes in trip length and mode share. For mode share this is in part due to the generally small mode share of modes other than driving. It should also be noted that while the range of change for NOx is 10.8% this includes both increases in NOx and decreases in NOx.

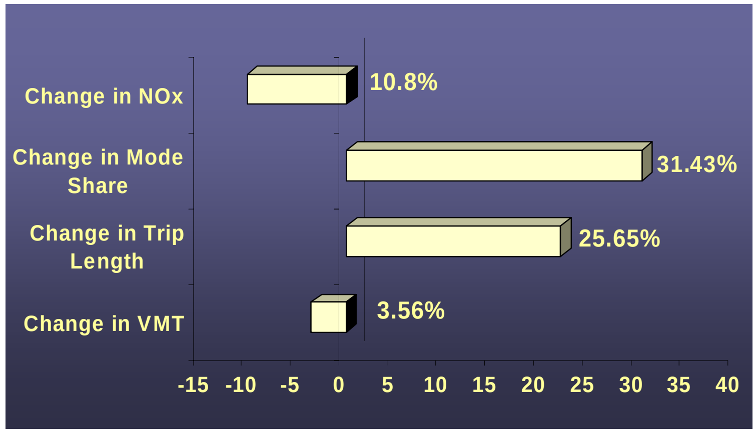


Exhibit 5-2. Ranges of Percent Change from Case Studies

5.2.3. Modifications to Mobile Emissions Estimation

Making changes to emissions estimations has traditionally been the responsibility of the USEPA, although input from MPOs and state air agencies has been provided to each new version of the MOBILE model. USEPA certifies modeling programs after extensive testing and comment periods. Hence, if a land use-emissions study is being conducted for conformity purposes, the MOBILE model (or EMFAC in California) is the tool that must be used to create emission factors. These factors are then applied aggregately to vehicle miles of travel to produce an emissions forecast. Some disaggregation is possible either by grouping links by type or classification, or by attributing the emission factors to links in the travel model network.

There are some well-known shortfalls to current emissions models that, either alone or in conjunction with a travel demand model, particularly affect the estimation of mobile sources due to land use changes. For example, the grid street pattern and narrow street widths preferred in many smart growth initiatives are often hypothesized to affect vehicular speeds in the research. If the travel demand model link attributes do not respect these differences as compared to other local, subdivision streets, then the VMTs on these grid streets may be subject to inappropriate speed/capacity constraints or be entirely ignored by the classification system used to aggregate the VMTs. This problem is (usually) easily remedied by adding one or more classification types to the appropriate network attribute, although collecting information on these street systems to a level necessary to differentiate a grid street systems' effects on VMT may be quite onerous for a small planning agency.

A second issue is the lack of appropriate information about acceleration events that may occur in a neotraditional, grid-like street pattern. The MOBILE model is sensitive primarily to speeds, not acceleration events, even though these events have been shown to make a disproportionate contribution to emissions for many trips and vehicle classifications[8]. Microsimulation modeling for small-scale studies as a post-processing step may be used to help overcome this particular shortfall, if the simulation captures vehicles (by type) during periods in which they are accelerating. Again, this a demanding amount of additional work over and above the work already put into land use and travel demand models.

A third issue is the refinement of the zone system in the travel demand model and how intrazonal trips are treated in the emissions analysis. The modeler must ask the question if there are trips that are being lost that should have shown up on the network, and if the intrazonal trip lengths are reflective of what is actually happening. The best way to overcome these problems is by having smaller zone sizes – again, this implies considerably more effort to develop demographic data and placing centroids and connectors for each zone that is split.

A final improvement that is taking place is the need for an improvement in the data input and data output capabilities of the MOBILE model. Currently, MOBILE is run as a batch file using line code; outputs are presented in many sheets of tabular information. Increasing link groups or scenarios greatly increases the magnitude of the output. At least one third-party vendor has produced software that interfaces with MOBILE to make data entry easier and displaying output more user-friendly. Additional products that perform the same function in the GIS and travel demand modeling realms is a desirable trend.

5.3 Accessibility

Although additional research is necessary to advance technical methods, the Research Team identified several other shortcomings in the dissemination and availability of techniques that must be addressed to make good practice available to more MPOs wishing to measure the emissions benefits from land use strategies. The four main categories of assistance are in training for staff, acknowledging data requirements to carry out various kinds of analyses, improving technical tools, and disseminating information through a consolidated community of end-users.

5.3.1 Training

The Research Team estimates that less than 10% of all MPOs have ever attempted to conduct a detailed land use-emissions study. Several barriers, including resource and time constraints, were noted within a number of small- and medium-sized MPOs. Training staff within the MPOs about data requirements, available methods, and realistic estimates of resources to conduct these analyses are needed. Making this report and other documentation available in a readily-absorbed format, conducting training workshops at major transportation conferences (notably, Transportation Research Board and Association of Metropolitan Planning Organizations), and providing information through the Internet are recommended strategies that would reach metropolitan planning organizations.

5.3.2 Data Requirements

The quantification of emissions benefits from land use strategies requires three types of information: land use, transportation (sometimes these two are integrated) and emissions. These models may not be complex affairs relying on dedicated software, but nevertheless fit the

[8] Christopher Frey, PhD, et al, "Emissions Reduction Through Better Traffic Management: An Empirical Evaluation Based Upon On-Road Measurements," North Carolina State University, 2001.

definition of a model as a simplification of reality. Each of these models requires significant amounts of data about the natural environment of the study area, sociodemographic characteristics, and vehicle information. Information is required to be in a specific format, and may require historical or detailed field data to calibrate properly. A menu of approaches should be developed that (1) provides an understood level of "robustness" as a trade-off in data requirements; and (2) is clear with respect to data input requirements for each method. This would allow a direct comparison of the needs of the analysis and data available to the agency conducting the study. Additional attention can be paid to local and federal data collection efforts, such as Census and PUMS (Public Use Micro Sample) datasets, to ensure that these products improve the data that is collected in a way that is meaningful to land use-emissions research (e.g., car ownership, trip behavior, lifecycle information).

5.3.3 Technical Tools

At least three models are required to conduct a quantification of emissions benefits from land use actions: land use, travel and emissions. Most of these models, depending on the vendor, are free or at relatively low-cost: land use models are generally less than $2,500/site, and the required emissions factor model in 49 states, MOBILE, is free. One exception is with travel demand modeling. While there are packages such as QRSII© that are fairly low-cost, the most common models charge $5,000 - $10,000 per site with an annual maintenance fee that is hundreds of dollars. The cost of a GIS usually has to be added to the cost of a land use model, since the latter often runs in concert with the former (or at least requires data to be manipulated in such a way that a GIS is almost a necessity). The most popular GIS package costs about $2,500/site plus an annual maintenance fee. The barriers to dissemination of appropriate technical methods and lack of technical support have also been deterrents to using more advanced tools.

A second clear need is for a sketch analysis tool based on estimated relationships between land use, travel behavior and emissions. As previously mentioned the data, skill sets, time, and financing are generally beyond the capability of many MPOs and other end-user communities. One interviewee suggested that less than 20 MPOs (out of about 350) have actually participated in a robust, quantifiable land use-transportation study. There would seem to be a strong benefit to developing a spreadsheet tool that has the following characteristics:

- Incorporates the elasticity-threshold concept that can be modified based on user inputs;
- Accounts for design features as well as land use shifts in density and diversity of uses;
- Applies default or most recently available emissions factors, and
- Accommodates sensitivity testing, presents a range of error values, and presents the outputs in tabular and graphical forms.

By applying this tool early in the feasibility stage of a long-range transportation planning effort, a community can gauge the degree to which land use strategies can realistically help them meet transportation conformity goals. A brief user's guide that explains the tool, its limitations, advanced procedures, and policy guidance could be developed to accompany the spreadsheet tool. Both products could be made available over the Internet.

5.3.4 Information Dissemination

Many studies that are conducted are never properly documented, or the documentation that is generated is never distributed beyond the immediate set of stakeholders. At a minimum, the following guidelines should be adhered to whenever a land use-emissions benefit study is conducted:

- Sponsoring agency and contact information;
- Date of study initiation and completion;
- Data input requirements;
- Financial, computing, and staffing requirements;
- Model parameters, software, and calibration information for every model and sub-model; and
- Outputs from analysis, including the results of any sensitivity testing.

