

California Smart-Growth Trip Generation Rates Study

Final Report

Appendix B

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Appendix “B”

Annotated Literature Review of Land Use-Transportation Relationships

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This document builds on an annotated literature review initially prepared in 2010 by Susan Handy, Richard Lee, and Rachel Maiss (UC Davis Institute of Transportation Studies) for the Caltrans-funded “Trip-Generation Rates Method for Smart Growth Land Uses in California” project.

During 2011, Jerry Walters and Richard Lee (of Fehr & Peers Consultants) augmented this review with additional literature relevant to another Caltrans-funded project “Improved Data and Tools for Integrated Land Use-Transportation Planning in California” project.

Terry Parker, Caltrans’ HQ project manager for both studies, provided input and review of both phases.

A. Overview

This literature review provides an annotated synopsis of studies produced by the transportation research and practitioner communities on relationships between the characteristics of the built environment and the generation of travel demand. It also identifies prominent tools used by planners and engineers to integrate these relationships into planning and project evaluation processes employed by local and regional governments and state agencies. The review was conducted to support two Caltrans-sponsored projects underway to create improved planning tools for evaluating: transportation impacts of smart growth land uses; and integrated local and regional land use/transportation planning. This document represents the combined work of the study teams working on the two projects.

The review includes literature found in online research resources such as TRIS/TRID, Google Scholar and the archives of *Transportation Research Record*. Bibliographies of key documents were reviewed for additional resources. Additionally, pertinent literature with which the researchers are familiar was included. The literature acquired was assessed regarding the development of analysis tools for assessing relationships between the built environment and travel demand, including vehicle trips and vehicle miles of travel (VMT).

B. Organization

This review divides available literature identified into two types: (1) “empirical research,” and (2) “applied methods.” The first category contains studies that focus on quantitatively analyzing the relationship between urban form and travel behavior, as well as meta-analyses and large-scale reviews of such literature. The second category contains literature that describes methods, models, and tools used by practitioners for improved understanding of the built environment and travel behavior, or specific elements thereof. Though the literature was divided as logically as possible, some overlap may exist between these categories. Where available, links to documents are provided.

Studies especially relevant to the site-specific smart growth trip-generation rates methodology effort are preceded by a single asterisk (*). Those especially relevant to integrated land use/transportation analysis tools and scenario planning processes are preceded by a double-asterisk (**).

C. Overview and Conclusions

The literature reviewed shows great diversity in the approaches taken by theorists and practitioners in studying relationships between the built environment and travel behavior in the U.S. Even so, there appears to be some consensus regarding key relationships useful for performing analysis of potential effects of alternative land use and transportation strategies on travel at the local and regional levels. This type of analysis is needed to develop and assess land use and transportation planning scenarios and

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implementation programs for integrated “Blueprint” planning and Sustainable Communities Strategies (SCSs), which are required as part of Regional Transportation Plans (RTPs) for California’s MPOs under SB 375¹. There is also interest by cities, counties, special interest and community groups, developers, etc. in such strategies.

The body of available literature indicates that certain built environment variables, such as development density, land use mixture (diversity), and design for walkability and transit access, can have an important influence on travel behavior expressed in travel mode, vehicle trips (VT) and vehicle miles traveled (VMT). However, the built environment does not represent the only, nor even the most important, determinant of household travel. Demographic variables, especially income, household size and composition, and automobile ownership/availability, have a larger influence on travel behavior. Even so, local land use and transportation variables are important because they are more susceptible to policy influence in the US political context compared to variables such as income, auto ownership and household size and composition. It should also be noted that certain of these variables, such as auto availability, can be estimated as a function of urban form and demographic variables (e.g., Holtzclaw et al, 2007).

A variety of studies indicate that if local variables - such as density, diversity, design, and accessibility to significant destinations via transit and non-motorized modes - are all enhanced simultaneously in urban areas, reductions in vehicle trips and vehicle miles traveled on the order of 25 percent or greater per household are possible in those areas.

The literature suggests that some of the explanations for lower VT and VMT rates in such “smart growth” areas are due to “self selection” – people wishing to reduce their need to drive seek out urban areas where this desire can be realized. The self-selection process occurs both in residential choice and well as the choice of workplace and shopping destinations. The self-selection process implies that, to the extent that there may be underserved demand for less auto-centric urban environments in a given region, estimates of the elasticity of VT and VMT with respect to the built environment provide better predictions of the changes that could occur if additional “less auto-centric urban environments” are built.