Particular attention should be paid to those requirements that mesh with those of the Environmental Protection Agency for agencies wishing to receive SIP credits. The USEPA has published guidance information about the documentation requirements of agencies wanting to claim emissions reductions due to proposed land use changes[9,10]. The USEPA reports preview some of the findings discussed in this report, and also identifies a number of areas that EPA can support to get more MPOs involved in, and better at, producing emissions-land use studies:

- Identify the effectiveness of urban policies at redirecting growth patterns;
- Increasing cooperation among "balkanized" local governments;
- Facilitating developer actions to produce lower-emissions developments through the use of the Smart Growth Network and other opportunities; and
- Using the expertise contained in the regional EPA offices to assist local, MPO staff in the quantification of emissions benefits from land use strategies.

Housing documentation in an Internet-based format can provide the basis for disseminating case studies to interested parties, regardless of the end-user community to which they belong. A central repository should be designated to aid in the distribution of case studies. Each case should be indexed by indicators describing its ease of use/resource requirements, purpose, and geographic scale of the study area. This would allow the potential end-user to select those studies that are of the greatest potential benefit to their own situation.

[9] USEPA, *Background Information for Land Use SIP Policy*, EPA Report No. EPA420-R-98-012. September 30, 1998.
[10] USEPA, *EPA Guidance: Improving Air Quality Through Land Use Activities*, EPA Report No. EPA420-R-01-001. January, 2001.

6. Definitions of Terms Used

Transportation conformity: Process whereby a metropolitan planning organization or unit of government determines that a geographic area will adhere to the standards set out for any or all of six criteria pollutants listed in the Clean Air Act legislation, including any mitigating actions (control measures) required to meet the standards.

Boundary Effect: The influence that a major physical, or perceptual barrier may have on land use and travel behavior. Examples include freeways, rivers, changes in income of the population, and perceived crime rates.

Connectivity: The connectivity of a street or other transportation system refers to the number of alternative paths that can be traveled between two or more points within the system.

Cellular Automation, Cellular Automata: A modeling construct that uses a set of user-defined rules (called transition rules) to sequentially migrate the conditions of cells.

Density: Density refers to an increase in the number of units or number of square feet of development (e.g., houses, offices, hotels, shopping centers) in a given geographic area.

Design: Design describes the physical characteristics of a community, including building height, mass, setbacks, and architectural/structural features; and the transportation features like sidewalk widths, bicycle lanes, street widths, lighting, pedestrian furniture, street layouts, and cross-sections.

Diversity: Diversity is a measure of the number of different types of land uses contained within a given geographic area.

Edge Effect: Refers to the effect(s) that neighboring areas with different land uses may have on the area under consideration.

Elasticity: As referred to in economics, elasticity is the proportional change in one variable relative to the proportional change in another variable. See also Appendix D of this document for a complete definition.

End-User, End-User Community: End-User Communities are those agents or agencies that conduct or use the results from land use-emissions benefits studies, chiefly metropolitan planning organizations and state air agencies.

Gravity Model: The gravity model is a mathematical formula used to estimate the number of trips between any two points depending on the attraction and production potential of the two points and the distance between them.

Local Scale, Local Scale Research: A local scale refers to study areas that are community or neighborhood-based in physical scope, typically less than two square miles in total area.

Metropolitan Planning Organization (MPO): Agency charged with the process of carrying out a cooperative, continuous, and comprehensive framework for making transportation investment decisions in metropolitan areas. Program oversight is a joint FHWA/FTA responsibility. *(source: AMPO)*

Regional Scale, Regional Scale Research: This refers to a study area that is large in physical scope, typically encompassing a several-miles-long corridor, subarea greater than two square miles in size, or entire metropolitan planning and non-attainment/maintenance areas.

Smart Growth: Development policies that aim to prevent urban sprawl and pollution, and reduce the profligate use of non-renewable fuels, particularly an excessive dependency on private cars in industrialized countries. (*source: Wikipedia, http://en.wikipedia.org/wiki/Smart_growth, August, 2004)*

Spatial Autocorrelation: The relationship(s) (correlation) between variables associated with two or more physical locations separated in space.

State-of-the-Practice: Methods, techniques and procedures that define how the majority of agencies are successfully conducting land use-emissions benefits studies.

Sustainable Living, Sustainability, Sustainable Development: Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. *(source: World Commission on Environment & Development. Our Common Future: The Bruntland Commission Report, 1987)*

APPENDIX A. DATA RESOURCES

The following is a listing of the research papers and reports available in electronic formats that are included on the accompanying CD-ROM. For a complete listing of documents used in the critical literature review, refer to Appendix B on the accompanying CD-ROM. Combined, these two sources provide a comprehensive review of the available information on the topic of land use, travel behavior, and emissions impacts.

Apogee/Haigler-Bailly, "The Effects of Urban Form on Travel and Emissions: A Review and Synthesis of the Literature." 1998.

Ilse De Bourdeaudhuj, James F. Sallis, Brian E. Saelens. "Environmental Correlates of Physical Activity in a Sample of Belgian Adults." The Science of Health Promotions, September/October 2003.

Charlotte/Mecklenburg Department of Transportation, "Air Quality Benefits of Brownfields Development: Methodology Report and Summary Results". Charlotte, NC. June 2003.

Clark, K.C.; Hoppen, S.; and Gaydos, L. "A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area." Department of Geology and Geography, Hunter College, The City University of New York Graduate School and University Center. Environment and Planning B: Planning and Design volume 24 (1997) pages 247 – 261.

Reid Ewing, Tom Schmid, Richard Killingsworth, Amy Slot, Stephen Raudenbush. "Relationship Between Urban Sprawl and Physical Activity, Obesity, and Morbidity." The Science of Health Promotions, September/October 2003.

Reid Ewing and Robert Cervero, "Travel and the Built Environment Synthesis". Transportation Research Record 1780 (2001); 87-122.

Jack Faucett Associates, "Background Information for Land Use SIP Policy," Prepared for United States Environmental Protection Agency Office of Mobile Sources Transportation and Market and Incentives Group. September 1998.

Sharon Feigon, David Hoyt, Lisa McNally, and Ryan Mooney-Bullock, "Travel Matters: Mitigating Climate Changes with Sustainable Surface Transportation." Transit Cooperative Research Program No. 93. 2003.

Christopher Frey, PhD, et al, "Emissions Reduction Through Better Traffic Management: An Empirical Evaluation Based Upon On-Road Measurements," North Carolina State University, 2001.

Howard Frumkin, "Urban Sprawl and Public Health," Public Health Records, May/June 2002.

Lawrence Frank, Brian Stone Jr., William Bachman, "Linking Land Use With Household Vehicle Emissions in the Central Puget Sound: Methodological Framework and Findings." Transportation Research Part D (2000); 173-196.

Steve French, William Bachman, Lawrence Frank, "Regional Land Use Database: Descriptive Analysis." Deliverable No. 8. Atlanta, Georgia. June 2001.

Georgia Institute of Technology: College of Architecture, "Regional Land Use Database: Land Use Measures." Deliverable No. 10. September 2002.

David Hartgen, Ph.D., "Highways and Sprawl in North Carolina". September 2003.

Amy Heling, "The Effect of Residential Accessibility to Employment on Men's and Women's Travel" Georgia.

Curtis Johnson, "Market Choices and Fair Prices: Research Suggests Surprising Answers to Regional Growth Dilemmas" Transportation and Regional Growth. January 2003.

J. Richard Kuzmyak, Richard Pratt, G. Bruce Douglas, Frank Spielberg, Transit Cooperative Research Program: Land Use And Site design: Traveler Response to Transportation System Changes. Washington D.C. 2003.

David Levinson, "Accessibility and the Journey to Work". November 1996.

Lincoln Institute of Land Policy, "Alternatives to Sprawl." Washington, D.C.: Lincoln Institute of Land Policy. 1995.

Kees Maat and Theo Arentze, "Variation of Activity Patterns with Features of the Spatial Context." May 2002.

Erica McArthur and Sara Hawkes, "Winning with Aces: How you Can Work Toward Active Community Environments." (North Carolina: The Department of Health and Human Services, June 2003), 1000, photocopied.

Ted Mondale and William Fulton, "Managing Metropolitan Growth: Reflections on the Twin Cities Experience." September 2003.

P.W. Newton, "Re-Shaping Cities for a More Sustainable Future Exploring the Link Between Urban Form, Air Quality, Energy and Greenhouse Gas Emissions". November 1997.

Peter Plumeau, "Noteworthy MPO Practices in Transportation-Land Use Planning Integration," Research Monograph No. 6. Wilbur Smith Associates for The Association of Metropolitan Planning Organizations. 2004.

Terry Parker, "The Land Use-Air Quality Linkage: How Land Use and Transportation Affects Air Quality" California Environmental Protection Agency Air Resources Board. 1997.

Steven E. Polzin, "The Relationship Between Land Use, Urban Form and Vehicle Miles of Travel: The State of Knowledge and Implications for Transportation Planning" Center for Urban Transportation Research, University of South Florida. March 2004

Protection Agency Office of Mobile Sources Transportation and Market and Incentives Group, Ann Arbor, Michigan. August 1997.

Jayanthi Rajamani, Chandra R. Bhat, Susan Hardy, Gerritt Knaap, and Yan Song, "Assessing the impact of urban form measures in non-work trip mode choice after controlling for demographic and level-of-service effects". August 2002.

Arlene Rosenbaum and Brett Koenig, "Evaluation of Modeling Tools for Assessing Land Use Policies and Strategies", Prepared for United States Environmental Protection Agency. 1997.

Ron Sands, "Pacific Northwest National Labor, USA: The Sixth AIM International Workshop" Tsukuba, Japan, 27-28. March 2001.

Paul Torrens, “How Land Use Transportation Models Work” (Centre for Advanced Spatial Analysis, University College London). April 2000.

Stephen A. Parker, “Traveler Response to Transportation System Changes: An Interim Introduction to the Handbook” Transit Cooperative Research Program No. 61. September 2003.

United States Department of Transportation, William Lyons, Scott Peterson, and Kimberly Noerager, Greenhouse Gas Reduction Through State and Local Transportation Planning. DOT-VNTSC-RSPA-03-02, September 2003.

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United States Environmental Protection Agency, A Technical Review of the Interaction between Land Use, Transportation, and Environmental Quality. EPA 231-R-01-002. January 2001.

United States Environmental Protection Agency, Travel and Environmental Implications of School Siting. EPA 231-R-03-004. October 2003.

United States Environmental Protection Agency, Characteristics and Performance of Regional Transportation Systems, EPA 213-R-04-011. January 2004.

United States Environmental Protection Agency, Comparing Methodologies to Assess Transportation and Air Quality Impacts of Brownfields an Infill Development, EPA420-R-97-007, Washington, D.C. August 2001.

United States Environmental Protection Agency, “Guidance on Applicable Methodologies to Account for the Benefits of Infill in SIPs and Conformity Determinations.” June 7, 2001.

United States Environmental Protection Agency and Criterion Planners and Engineers, “Smart Growth Index, A Sketch Tool For Community Planning: Indicator Dictionary”. October 2002.

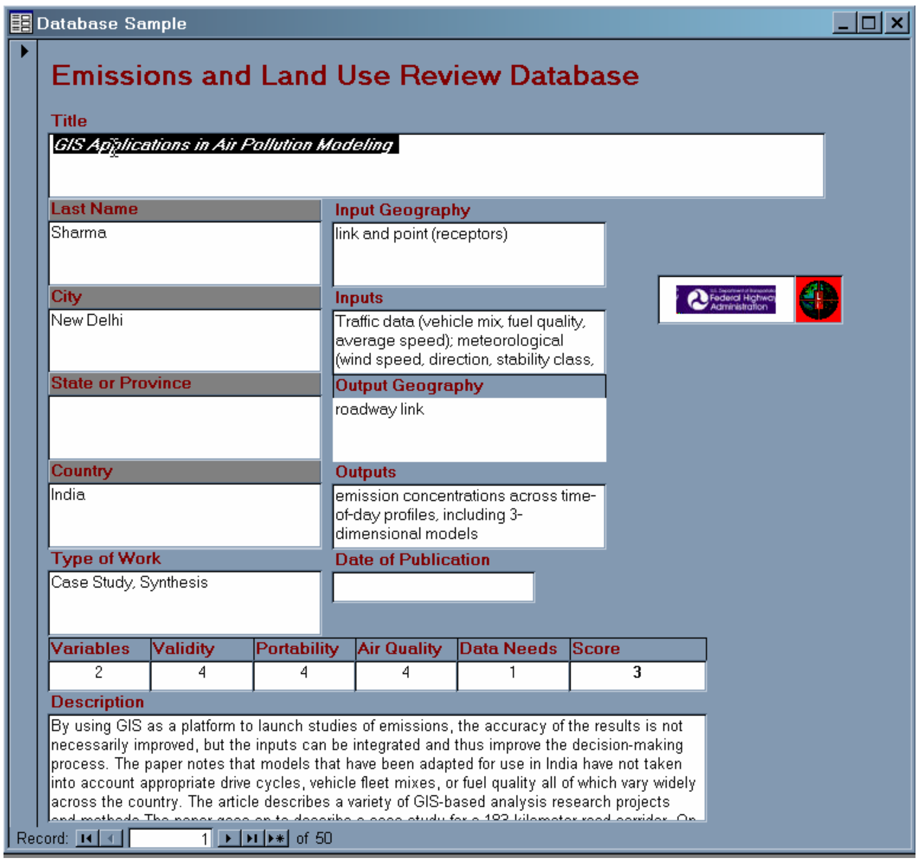
Bertil Vilhelmson, “Mobility Changes of People Living in Different Urban Areas of Sweden 1978-1997”. June 1999.

Gerard Walters, “Peak Hour Traffic Generation for Mixed Use Development Areas”. Reprinted from compendium of Technical Papers, Institute of Transportation Engineers, District 6 Regional Conference. July 1987.

APPENDIX B. ANNOTATED BIBLIOGRAPHY DATABASE

On the accompanying CD-ROM, the Research Team has created a Microsoft Access© database that contains information used during the critical review of each literature item considered during this project. The development of this database was essential to managing the large amounts of data and review information captured during the course of the project. Additional literature items can be added to this database, if desired.

Below is a screen capture of the actual database form that was approved by FHWA and developed by the Research Team.



Six rating factors were used to individually assess each literature item reviewed for this project. Each was assigned a 0-5 ranking based on the strength of how well each literature item addressed the variable. A "0" indicated that the particular variable was not applicable to that literature item. The rating factors used were:

Exogenous/Endogenous Variables. This category describes how comprehensively the research addresses variables that may affect the outcomes or conclusions contained in the article. For example, household income is an exogenous variable that affects travel behavior and should be controlled in studies of design elements.

Validity. Essentially, this category measures how well-constructed was the research. Validity also tests how well the conclusions match the data outputs from the research.

Portability. This category of measurement determines if the research can be used in other geographic locations with the same facility as it was applied in the particular case shown in the research. For example, those studies that looked at conditions that were peculiar to a specific geographic area received lower scores; those that drew their data from a larger, more diverse geographic area received higher scores. In a few of the out-of-country studies, some datasets would clearly not be readily available in a usable format in the U.S.

Air Quality. This measure ascertains how directly relevant the research is to the area of air quality. Many articles examined the relationships between travel behavior and land use (low score), but a few researchers went further by attempting to quantify the actual emissions changes from the land use scenario (higher score).

Data Needs. Not a measure of data quality, this category describes how demanding the data collection process would be if applied to another, similar case. Those studies that were data-intensive received a lower score, particularly those that required detailed investigations of travel diary data or large field data collection efforts.

Cost-Benefit. If the research attempted to measure how cost-effective a particular action was in the research, then it received a higher score in this category. There were very few articles that received non-zero scores in this category.

APPENDIX C. CASE STUDY SUMMARIES

The table below summarizes the data taken from the case studies and allows users to more readily determine which of the case studies is most appropriate in their circumstances. The left hand column of the table divides the case studies into site specific, corridor level, and regional level analyses. The second column rates the level of practice as fair, good, and better. The right hand column names the case study so that that the users can look directly for the case studies that are most beneficial for their situation.