A parallel study (Vision California) suggests that “smart growth” development of all types may be significantly under-provided in local plans, indicating that there will be substantial unmet demand for “smart growth” in California in the decades ahead. This implies that if more “smart growth” development is built, there will be a sufficient supply of “self-selectors” to live, work, and shop in them. This attenuates the need to adjust for self-selection, at least in California. Self-selection is still important from a policy

¹ See the California Transportation Commission’s *2010 Regional Transportation Guidelines*, Chapter 3 at: http://www.catc.ca.gov/programs/rtp/2010_RTP_Guidelines.pdf

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standpoint, in that the under-supply of smart growth development needs to be addressed if we want to take full advantage of the connection between the built environment and travel behavior.

Among local land use factors affecting travel demand, the literature indicates that access to regional destinations via non-automobile modes is the single most important built environment factor. Development in areas of high accessibility— e.g., in or near central cities—tends to produce lower VMT per capita compared to even dense mixed-use development located on the “fringe.” Diversity – land use mixture -- is also influential, though identifying appropriate land use mixtures can be challenging. (For example, a restaurant located near an office or home may attract walking trips, while a furniture store might not - even though both may be classified as “retail” in land use databases and local zoning codes.) **Density (of population and employment), and design or connectivity (especially when measured as the density of intersections and/or streets, bicycle facilities, and sidewalks), are often highly correlated variables** (which often results in only one variable appearing significant in regression analyses). An optimal method of sorting out these intertwined variables has not yet emerged in the literature reviewed, though methods have been developed by researchers.

Another set of issues the literature does not fully address include the transferability of relationships between built environment and travel behavior: there is variation across metropolitan areas regarding alternatives to automobile travel. **Opportunities to lower levels of VT and VMT are greatest where urban areas and transit systems offer accessibility that provides truly attractive alternatives to automobile travel.**

The land use–travel literature, though vast, is lacking in longitudinal and retrospective studies. Very few “before and after” studies exist, and the literature remains dominated by cross-sectional studies and forecasting model analyses. Another limitation is that the current body of literature is almost entirely comprised of studies based on data that is at least a decade old. And, only a few are based primarily on California data.

Thus, the data collection and analyses being conducted for the two Caltrans-funded data and tools development projects are important to advancing the state-of-practice in California. These projects are providing locally-derived and up-to-date quantitative data regarding land use/travel relationships. The “Improved Data and Tools for Integrated Land Use-Transportation Planning in California” project (SACOG, Fehr & Peers Consultants, UC Davis’ ULTRANS, and Caltrans) has made these relationships available for use in “sketch-planning” analysis tools, GIS-based “visioning” software, and travel demand modeling.²

² <http://ultrans.its.ucdavis.edu/projects/improved-data-and-tools-integrated-land-use-transportation-planning-california>

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The “Smart Growth Trip-Generation Methodology” effort by researchers at the Institute of Transportation Studies at UC Davis will provide a methodology for use in preparing transportation impact analyses of proposed “smart growth” land use development projects in California (for which ITE’s suburban-based vehicle trips estimation data are not applicable, according to the ITE [Trip Generation Handbook](#), 2004).

Such data and tools will be useful for integrated regional Blueprint scenario planning, preparing and analyzing Sustainable Communities Strategies and Regional Transportation Plans, as well as for local land use General and Specific Community planning and smart growth project implementation.

A. Empirical Research

- *Arrington, G. B. and Cervero R. (2008). **Effects of TOD on Housing, Parking, and Travel**, Transit Cooperative Research Program (TCRP) Report 128.
<http://144.171.11.107/Main/Public/Blurbs/160307.aspx>

The objectives of this research were to learn more about the behavior and motivation of TOD residents, employees, and employers in their mode choice, as well as identify and recommend use of best practices to promote transit ridership in TODs. An extensive literature review was conducted regarding the TOD travel behavior and motivation. Unveiled in this review were the findings that transit system extensiveness, parking prices, and traffic congestion are all positively correlated with transit ridership. Relative transit travel time to auto travel time is more important to ridership than any land use factor. Aside from this, the most effective way to increase TOD transit ridership is to increase development densities in close proximity to transit. Also discovered was a lack of information regarding TOD trip generation characteristics, as the grid patterns typically associated with the dense development within TODs make it more difficult to conduct trip counts. Overall, it was found that policy factors that most strongly influence transit ridership in TODs include transit service levels, prices, and parking supply and costs.

Beyond the literature review, the study aimed to provide more information regarding vehicle trips generated by TODs, by collecting empirical trip generation data at a representative sample of TODs. Seventeen residential case studies were conducted in four metropolitan areas of the U.S.: (1) Philadelphia/Northeast New Jersey, (2) Portland, OR, (3) Washington D.C., and (4) the East Bay of the San Francisco Bay Area. Six of the surveyed projects included ground-floor commercial, but were primarily residential, and none of the projects were immediately accessible to a freeway interchange. Based on these counts, over a weekday period residential TODs averaged 44% fewer vehicle trips than estimated by ITE (based on a weighted average). The data collected by these counts are made available in the report. Additionally, the researchers ran a multivariate regression analysis to predict trip generation rates of residential TODs based on (1) distance of the project to the central business district, (2) distance of the project to a transit station, (3) residential densities around the station, and (4) parking provision. The

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bivariate relationships between residential TOD trip generation and other variables were weak and statistically insignificant.

Residential density within ½ mile of the transit station proved to be the most explanatory of the variables included in the regression. Thus, the effect of increased parking provision due to overestimating trip generation is discussed. As increased parking typically leads to decreased density (as previously mentioned, the most explanatory predictor of trip generation for TODs), the implications of overestimating trip generation rates for TODs are significant. Essentially, a feedback cycle is created in which developers decide to decrease density and increase parking provision at their TODs in order to get their development approved, which in turn leads to less transit use than originally anticipated by the TOD, and reaffirms initial concerns regarding the traffic impacts of the development. Thus, more accurate predictions of traffic generated by TODs are necessary in order for TODs to reach their full potential. This report provides valuable data that can serve as a starting point in putting together a tool that more accurately estimates trip generation for smart growth type developments.

- ****Boarnet, Marlon G. (2011). A Broader Context for Land Use and Travel Behavior, and a Research Agenda. *Journal of the American Planning Association*, 77:3, 197-213**

Planning studies of land use and travel behavior focus on regression analysis of travel as a function of traveler demographics and land use near study subjects' residences. Methodological debates have tended to focus almost exclusively on the possibility that persons choose their residence based on how they wish to travel. This longer view steps back from the confines of the regression-based literature to explain the historical roots, methods, and results of the literature, and to assess how the land use–travel literature must be transformed to be more relevant to planning.

The article acknowledges the many prior summaries and meta-analyses of the impact of land use on travel. Its primary intent is not to summarize the results of past studies, but rather to explain how a literature that has become fundamental to planning scholarship is failing to be sufficiently planning-focused. It then describes how the literature can be transformed to address the planning challenges of today and tomorrow.

Over 100 articles are summarized, covering transportation methods from the dawn of the interstate highway era to topics that include program evaluation, land development, and cognitive aspects of travel behavior. The primary focus is on the land use and travel literature, but the review and analysis is broad ranging and places the literature and its challenges within the broader context of recent developments in the social sciences, planning, policy, and electronic data collection.

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Progress on three research frontiers is needed to move the land use–travel literature forward: First, behavioral models of land use and travel must expand to consider how land is developed, how places are planned, and how cities are built. Second, the land use–travel literature should build a robust retrospective program evaluation tradition, which is currently almost completely absent in a scholarly field dominated by cross-sectional hypothesis tests and forecasting models. Third, economic social welfare analysis must be carefully researched, including questions of preferences for neighborhood types and whether such preferences are fixed or malleable.

The article concludes by noting that planning is fundamentally about city building, and the literature and practice on land use and travel behavior should adapt to better support city building. This requires both a serious commitment to social science research and planning’s characteristically broad view of context, problem, and place. In an era of climate change, and amidst debates about sustainability, the land use–travel literature must more aggressively examine the process of plans and place-making, evaluate the increasingly innovative transportation policies being implemented at the local level, and develop methods that allow more informed discussion about the costs and benefits of transportation policies.