Scale	Level of Practice	Credit Received	Sponsor	Strengths	Case Study Name
Site	Fair	TCM in GA SIP (no emissions credit received)	Private Sector	Proved Lower Emissions Over Conventional Development	Atlantic Steel (Atlanta, GA)
Region	Good	None	MPO	Technically Strong	Baltimore Metropolitan Council
Region	Good	None	MPO	Evaluates multiple land uses and transportation plans. Use of multiple performance measures and peer review process.	CAMPO
Region	Better	None	MPO	Technically Strong, Land Use Model	DRCOG (Denver, CO)
Region	Fair	None	MPO	Model for Entry-Level Practice	Mid-Region Council of Governments (Albuquerque, NM)
Region	Good	None	MPO	Evaluates Multiple Land and Transportation Plans	Lane COG (Eugene, Or)
Corridor	Fair	None	MPO	Recognized and Mitigated Local VMT Increases	MUMPO (Charlotte, NC)
Region	Good	None	MPO	Public Participation, Land Use Planning	SACOG (Sacramento, CA)
Region	Good	Plan Conformity	MPO	Done through Conformity Process	SANDAG (San Diego, CA)
Region	Good	None	MPO	Public Participation, Land Use Planning	Tri-County Planning Commission (Lansing, MI)
Site	Fair	SIP/CMAQ	Private Sector	Proved Lower Emissions Over Conventional Development	Woodlands Town Center (Houston-Galveston, TX)

Scale - for which the analysis was performed. This factor is intended to give users some indication of whether or not this particular case study matches the scale of analysis in which they are interested. There are case studies at three scales: site specific, corridor, and regional level. Note that there is some upward overlap between the scales so that a site scale analysis may include elements of corridor or regional analysis.

Level of Practice - is an indicator of how the case study compares to the others in its application of tools. Level of practice is characterized as good, better, or best.

Credit Received – indicates whether or not the project sponsor received formal emissions credit in either a state implementation plan or from the congestion mitigation air quality program.
Key Player - shows the driving party of the case study. While the key player may not have done most of the work they are the entity that is creating the desire to move forward on the project.
Strengths – indicates the notable features that can be cited as best practice for other, similar efforts.

Atlanta Regional Commission* (Atlanta, GA)

Context

In the Atlantic Steel case the Atlanta Regional Commission evaluated the potential emission change associated with locating a major development project in three different parts of the region. During 1998 the Atlanta region was in conformity lapse for ozone. During this lapse Jacoby Development Corporation sought to redevelop a 138-acre site near Atlanta's central business district at the interchange of I-75 and I-85 and across from 17th street. Because of the conformity lapse the 17th street bridge, connecting the development site with the transit station and providing access to the interstate could not be built unless the developer was granted flexibility under EPA's project XL provisions. The flexibility allowed the entire redevelopment to be considered a TCM. This included the location, transit linkage, site design, and other transportation elements. It also allowed an innovative approach to estimate the air quality benefits. The proposed development included approximately 17,500 jobs and approximately 6,000 people. Total growth for the City of Atlanta for the same time frame was 33,600 jobs and 18,200 people. Because the Atlantic Steel site was a downtown brownfields site, a group of stakeholders including the developer, Atlanta Regional Commission, USEPA, the Federal Highway Administration, Georgia Department of Environmental Protection, Georgia DOT, and local citizen groups used the opportunity to evaluate the benefits of the Atlantic Steel site as a brownfield re-development project.

Project Summary

The Atlantic Steel project included a multi-level evaluation of the proposed Atlantic Steel re-development project. The evaluation included comparisons of travel and emissions at both the regional and site levels, as well as local hot spot impacts. At the regional level the travel and emissions associated with the proposed project were compared with the travel and emissions that would result from adding the same development at three other around the Atlanta Metro Area. At the site level EPA analyzed the impacts of the different site designs. EPA found that the most regionally central, most pedestrian-friendly location and site design combinations, those at the Atlantic Steel location, produced the least VMT, emissions, and other environmental impacts.

Project Detail

The analysis of the Atlantic Steel site included regional and site specific analyses of trips and emissions. In the Atlantic Steel study the emissions effects of locating growth at one of four sites was evaluated. Because a no build or existing trends case were not included and the trip generation and distribution methodology was not clear, Atlantic Steel is not a complete template for supporting land use credit for either the SIP or a conformity determination. Although the proposal included accommodations for transit service, urban design guidelines, and performance monitoring, some aspects of the project such as increasing automobile accessibility and capacity packaged with the development; and the proposed presence of "big box" retailers on the site did not fit the traditional definition of smart growth.

* Note: While this case study has been used to show the use of the travel demand model and emissions model to determine the impacts of development on different locations within a growing urbanized area, areas should not consider this a model for TCMS. While portions of this project do meet the traditional TCM definition, the 17th Street bridge and freeway ramps would not qualify as a TCM without the Project XL designation.

The regional level analysis compares the travel and emissions resulting from placing the proposed development at the Atlantic Steel site and three other sites (one urban and two suburban) of approximately the same acreage. This analysis is in contrast to the other common practice of concentrating growth in a receiver area (or zone) while removing growth from widely dispersed donor areas. The regional emissions estimate was performed for VOC and NOx using the MOBILE model. Cold start emissions from each site were calculated separately for both VOC and NOx. A hot spot analysis for CO was also performed for the streets adjacent to the proposed Atlantic Steel site. The purpose of this analysis was to determine if the additional development and travel associated with the site would crate a localized violation of the CO standard. At the regional level the Atlantic Steel site produced less VMT and emissions than the other three sites. For the locations evaluated the proposed Atlantic Steel site resulted in estimated NOx emissions an average of 0.26 percent or 0.25 tons per day lower than the other sites. The proposed Atlantic Steel site resulted in estimated VOC emissions an average of 0.75 percent or 1.15 tons per day lower than the other sites.

In the site-specific analysis, the developer's original site design was compared with typical developments in the Atlanta area; a proposed new urbanist site design developed for EPA by Duany Plater-Zyberk & Company (DPZ); and revision of the original design that incorporated some of the DPZ design elements. The vehicle trips from the Atlanta Regional Commission travel mode were factored using elasticities to account for the increased diversity, varied design elements, and site density in the three site plans. All three of the proposed site plans resulted in lower estimated VMT and emissions compared to similar parcels in Atlanta.

From the report it is possible to infer the need for travel demand models that are sensitive to urban design factors and the need for emission models that can separately account for trip end emissions.

Comparative Description		
Project Timeframe	Start: 1998	End: 2000
Data Inputs	All typical travel demand model inputs plus GIS based data on similar sites in the region and relative estimates of the urban design factors such as street slope, diversity, density, and walkability. This study also used an extensive urban design effort that was very costly.	
Data Outputs	Person trips, vehicle trips, transit trips, VMT, and emissions at both regional and site level.	
Sensitivity Analysis	Yes, at regional and site level.	
Cost-Benefit Analysis	No	
Land Use Control Strategies	Included in Georgia SIP, but no emissions credits were taken, which is fairly standard approach for other TCMs from the Atlanta region and is not indicative of any specific feature of this project.	

Baltimore Metropolitan Council (Baltimore, MD)

Context

Within the context of Maryland's smart growth initiative Baltimore is estimating changes to trip generation and mode choice based on housing density. The agency has focused on the changes in trip-making associated with land use and travel behavior but does not seem to have evaluated the effect on emissions or to have done a sensitivity analysis.

Project Summary

Baltimore applies differential trip rates at two points in the travel demand modeling process and estimates travel and emissions based on this two-level screen. Trip generation and mode choice both include a land use intensity or density variable estimated based on the 1993 Household Travel Survey. Trip generation and mode choice are influenced by the area type in which they occur.

Project Detail

In the trip generation portion of the model home based trip productions are estimated based on the number of household members and the average number of vehicles per household. Trip productions are then split into motorized and non-motorized parts using a logit model that includes a land use variable. A similar process is used for non-home based trips except that trip productions are estimated, by traffic analysis zone, and are allocated differently. The allocation uses a regression equation to synthesize trip origins and destinations. The 2000 model also includes a commercial vehicle (truck) model that estimates trip productions and attractions for commercial vehicles based on type of employment (retail, non-retail, and household) and the land use variable.

In addition to the work done on the 2000 model BMC participated in the add-on portion of the National Personal Transportation Survey and has new data on trip generation and mode choice. They are currently modifying their trip generation and mode choice modules to reflect this data. The revised models will include urban design level data such as sidewalks, street width, and street slope. This is in addition the current area type variable.