- ****Boarnet, M., Nesamani, K.S., & Smith, C. (2003). Comparing the Influence of Land Use on Nonwork Trip Generation and Vehicle Distance Traveled: An Analysis Using Travel Diary Data.** Transportation Research Board, 83rd Annual Meeting.
<http://www.its.uci.edu/its/publications/papers/CASA/UCI-ITS-AS-WP-03-1.pdf>

This article examines the relationship between land use and non-work trip generation and vehicle miles traveled (VMT). The authors hypothesize that land use impacts VMT more than it impacts trip generation. They use travel survey data to test this hypothesis. Portland Travel Diary data are used, which include information regarding ethnicity, income, employment, and a “pedestrian environment factor” based on the area’s level of pedestrian infrastructure and design. Further, census data for the Portland region were examined, in addition to transportation network data from Portland’s Regional Land Information System. The authors used regression techniques to model non-work vehicle trip frequency and VMT separately, both as functions of socio-demographic variables, and land use variables. Three of the “D-factors” were taken into account.

First, density was measured by population density within the respondent’s census tract. Second, employment density, and retail employment density within the respondent’s census tract served as indicators of land use diversity. Finally, design was measured by the percent of the street grid comprised of four-way intersections within a ¼ mile of the respondent’s home. Based on their models, the authors conclude that income plays the largest role in determining both trip generation and VMT. However, after income is taken into account, the effect of land use variables is comparable to that of other socio-

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demographic variables. Ultimately, the authors' initial hypothesis was rejected in favor of the conclusion that land use variables have a similar effect on both VMT and trip generation.

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- ****Cambridge Systematics, Inc. (2009). *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions*. Washington D.C.: Urban Land Institute.**

Moving Cooler is a study designed to analyze the potential for different strategies to reduce transportation related greenhouse gas (GHG) emissions in the United States. Various greenhouse gas (GHG) reducing strategy bundles are explored and analyzed. GHG reductions are estimated from reductions in vehicle miles traveled (VMT) and improvements in system efficiency. The bundles are analyzed at two levels of deployment: (1) aggressive, and (2) maximum. The bundle that is most reflective of the VMT reduction strategies examined by projects attempting to explore the relationship between land use and transportation is the “Land-Use/Transit/Non-Motorized Bundle.” This bundle could potentially achieve significant GHG reductions through reduced automobile dependence by 2050. Specifically, GHG emissions could be reduced by up to 9% under aggressive deployment (assuming 54% of new development by 2050 is dense development of 5 or more units per acre), and up to 15% under maximum deployment (assuming 90% of new development by 2050 is dense development as defined above). Specific explorations of VMT reductions achieved through each bundle are not provided.

- ****Cervero, R. (2007). *Transit-Oriented Corridors. The Transportation/Land Use Connection*, T. Moore, P. Thornes, B. Appleyard, Planning Advisory Service Report Number 546/547, pp. 136-137.**

The author notes that “atomized” transit-oriented development (TOD) – i.e., development around a single transit station – has not produced significant regional benefits – reduced congestion, improved air quality, and land conservation. In fact, isolated TODs in a sea of auto-oriented development may be counter-productive, creating pockets of congestion as residents beyond the TOD drive to and through it. What is needed is a sufficient number of TODs aligned in a corridor, six to eight miles in length that will enable many trips to and from a TOD to also be made by transit. The author suggests that Transit Oriented Corridors (TOCs) on this scale are the important planning construct for analyzing the effectiveness of the TOD concept. Stockholm, Sweden is cited as an example of successful implementation of TOC; over decades planners there worked to coordinate development along linear axes, forming a “necklace of pearls.”

TODs within the corridor can be specialized toward employment or housing, or mixed, but ideally the resulting corridor land use pattern will result in high transit use in both directions, facilitating both regional goals and efficient transit operations.

- ****Cervero, R; Duncan, M (2006). [Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?](#) *Journal of the American Planning Association*, Autumn 2006, 72; 4; 475-490**

Which land-use strategy yields greater reductions in vehicular travel: improving the proximity of jobs to housing or bringing retail and consumer services closer to residential areas? The authors’ probe this

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question by examining the degree to which job accessibility is associated with reduced work travel and how closely retail and service accessibility is correlated with miles and hours logged getting to shopping destinations. Based on data from the San Francisco Bay Area, they find that jobs-housing balance reduces travel more, by a substantial margin. The article concludes by discussing policy measures that have been introduced in California to bring housing, workplaces, and retail centers closer together. The authors document an inverse relationship between jobs housing balance and VMT of 0.05.

- Chatman, Daniel G. (2003). **How Density and Mixed Uses at the Workplace Affect Personal Commercial Travel and Commute Mode Choice.** *Transportation Research Record*, 1831, 193-201.

This paper describes a model that examines the relationship between land use characteristics at the workplace and commute and commercial travel choices. The built environment at the workplace is of particular interest as changes in land use patterns may be more politically feasible in these areas than in residential locations, and the self-selection problem is less of a concern when examining workplace locations. Data for the model is drawn from the 1995 Nationwide Personal Transportation Survey (NPTS). The test independent variables to estimate VMT are employment density and share of retail employment. A variety of demographic variables are included as controls. The model determined that high workplace density demonstrates a slight correlation with reduced VMT (with an increase of 10,000 employees per square mile yielding a 0.5 mile reduction in per capita personal commercial VMT), and retail at the workplace did not demonstrate a statistically significant correlation with VMT. However, a potential explanation for the latter finding could be that retail employment density is not a good indicator of activity accessibility as it does not include non-retail services such as banks or restaurants.

- **Chatman, D. (2009). **Residential choice, the built environment, and nonwork travel: evidence using new data and methods.** *Environment and Planning A*, Vol. 41, No. 5, pp.1072 – 1089.

This study confirms that residents of dense, mixed-use, transit-accessible neighborhoods use autos less. Recent studies have suggested that this relationship is partly because of the phenomenon of self-selection, i.e., households that prefer to use transit and walk or bike seek and find such neighborhoods. If this is the case, and if the number of such households is small, policies to alter the built environment may not influence auto use very much. The author argues that many of these studies are inconclusive on methodological grounds, and that more research is needed. A purpose-designed survey of households in two urban regions in California (the San Francisco Bay Area and San Diego region) is investigated, with the aid of a new methodological approach. The study finds that most surveyed households explicitly consider travel access of some kind when choosing a neighborhood, but that this process of residential self-selection does not bias estimates of the effects of the built environment very much. To the extent that it does exert an influence, the bias results both in underestimates and overestimates of the effects of the built environment, contrary to previous research. The analysis not only implies a need for deregulatory

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approaches to land-use and transportation planning, but also suggests that there may be value in market interventions such as subsidies and new prescriptive regulations.

- ****Chatman, Daniel G. (August 2006). Transit-Oriented Development and Household Travel: A Study of California Cities.** Institute of Transportation Studies, School of Public Affairs, University of California, Los Angeles. For the California Department of Transportation (Caltrans).
http://www.policy.rutgers.edu/faculty/chatman/documents/TODs_and_travel_in_CA.pdf

This paper outlines a model of travel patterns of those living in transit-oriented developments (TODs) in California. The model is based on data from a survey of randomly selected households and workers within a 0.4 mile radius of selected rail stops in San Diego and the San Francisco Bay Area. The survey consisted of a telephone questionnaire and 24-hour activity and travel diaries. It included not only those living in TODs, but also those living in the greater metropolitan area in which the TODs were located, providing for better “control” than census data. The built environment characteristics included in the model were as follows: (1) built form density (structural density of developed land), (2) activity density (mix of uses), and (3) network load density (number of local users per unit of network capacity).

Combined home and work transit proximity demonstrated the strongest correlation with transit commuting; however, the built environment variables most strongly correlated with travel decisions were those that reduce the convenience of auto use. The important consideration is not so much that these variables increase the convenience of non-motorized travel, but that they typically decrease the convenience of motorized travel. Thus, TODs that accommodate the automobile through increased capacity do not tend to produce the desired effect of TODs on travel.

The residential self-selection problem is explored as well. In order to incorporate the potential for residential self-selection into the model, respondents were asked to describe what factors were considered when choosing their current neighborhood, instead of describing their travel preferences (which could be influenced by current travel patterns). Based on statistical tests conducted on survey data, the residential self-selection problem exists, but is not necessarily a strong indicator of travel behavior.