Comparative Description		
Project Timeframe	Start: 1999	End: 2003
Data Inputs	All standard model parameters plus land use classification code.	
Data Outputs	All standard model outputs.	
Sensitivity Analysis	The model was compared to census data in the validation/evaluation process, but no formal sensitivity analysis was done.	
Cost-Benefit Analysis	None	
Land Use Control Strategies	None	

Capital Area Metropolitan Planning Organization (Raleigh, NC)

Context In the Capital Area Metropolitan Planning Organization faced with multiple challenges while preparing the update of its long range transportation plan. The Research Triangle Area is a rapidly growing area. It is facing many of the challenges associated with rapid growth including suburbanization, habitat loss, and other quality of life issues. Among these issues was the recognition that USEPA was preparing to designate nonattainment areas under the eight-hour ozone standard. The MPO staff were seeking to proactively assess several land use and transportation plans that could meet transportation needs while maintaining the region's quality of life.

Project Summary
CAMPO staff used the newly developed Triangle Regional Model to evaluate five transportation options and five land use plans. The evaluation process was a 'hill climbing' technique in which all the transportation plans were evaluated using one land use and all the land uses were evaluated using the same transportation plan. The process also included a peer review panel that considered mobility, reliability, safety, water quality, open space environmental justice, economics, and air quality. Data management and evaluation were accomplished using spreadsheets.

Project Detail
As noted CAMPO evaluated five land use plans (mixed-use suburban, corridors and nodes, flexible growth boundary, adequate public facilities, and neotraditional/infill) and five transportation systems (current trends, intensive highway, managed lanes/rail, current trends plus rail, and intensive management/rail). A full estimate of emissions was prepared for the mixed-use suburban land use scenario and all five transportation systems. Using the current trend scenario as a baseline CO emissions changes range from a 3.4% increase to a 7.4% increase; VOC emission changes range from a 0.2% decrease (intensive management/rail) to a 6.4% increase (intensive highway); and NOx emissions changes range from an 18.5% decrease (intensive management/rail) to a 6.9% increase (managed lanes/rail).

This case is notable for the information given to the peer review panel. This information included emissions, travel times to key destinations, open space used, acres of wetlands affected, and historic sites near new construction.

Comparative Description		
Project Timeframe	Start: 1999	End: 2001
Data Inputs	All standard model inputs plus multiple land uses and transportation networks.	
Data Outputs	Standard transportation model outputs VMT, travel times, congested links.	
Sensitivity Analysis	Yes	
Cost-Benefit Analysis	No	
Land Use Control Strategies	None adopted.	

Denver Regional Council of Governments (Denver, CO)

Context

The Denver Regional Council of Governments was interested in quantifying the benefits and costs of promoting infill development in the Denver Region. Historically the DRCOG board had adopted an urban growth boundary. This study allowed DRCOG to evaluate the effect of different land uses inside the urban growth boundary. The DRCOG cooperated with the Environmental Protection Agency in evaluating the regional effects of changed land uses in the Denver Area. The study format benefited DRCOG by providing funding for this analysis and for improvements to their travel demand model.

Project Summary

In this project DRCOG staff evaluated three different land use patterns inside the urban growth boundary. The land uses evaluated were a continuation of lower density development throughout the urban growth area, concentrating growth in forty centers inside the growth area, and further concentrating growth in the centers inside the growth boundary. The changes in trip making and emissions were consistent with work performed by Charlotte North Carolina and Boston Massachuttes who also participated in this effort with EPA.

Project Detail

The DRCOG evaluated three land use proposals along while maintain a consistent transportation network. The total population and employment were kept the same, but the location of both population and employment were varied according to preset patterns. In all three scenarios the COG allocated 60 percent of growth using their land use model. In scenario A the remaining 40 percent was allocated to the urban fringe (outside the existing developed area), in scenario B the remaining 40 percent was allocated to thirty one activity centers (primarily in the older urbanized area), and in scenario C the remaining 40 percent of growth was allocated to ten large urban centers (primarily in the existing urbanized area).

Vehicle miles of travel ranged from a high of 92,308,000 in scenario A to a low of 88,966,000 in scenario C. Under the B and C scenarios motor vehicle emissions, and congested vehicle hours of travel drop while congested speed and transit shares both rise. Under scenario C VOC emissions drop by 4 percent, CO emissions by 3.6 percent, and NOx emissions by 3.7 percent or approximately 1,400 kg, 36,100 kg, and 1,100 kg respectively.

Mr. May noted the following needs in performing this type work: (1) real world data that quantifies the changes in trip making associated with changes to land use, (2) work on the internal capture rate of trips in mixed use developments, (3) work showing how much of the land use effect is 'lost' in traditional regional travel demand models.

Comparative Description		
Project Timeframe	Start: 2000	End: 2003
Data Inputs	In addition to the usual travel model inputs this work requires multiple land use scnearios based on varying land use policies. The work may also require that the production and attraction balancing in the gravity model be re-evaluated.	
Data Outputs	VMT, Congested VMT, Congested Speed, Transit Share, Motor Vehicle Emissions (VOC, CO, NOx)	
Sensitivity Analysis	Yes: three scenarios were compared.	
Cost-Benefit Analysis	No	
Land Use Control Strategies	Evaluated three land use strategies but did not implement controls.	

Mid-Region Council of Governments (Albuquerque, NM)

Context
The work on land use alternatives was done as a preliminary step in revising the MPO's long-range transportation plan. In the previous effort, the land use was fixed early in the planning process and several groups attacked the resulting plan because multiple land use patterns were not evaluated.

Project Summary
The MPO evaluated the effect of four growth patterns as part of their LRTP but did not vary density. The changes performed made a very small change in emissions of CO. The emissions analysis was based on network level statitics including VMT, and VHT. The modeling platform for this effort was EMME2.

Project Detail
Early in the long-range transportation plan update the MPO evaluated four possible land uses for their effect on travel and emissions. The land use patterns evaluated included a trend land use, a compact land use, a significantly sprawling land use, and a concentration of new development on large tracts of available land.

The evaluation discovered changes in travel, travel time, and emissions on the order of one percent between land use patterns. In part this may be due to the limited transit options available in Albuquerque to support higher density land use alternatives. While the model includes a predictive mode choice step only a fixed route bus mode was available at this point. An HOV mode has since been added to the model. The estimated change in CO was approximately 1 percent.

The project found that in the current model stream, whereby the travel model is disconnected from the emissions model, was not sensitive to changes on the scale that the land use alternatives presented. As a partial result of this exercise, the MPO has embarked on an ambitious model improvement program that involves creating a custom model in a GIS environment. This model allows much broader analysis of the data than did the earlier model.

Comparative Description		
Project Timeframe	Start: September 2002	End: January 2003
Data Inputs	All standard travel model inputs	
Data Outputs	All standard travel model outputs	
Sensitivity Analysis	No	
Cost-Benefit Analysis	No	
Land Use Control Strategies	Evaluated four land use patterns but no additional controls.	

Lane Council of Governments (Eugene, OR)

Context
Oregon's transportation planning rule (TPR) requires all cities to consider land uses when developing transportation plans. The City of Eugene Oregon has just completed this process for their current long range transportation plan.

Project Summary
The Eugene MPO has evaluated a series of integrated land use and transportation plans. The land use plans were selected to represent a range of variability based upon current policies. These policies ranged from no changes to extreme changes. For each land use plan a transportation plan was developed that supported that land use plan. Taken together the land use and transportation plans provided elected officials with a range of options that they could modify to meet the needs of the region.

Project Detail
Eugene evaluated a current trends scenario and five alternative plan concepts. In Eugene both land use measures and transportation measures were evaluated. The land use measures included a continuation of the existing land use plan. In this scenario growth is allocated evenly to developable land within the urban growth boundary. The other four land use scnearios are variations of a nodal development plan. In the nodal development concept a mix of land uses are developed in centers that support 1/4 mile walks to their commercial core and transit stops. The four nodal concepts are: development of nodes in all potential areas, development of nodes in new growth areas, development of nodes only in central areas, and development of nodes only along major transit (bus) routes.