One important policy implication of this study, as discussed previously, is the fact that changes made to the built environment in order to make alternative travel modes more convenient must also make auto use less convenient (i.e. avoid improving road capacity and parking provisions). The second critical policy implication is that TODs should be conceived within the context of a regional scale rather than a local scale, as the large-scale built environment has a substantial impact on travel behavior.

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- ****Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., & Chen, D. (2007). *Growing Cooler: Evidence on Urban Development and Climate Change*. Washington D.C.: Urban Land Institute.**

Growing Cooler examines the relationship between the built environment, transportation, and greenhouse gas (GHG) emissions. The relationship between smart growth type land use patterns and travel is discussed, as well as the potential for the general public to embrace smart growth strategies. A comprehensive review and analysis of the literature regarding the relationship between land use and travel patterns is conducted. The EPA's Smart Growth Index is presented, which defined sprawl as being composed of four factors (density, mix, centeredness, and street accessibility), and demonstrated that as sprawl decreases, average vehicle ownership and daily VMT per capita decrease, though the density factor has the strongest and most significant relationship to travel. In order to quantify the effects of density on congestion, data from a study examining the relationship between density and congestion were used by the authors to develop an elasticity of congestion with respect to density of 0.14, indicating that density only exacerbates congestion mildly. Elasticities comparing the initial three "Ds" (density, diversity, and design) to VMT and vehicle trips are provided (taken from Ewing and Cervero 2001). The effects of site location on the VMT of project-scale development are examined, and it is found that VMT reductions between 30 and 60 percent are typical of infill locations, when compared to Greenfield development. Overall, the evidence on the built environment and driving indicates compact development can reduce the need to drive by 20 to 40 percent relative to sprawl.

- ****Ewing R, & Cervero R, (2010). "Travel and the Built Environment: A Meta-Analysis" *Journal of the American Planning Association*, Vol. 76, No. 3, pp. 265 – 294.**

The study begins by noting that both local governments and states are turning to land planning and urban design for help in reducing automobile use and related social and environmental costs. The effects of such strategies on travel demand have not been generalized in recent years from the multitude of available studies. To address this, the authors conducted a meta-analysis of the built environment-travel literature existing at the end of 2009 in order to draw generalizable conclusions for practice. The authors aimed to quantify effect sizes, update earlier work, include additional outcome measures, and address the methodological issue of self-selection. Elasticities were collected and in some cases computed for individual studies and pooled them to produce weighted averages.

Key results: Travel variables are generally inelastic with respect to change in measures of the built environment. Of the environmental variables considered here, none has a weighted average travel elasticity of absolute magnitude greater than 0.39, and most are much less. Still, the combined effect of several such variables on travel could be quite large. Consistent with prior work, the authors find that vehicle miles traveled (VMT) is most strongly related to measures of accessibility to destinations and secondarily to street network design variables. Walking is most strongly related to measures of land use

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diversity, intersection density, and the number of destinations within walking distance. Bus and train use are equally related to proximity to transit and street network design variables, with land use diversity a secondary factor. Surprisingly, the authors find population and job densities to be only weakly associated with travel behavior once these other variables are controlled.

The elasticities derived in this meta-analysis may be used to adjust outputs of travel or activity models that are otherwise insensitive to variation in the built environment, or be used in sketch planning applications ranging from climate action plans to health impact assessments. However, because sample sizes are small, and very few studies control for residential preferences and attitudes, it cannot be said that planners should generalize broadly from our results. While these elasticities are as accurate as currently possible, they should be understood to contain unknown error and have unknown confidence intervals. They provide a base, and as more built-environment/travel studies appear in the planning literature, these elasticities should be updated and refined.

- ****Ewing, R., & Cervero, R. (2001). *Travel and the Built Environment: A Synthesis*. *Transportation Research Record*, 1780, 87-114.**

This paper summarizes the majority of recent (as of 2001) studies examining the potential to influence travel behavior through land use changes. Elasticities of VMT and vehicle trips with respect to the three Ds (density, diversity, and design) as well as regional accessibility are provided. General findings regarding household VMT include the fact that trip frequency (regardless of mode) is more dependent on sociodemographic characteristics than on land use variables, whereas trip length is more dependent on land use variables, and mode choice is dependent on both land use and sociodemographic variables. The direct relationship between density and travel is uncertain (i.e. other variables associated with density could be the true cause of observed changes in travel patterns). The evidence regarding the relationship between vehicular travel and transportation networks (e.g. grid patterns versus arterials) is considered inconclusive. The elasticities provided by this study are small, but significant, and could have considerable impacts if additive effects are taken into account.