In conjunction with the five land use plans, three transit systems and two highway systems were tested. The base transit system is a small expansion of the existing bus system intended to keep the bus system comparable with highway improvements. The enhanced transit system adds ten minute headways on major buss routes and twenty minute headways on service to nodal development areas. The bus rapid transit system builds upon the two lower service levels and provides eight radial routes and a circumferential route on exclusive right-of-way. In addition to the transit systems the MPO evaluated two highway systems (an existing plus committed system and an existing, committed, and planned network).

The results of the analysis described above are reported in a summary table comparing each of the alternatives evaluated with the existing situation and the base case with ten objectives listed. The six objectives are to minimize daily fuel use, minimize congested miles of travel, reduce per capita VMT, increase the number of person trips shorter than one mile, change the mode choice away from single occupant vehicle, and decrease motor vehicle emissions. Lane COG estimated emission reductions only for CO. In the four scenarios evaluated the change in CO emissions ranged from 4.5 percent for the scenario empahsizing land use changes to 26.6 percent for the scenario that meets Oregon's transportation planning goals. The CO reductions are 592 kg for the land use only scneario and 3650 kg for the planning goal scneario.

In staff's view the most difficult aspects of the process are political. Elected officials have differing opinions on planning and visions for the future. The most significant technical issue was a predictive model that could be used to evaluate the probable results of implementing a suite of land use, transportation, and pricing policies.

Comparative Description		
Project Timeframe	Start: 1997	End: 2001
Data Inputs	All standard inputs for travel demand models and emission models. Multiple sets of land use.	
Data Outputs	Standard travel demand model outputs and emission model outputs that must then be formatted for easy understanding by elected officials.	
Sensitivity Analysis	Yes	
Cost-Benefit Analysis	No	
Land Use Control Strategies	No	

Mecklenburg-Union Metropolitan Planning Organization (Charlotte, NC)

Context

The City of Charlotte participated in a USEPA grant program intended to assess the transportation and emissions effect of non-conventional development in urban areas. In Charlotte's case the original intent was to evaluate the effect of redeveloping existing industrial sites within the city limits.

Project Summary

In the brownfields re-development project MUMPO assessed the air quality benefit of concentrating additional development along proposed mass transit corridors within the City of Charlotte. Approximately 16,500 households were moved from the suburban fringe of Mecklenburg County into a proposed transit corridor south of Charlotte's city center. Travel and emissions were estimated for two land use scenarios and three transportation scenarios. Emissions and travel are both lower in the scenarios that redistribute growth into the corridor served by transit.

Project Detail

The MUMPO evaluated the emissions and travel effect of redistributing households and employment from the suburban fringe of Charlotte into a proposed light rail corridor south of the city center. MUMPO used their existing four-step travel demand model and MOBILE 6 to evaluate the travel and emissions effect of changes in land use and transportation networks caused by redeveloping brownfields near the proposed outh light rail corridor.

In the evaluation the land use in thirty-six traffic analysis zones along the LRT corridor were adjusted upward to reflect an additional 16,500 households and an additional 10,500 jobs. These jobs were taken from wedge areas outside the center city area so that the total housing and employment in Mecklenburg County was constant. Wedge areas are suburban fringe areas between proposed transit corridors for Mecklenburg County. The integrated land-use and transportation plan seeks to limit growth in wedge areas. The revised scenarios ealuated show emission savings of 1.3% for NOx, 1.6% for VOC, and 1.4% for CO which implies approximately 90 kg, 110 kg, and 1900 kg of daily emission reductions respectively.

The project contact noted no significant process or tool needs. He did note that using geographic information systems to analyze and reallocate data made the process much easier. In addition the MPO developed spreadsheet templates to manipulate MOBILE 6 output.

Comparative Description		
Project Timeframe	Start: August 2002	End: September 2003
Data Inputs	Standard travel model parameters plus hand adjustments to socio-economic data for specific analysis zones and multiple transportation networks.	
Data Outputs	Trips, VMT, and emissions of VOC, NOx, and CO in kg.	
Sensitivity Analysis	Yes	
Cost-Benefit Analysis	No	
Land Use Control Strategies	No	

Sacramento Area Council of Governments (Sacramento, CA)

Context
The 2050 Blueprint Study is an outgrowth of a desire by the SACOG policy board to improve the integration of land use and transportation and to address perceived regional problems in a regional manner. There was some interest in improving the connection between land use planning and transportation planning beginning with the 1999-2001 update of the Long Range Transportation Plan but neither staff nor tools were available.

Project Summary
The 2050 Regional Blueprint is a 2-1/2 year integrated land use and transportation study for the Sacramento Council of Governments. Beginning in 2002 the study covered six counties in the Sacremento region and used the PLACES3 GIS package as a scenario builder. The 2050 Regional Blueprint is a multi-level land use and transportation study the evaluates the interaction of land use and transportation at the regional, county, and municipal levels. In each case both a trend land use and a smart growth land use are evaluated for a number of factors.

Project Detail
The 2050 Blueprint staff believes there are several things that can be done overall to improve the state of practice in integrating land use and transportation models. Keys to this effort are fully integrated travel and land use models. Important features of the integrated modeling package are tour based travel demand models and economically based land use models. In addition to the needed improvements to the travel and land use models the 2050 staff believe that emissions models should have sufficiently long time horizons to reasonably evaluate transportation scenarios more than thirty years into the future.

The 'Regional Blueprint' evaluated four land use scenarios: (A) existing trends, (B) growth focused at the edge of the region, (C) growth focused on the inner ring of suburbs, and (D) growth focused on the center of the region. Options B, C, and D reduce CO2 and fine particulates by 88 percent, 86, percent, and 85 percents respectively from Option A.

Comparative Description		
Project Timeframe	Start: 2002	End: 2004 (Final Phase)
Data Inputs	In addition to the usual travel model inputs this work requires multiple land use scnearios based on varying land use policies. The work was done in California so the emission model used was the EMFAC/BURDEN series.	
Data Outputs	Data outputs are vehicle miles of travel by mode, hours of travel, and speed, raw and adjusted link volumes, and emissions of CO, NOx, and ROG (aka VOC).	
Sensitivity Analysis	Yes	
Cost-Benefit Analysis	No	
Land Use Control Strategies	The transportation and emission effects of multiple land uses were evaluated.	

San Diego Association of Governments (San Diego, CA)

Context

This work was performed in the context of developing a long-range transportation plan, transportation conformity determination, and evaluating CMAQ projects. They have not done land use work down to the emissions estimation level that has gotten approval as a control measure. The agency's work is documented in the the 2020 Long-Range Transportation Plan and conformity appendix.

Project Summary

SANDAG has evaluated the travel and emissions effect of four different land-use scenarios. The four land-use scenarios are: (A) continuing existing policies, (B) locating the highest densities within 1000' of transit stations, (C) option B plus assuming that all future residential development occurs at that highest density permitted in the general plans and (D) option C plus a cap on residential development in unincorporated areas.

Project Detail

SANDAG uses a standard four-step travel demand model in the TRANPLAN platform. The model includes two iterations of congested speeds back into the trip distribution phase of the model to assure that congestion is correctly accounted for. SANDAG estimated emissions using EMFAC/Burden as required in California.

In the 2000 update of their long range transportation plan SANDAG has evaluated the travel and emissions effect of four different land-use scenarios. The four land-use scenarios are: (A) continuing existing policies, (B) locating the highest densities within 1000' of transit stations, (C) option B plus assuming that all future residential development occurs at that highest density permitted in the general plans and (D) option C plus a cap on residential development in unincorporated area. In addition to the land use measures studied the emissions analysis included the effects of new heavy duty diesel controls, an enhanced inspection and maintenance program, Federal and California 'M' measures for NOx and reactive organic compounds (aka hydrocarbons or VOC).

Implementing option D would result in emission reductions of 14.2%, 15.4%, and 11.2% for carbon monoxide, hydrocarbons (ROG), and oxides of nitrogen respectively relative to Option 1 or 50 kg, 6 kg, and 12 kg respectively.

The interagency consultation process for SANDAG includes SANDAG itself, APCD, Caltrans, CARB, USEPA, and USDOT. The interagency consultation process is strength of this study.

Comparative Description		
Project Timeframe	Start:	End: 2000
Data Inputs	In addition to the usual travel model inputs this work requires multiple land use scenarios based on varying land use policies. The work was done in California so the emission model used was the EMFAC/BURDEN series.	
Data Outputs	Data outputs are vehicle miles of travel by mode, hours of travel,	

	and speed, raw and adjusted link volumes, and emissions of CO, NOx, and ROG (aka VOC).
Sensitivity Analysis	The analysis may be considered a sensitivity analysis or a solution space.
Cost-Benefit Analysis	No
Land Use Control Strategies	No transportation control measures have been included in the SIP.

Tri-County Regional Planning Commission (Lansing, Mi)

Context

The Tri-County Regional Planning Commission is the Metropolitan Planning Organization of Lansing Michigan. It consists of 78 units of government of whom 50 have direct land use authority. The TCRCP is growing steadily and is consuming agricultural land at four times the rate of population growth. Development is occurring along existing arterials that are becoming stripped out. Local officials are concerned with preservation of open space and the cost of maintaining transportation and other infrastructure. Until recently the Tri-County area was attainment for all pollutants. It was declared nonattainment under the eight-hour ozone standard in April of 2004.

Project Summary

The project is a broadly scoped effort to implement performance based planning. The effort included up front stakeholder involvement to develop consensus, development of multiple land use scenarios, and evaluations of the impact on transportation, future budgets, and air quality. The project has been accepted by the many local governments with all 78 expected to approve the plan by fall of 2004. The plan is currently in the early phases of implementation.

Project Detail

The project involved multiple phases including stakeholder involvement, land use modeling, transportation modeling, and evaluation of consequences. Several of these efforts were prepared in parallel.

The stakeholder involvement process included five focus groups for citizens, interest groups and decision-makers. At the end of the stakeholder process over eighty percent of the particpants agreed with the vision of community developed in the stakeholder process.

The formal analysis included the evaluation of four land-use and transportration scenarios. The scenarios are a trend land use, a build-out of the trend, a 'wise growth' scenario, and a build out of the 'wise growth' scenario. For the land use component the evaluation criteria included population accessibility to public services (parks, transit, sewer) and public expenditures on policing, fire protection, and EMS services. The transportation component was evaluated on transit ridership, deficient and near deficient VMT and VHT, and hours of delay. Emissions of ozone precursors and CO were also evaluated. At the 2025 design year emissions for all pollutant from the base case and the 'wise growth' case are essentially equal. In a build-out analysis that included an additional 912,500 people in the Tri-County area the 'wise growth' scenario reduced VOC emissions by 22 percent, CO emissions by 29.5 percent, and NOx emissions by 25% or approximately 11,130 kg, 72,500 kg, and 19,200 kg respectively.

At each phase of the evaluation the focus groups were asked to select their preferred alternative. Approximately 80 percent of respondents preferred the wise growth alternative.

The Tri-County alternative future project has entered the implementation phase with several municipalities adopting the land use maps and policies recommended in the project.

Comparative Description		
Project Timeframe	Start: 1999	End: 2004
Data Inputs	Data inputs included existing and proposed land use, future land use and zoning rules. Travel modeling and emission modeling inputs are standard for the area. MOBILE 6 defaults may be used in this analysis.	
Data Outputs	Travel, Travel by mode, housing density/location, emissions, public sector costs, and motor vehicle emissions.	
Sensitivity Analysis	No	
Cost-Benefit Analysis	A Cost benefit analysis was used in conjunction with other factors to rank alternative futures.	
Land Use Control Strategies	A land use policy map that is used as part of project and site selection criteria. Commitments to co-locate or maximize the utility of public facitlities. Transportation projects are screened against the area's land use map.	

Woodlands Town Center (Houston-Galveston, TX)

Context

The Woodlands Town Center is a long term 'greenfield' development project with multiple public and private partners. The goal is to provide a large mixed use development north of Houston Texas (Montgomery County). The analysis of land use and emission was undertaken, in part, in an effort to justify funding of an integral trolley line and water taxi for congestion mitigation air quality funding. The Woodlands Town Center is a long term project that began in 1985 and has only recently come to fruition. Partners include the Woodlands Operating Company, The Brazos Transit District, The Goodman Corporation, Federal Transit Administration, Federal Highway Administration, Texas DOT, Woodlands Road Utility district, and Town Center Public Improvement District. The project has received both CMAQ funding and a STEP grant.

Project Summary

The Houston Region is expected to grow from a population of 1,000,000 to a population of 1,500,000 during the life of the project. The Woodlands development itself expects a build out population of 125,000 with 72,000 jobs and 2,750 employers. The private developers intend to plan for growth today to avoid remedial infrastructure work later; de-emphasize the automobile as the mode of transportation; provide alternative modes of transportation to address transportation needs; and link major destinations along the corridor to adjacent development.

The benefits of this approach are ehanced mobility, reduced parking ratios, reduced air pollution, increased land values, economic growth, and a viable downtown.

Project Detail

Trips associated with the Woodlands Town Center were estimated by construction phase using the ITE Trip Generation Manual. Once the land use was turned into trips design elements and the transit system were sized to accommodate a high percentage of the internal trips. A trolley and water taxi system was sized to capture both peak period trips and event traffic from hotels and a convention center. The site design anticipates eliminating 6,500 vehicle trips a day along with 13,000 kg of VOC, 4,800 kg of NOx, and 102,000 kg of CO per day.

A key need for this type project is accepted methodologies to evaluate the transportation and emissions differences between urban and suburban development patterns. Both travels model and the emission models are scaled to regional level analysis.

Comparative Description		
Project Timeframe	Start: 1989	End: 2000
Data Inputs	Site plan and parcel level land use data.	
Data Outputs	Annual trips, daily trips, transit passengers, VMT savings, emissions savings, and energy savings.	
Sensitivity Analysis	No	
Cost-Benefit Analysis	No	
Land Use Control Strategies	Yes, included in the Texas SIP	

APPENDIX D. LAND USE CHARACTERISTICS AND TRAVEL VARIABLE ELASTICITIES

Explanation of Elasticity. Elasticity is a measure of the responsiveness of one (dependent) variable to changes in another (independent) variable. Elasticity is a popular method of looking at these interdependent variable changes since the elasticity is measured in percentage terms, thus negating the need to compare items in the same units of measure (dollars per ton or trips per land use density, for example). In transportation the most often used elasticities are demand elasticities[11]. This describes how the *demand* for travel changes as the *price* of travel changes. However, researchers have calculated the elasticity for many variables. While some transportation researchers champion the use of elasticities to evaluate the potential for changes in trip making that result from changes in urban form, others believe that elasticity variables are surrogates for unknown relationships between urban form and transportation.

Elasticity is readily calculated as:

$$\text{Elasticity} = (\Delta Y/\Delta X) * X/Y$$

Note that the presence of both the change in variables (ΔY and ΔX) as well as the absolute value of the variables themselves are being considered simultaneously in this equation. Hence, the elasticity can, and usually does, change as the value of X and Y change. In other words, the elasticity can change at different points on the curve representing the supply or demand of an item. Where there are two goods that are complements to each other, the elasticity will be negative, such as the relationship between price of fuel and gas-guzzling cars. When the price of fuel goes up, the demand for cars with low fuel efficiencies goes down. For items that are substitutes for one another, the elasticity relationship is positive. This is the case for margarine and butter, wool and cotton, and so forth.

Values of elasticity greater than 1.0 are called *relatively elastic*, meaning that small percentage changes in the independent variable cause larger percent changes in the dependent variable. Conversely, values of elasticity less than one are called *relatively inelastic*. That is, percentage changes in the independent variable cause relatively smaller changes in the value of the dependent variable. In those rare instances where a change in one variable exactly equals the change in another variable (elasticity of 1.0), the relationship is called *unit elasticity*. Those familiar with elasticity will notice that transportation-related elasticities are typically relatively inelastic: a one percent change in the independent variable causes less than a one percent change in the dependent variable.

While some researchers find elasticities useful others argue that elasticities do not represent meaningful relationships. The thrust of the argument is that land use density is confounded with other key variables such as sidewalks, local design factors, accessibility, or land use mix. These researchers argue that there are threshold values that must be attained before accessibility, density, design factors, or diversity cause measurable changes. This makes the

[11] www.mintercreek.com accessed August 9, 2004.

elasticity relationship non-smooth, with sudden rises according to synergistic effects of multiple variables.