- Ewing, R., Dumbaugh, E., & Brown, M. (2001). **Internalizing Travel by Mixing Land Uses: Study of Master-Planned Communities in South Florida**. *Transportation Research Record*, 1780, 115-120.

This study seeks to model the effects of land use mix on internal trip rates using 20 mixed use master-planned communities in south Florida. Prior to this, no study had modeled the interaction of such variables. The authors discuss the problems posed by lack of research on internal capture rates of mixed use developments, and state that "...traffic impact studies for mixed use developments are little more than exercise in speculation." Internal capture rates (i.e. trips with both trip ends within the community) were found to range from 0 to 57 percent. Land use measures examined were community size (population +

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jobs), density (size / area), entropy (level of land use mix within the development), balance (the development's jobs-housing ratio as compared to that of the county as a whole), and accessibility. After controlling for size and regional accessibility in the model, land use mix and density were not found to be significant determinants of internal capture rates. This could be due to a variety of sampling errors, or issues of construct validity in the density and land use variables. For example, the density variable included all land area in its denominator, including land unable to be developed. Further, construct validity problems in the land use mix and balance measures may arise due to the fact that many of the businesses included in the commercial category meant to serve larger regional markets (e.g. furniture stores, automobile dealers, etc.). The variable found to be most strongly correlated to internal trip rates in this model was development size, with regional accessibility following as the second most strongly correlated variable (a negative correlation). The authors conclude with a discussion of the need for further empirical research on internal capture rates for such developments.

- ****Ewing, R., et al. (2009). Traffic Generated by Mixed-Use Developments – A Six Region Study Using Consistent Built Environmental Measures.** Transportation Research Board, 88th Annual Meeting. <http://www.reconnectingamerica.org/public/show/trafficmixedusedevelopments2009>

This study aims to measure the traffic impacts of multi-use developments using a variety of innovative methods. Six regional household travel databases of multi-use developments were chosen for analysis. All trips were able to be classified by purpose and mode, socioeconomic characteristics were controlled for, and data were linked to built environment databases. A total of 35,877 trip ends were generated by the multi-use developments, 29% of which were either internal trips, or non-motorized or transit trips, detracting from the total amount of external vehicle trips generated by these developments. Elasticities are developed to quantify the relationships between a variety of land use and socio-demographic variables and internal trip capture rates, the likelihood of walking or taking transit on external trips, and trip distances for external automobile trips. Overall, variables found to contribute to a reduction in automobile travel include: (1) total and relative amounts of on-site population and employment, (2) site density, (3) size of households and auto ownership characteristics, (4) level of employment within walking distance of the site, (5) pedestrian-“friendliness” of the site, and (6) level of transit provision and access to employment via transit.

- Handy, S. (2004). **Critical Assessment of the Literature on the Relationships among Transportation, Land Use, and Physical Activity.** Department of Environmental Science and Policy, University of California, Davis. Prepared for the Committee on Physical Activity, Health, Transportation, and Land Use, July. <http://onlinepubs.trb.org/onlinepubs/archive/downloads/sr282papers/sr282Handy.pdf>

This report provides a discussion and review of the empirical evidence regarding the interaction of the built environment and physical activity (often times associated with non-motorized travel). A variety of travel behavior and built environment theories are discussed, most of which shed light on the fact that the

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relationship between the built environment and travel behavior is complex. Studies examining the relationship between the built environment and active travel are explored. Dependent variables examined in these studies included walk trips, non-motorized trips (i.e. walk and bike trips), and non-automobile trips (including transit). Built environment characteristics (i.e. independent variables) included in the studies are population and employment density, land use mix, transportation system measures, measures of accessibility, design measures, and neighborhood type. Control variables consisted of sociodemographic characteristics typically included in regional travel surveys.

Many studies found that population and density measures are significantly positively correlated with non-motorized travel modes. The findings across studies of effects of transportation system measures on active travel were somewhat inconsistent. The variable capturing the distance to destinations generally demonstrated a negative correlation with walking trips, as expected, while other measures of accessibility tended to demonstrate positive correlation with non-motorized trips. Design variables were shown to be statistically insignificant, which could simply serve as an indicator that the variables typically used to measure design are insufficient. The studies that focused on neighborhood type as opposed to various built environment variables tended to demonstrate higher levels of non-motorized trips in traditional or walkable neighborhoods, than in suburban or auto-oriented neighborhoods.