Using Elasticity. Elasticity measures can provide useful insights into the likely travel-related responses to changes in land use patterns. However, their best use may be in broadly assessing the direction and possible magnitude of changes. The explanatory power of elasticity as it relates to changes in travel is fairly weak with most values being less than -0.1 (that is, a 10% change in the degree of diversity in an area, for example, produces a 1% change in trip-making behavior). The analyst should consider the following general guidance when using elasticity to measure effects.

1. Consider the interaction between categories that either reinforce or dampen the elasticity relationship.
2. Accessibility has the strongest effect in most of the research dealing with the subject and should always be considered.
3. The three D's (Density, Diversity, and Design) have relatively small effects individually, particularly if there is little support for alternative modes of travel.
4. Unless density is above 7-10 dwelling units per acre it is unlikely that the other D's will have any effect, even in combination.

Selecting Elasticity. The tables on the following pages summarize the elasticities associated with four categories: regional accessibility, local density, local design, and local diversity. Most of these values are summarized from Ewing and Cervero's "Transportation and the Built Environment – Synthesis". The top row of each table shows a typical elasticity for vehicle trips and vehicle miles of travel. *While the typical elasticity shown for each category is probably a good beginning point, the user should carefully consider whether or not the proposed changes are in a range of the independent variable that shows sensitivity.* For example, doubling the housing density from two to four units per acre is unlikely to cause a measurable change in transit use. However, above seven dwelling units per acre there is a measurable change in transit use as density increases.

It is also important to reemphasize that the broad categories in the tables below are interrelated, and as such changes in one of the categories may not be effective without concurrent changes in another of the broad categories. For example, adding sidewalks without changing land use mix will not necessarily create more walking trips.

Regional Accessibility Measures. Regional accessibility is typically a measure of the number of jobs available within a certain distance or time. If time is the measure it is often set at the average or median amount of time required for people within a study area to reach their jobs from home. Measuring outward from the study area in travel time increments can define a commuteshed, which is an area or buffer describing a travel time isochrones.

Network connectivity measures are also included in this category. More highly connected networks tend to offer more route choice and greater accessibility. There is some evidence that highly connected networks, as measured by the percentage of four-way intersections, reduce the total amount of congested travel although possibly not the total amount of travel. The mechanism for this effect seems to be the creation of more, and better direct, connections between origin and destination.

Regional Accessibility		
Variable Description	**Elasticity**	
Typical Value	Trips N/A	VMT -0.20
Reported Values		
Regional Accessibility	VMT -0.34	
	VMT (non-work) -0.35	
	VMT -0.31	
	VMT -0.04	
	VMT -0.15	
Regional Accessibility to Jobs	Vehicle Trips 0.13; -0.36	
	VMT -0.29; -0.31	
Fraction of 4-way intersections	VMT -0.09	
Employment Accessibility by Transit	VMT -0.06	
Jobs within 5 km	VMT -0.05	
Intersections /road-km	VMT -0.04	

Local Density Measures. Local density is one of the more common measures used to assess the number of trips, vehicle trips, transit trips, and vehicle miles of travel associated with an area. Researchers have speculated on whether density alone accounts for changes in trip making as density increases, or whether density is simply the most readily observable component of a group of features that vehicle travel albeit inducing more total trips . Regardless density is one of the easier urban form variables to observe, understand, and explain and so is commonly used as the explanatory variable.

The threshold value at which density seems to have a meaningful effect upon VMT, or trips, is somewhere probably between 6,000 and 7,000 persons per square mile (7-10 dwelling units per acre). At that point the doubling of land use/development density seems to reduce new VMT by as much as 40 percent.

Local Design Measures. The term local design measures accounts for those local scale design features such as sidewalks or building orientation that can subtly influence a person's desire to walk or bicycle. Local design features affect the way people perceive walking, bicycling, and transit as travel choice. Local design features can work one of two ways. A person may choose to walk to a closer location or may choose to make a walking trip that would not otherwise occur. A note of caution, sidewalks alone do not create a viable pedestrian environment. Jamboree Road in Irvine, California is a six-lane arterial street with ten-foot sidewalks on both sides and little pedestrian traffic. Notably there are few desirable destinations connecting directly to the sidewalks as most of the adjacent properties belong to gated communities. Conversely, the streets on nearby Balboa Island teem with pedestrian, bicycle, and automobile traffic. Without higher density (over four dwelling units per acre) and diverse land use it is unlikely that local design measures have much effect on travel patterns and behaviors.

Local Density		
Variable Description	**Elasticity**	
Typical Value	Trips -0.05	VMT -0.05
Reported Values		
Net Density	Vehicle Trips -0.07	
Overall Density	Vehicle Trips -0.03	
	VMT -0.05	
Employment Density	Vehicle Trips -0.002	
	Vehicle Trips(work) -0.04	
	Vehicle Trips (non-work) -0.04	
	VMT -0.03; -0.09	
Population Density	Vehicle Trips(work) -0.05	
	Vehicle Trips (non-work) -0.11	
	Vehicle Trips -0.05; -0.14; -0.013	
	VMT -0.16; -0.09; -0.07	
Business Density	Vehicle Trips (non-work) -0.03	
Zonal Density	VMT -0.06	

Design Measures		
Variable Description	**Elasticity**	
Typical Value	Trips -0.03	VMT -0.03
Reported Values		
Presence of Sidewalks	VMT -0.14	
Pedestrian Environment Factor	VMT -0.19	
% Buildings Built before 1951	VMT -0.06	

Local Diversity Measures. Diversity measures are measures of the variability of land uses within a given area. As land use becomes more diverse (*i.e.,* more different types of land use closer together) trips by vehicle will tend to decrease as will VMT. Essentially these measures try to assess how closely jobs, or retail, and housing balance within a local area.

Entropy measures deserve additional explanation because entropy is not a commonly used, or understood. Entropy is a measure of the homogeneity of an area. The entropy variable is an index ranging from 0 (homogeneity) to 1 (maximal heterogeneity) that is sometimes used to define "degree of land use mix". A high degree of uniformity (0) describes single use settings while maximum entropy (1) a high level of uniformity (equality among land use categories) denotes high mix.

Diversity Measures		
Variable Description	**Elasticity**	
Typical Value	Trips -0.03	VMT -0.05
Reported Values		
%non-residential within 300’	Vehicle trips(work) -0.005 VMT – 0.032	
Fraction of retail within ¼-mile	Vehicle trips -0.08	
Fraction of vertical mixed use	VMT -0.07	
Jobs/Population Balance	VMT -0.09	
Land Use Mix (entropy measure)	Vehicle Trips (work) -0.12	
Land Use Balance (entropy measure)	VMT -0.10; -0.11	
Land Use Balance (dissimilarity measure)	VMT -0.10	
Proximity to Grocery	VMT -0.09	

Other Useful Elasticities. The elasticities presented in the previous tables describe possible relationships between land use and travel characteristics. Historically, most work on the elasticity of travel has been related either directly or indirectly to the cost of travel. For example, the elasticity of transit use with respect to fares or the elasticity of vehicle miles of travel with respect to lane miles. The following table presents some elasticity results for vehicle miles of travel and transit ridership as compared to capacity and demand variables. While not to be interpreted as additive, these relationships may enhance or dampen the effects of land use variables.

Relationship	Elasticity
Vehicle Miles of Travel and Lane Miles	0.2 – 0.6[12] 0.5 – 0.9[13]
Vehicle Miles of Travel and Travel Time[14]	-0.3 – -0.5
Transit Ridership and Transit Service[15]	0.5 – 1.1
Transit Ridership and Regional Employment[16]	~0.25
Transit Ridership and Vehicle Miles of Service[17]	~0.71

[12] Lewis M. Fulton, Robert b. Noland, Daniel J. Meszler, John v. Thomas, "A Statistical Analysis of Induced Travel Effects in the U.S. Mid-Atlantic Region. 79th Annual Meeting of the Transportation Research Board, Washington, DC, January 2000.
[13]Norman L. Marshall, Resource Systems Group Incorporated., "The Need to Account for the Effects of Induced Demand to Support Reliable Travel Demand and VMT Estimates for Metropolitan Planning, Project Need and Alternatives Analysis and Conformity." September 2000
[14] Ibid.
[15] Victoria Transportation Policy Institute, *Online TDM Encyclopedia – Transportation Elasticities,* Accessed August 17, 2004.
[16] Ibid.
[17] Ibid.