Next, physical activity studies are explored, falling into two categories: (1) correlative studies, and (2) intervention studies. The former identifies relationships between a dependent variable and a variety of independent variables at one point in time, while the latter surveys participants before and after an intervention, and results are compared to a control group in order to determine the effect of the intervention. Many of the correlative studies relied on subjective reported measures of the built environment and mode choice, while a few used more objective measures of the built environment to supplement or replace the reported measures. Measures of physical activity in these studies fell into the categories of walking, other physical activity, and total physical activity. Neighborhood characteristics used to measure the built environment for these studies were different from those in the travel behavior literature. Transportation, design, and safety characteristics were the most used measures of the built environment in the physical activity literature. Overall, it was found that measures of accessibility demonstrate a positive impact on total physical activity, while perceived neighborhood aesthetics, and objective neighborhood characteristics demonstrated strong positive associations with walking.

Although various methodologies were used in these studies, the travel behavior and physical activity studies produced consistent results, indicating that a strong association exists between the built environment and physical activity. However, some ambiguity is present regarding which specific features of the built environment influence physical activity. Though density and neighborhood type were found in some studies to have a strong impact on active travel, more exploration is needed to determine the specific

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qualities of these variables that impact travel behavior as measures of these variables were inconsistent across studies. On the other hand, accessibility is one variable that, regardless of how it is measured, seems to have a strong influence on physical activity.

Finally, the question of causality versus correlation is raised, and the self-selection problem is discussed. The built environment's interaction with residential self-selection can be conceptualized in a variety of ways. One with a propensity toward active travel modes can either be encouraged or inhibited depending on neighborhood characteristics, or the neighborhood characteristics of one with a low preference for active travel modes can reinforce this low preference, or encourage one to change preferences. Various cross-sectional (correlative) studies have indicated that residential self-selection does play a role in travel behavior, though the author discusses the potential of intervention studies to improve understanding of residential self-selection.

Overall, the author finds that further research is needed in order to sort out the degree to which different aspects of the built environments can have a causal effect on physical activity. However, the author concludes that the lack of definitive evidence should not serve as a deterrent to changing the way our communities are designed. Based on existing research, a causal link between the built environment and physical activity is certainly a possibility. Further, other positive outcomes are associated with making neighborhoods less auto-oriented, and minimal risk and cost is associated with doing so.

- ****Handy, S., Cao, and Mokhtarian, P. (2005). Correlation or Causality between the Built Environment and Travel Behavior? Evidence from Northern California.** Transportation Research Part D 10, 427-444. http://www.dot.ca.gov/researchconn/past_speakers/DrHandy/trd_paper.pdf

This study seeks to move beyond establishing a correlation between built environment characteristics (e.g. density, land use mix, transit accessibility, pedestrian friendliness, etc.) and travel choices by exploring a causal relationship between the two. In other words, this study aims to explore whether neighborhood design affects travel behavior, or if instead travel preferences play a role in determining neighborhood choice. In order to do this, a survey was conducted comparing those who had recently switched neighborhood types (the “treatment” group) to those who had not recently moved (the “control” group). Reported vehicle miles driven were used as the dependent variable. Independent, or explanatory, variables included: reported neighborhood characteristics and neighborhood preferences, objective measures of accessibility, travel attitudes, and sociodemographics. Based on a cross-sectional analysis of reported vehicle miles driven, it was found that residential self-selection plays a significant role in the observed correlations between the built environment and travel behavior. Based on the quasi-longitudinal analysis of the change in travel behavior after a move, or after one year of staying in the same neighborhood (controlling for attitudes toward different modes of travel), it was found that changes in the built environment do have an impact on vehicle miles driven. Increased accessibility was the variable that had

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the greatest negative impact on driving. These findings serve to substantiate the conclusions of previous cross-sectional studies that found a direct relationship between the built environment and travel behavior.

- ****Holtzclaw, J., Clear, R., Dittmar, H., Goldstein, D., and Hass, P. (2002). Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use – Studies in San Francisco, Los Angeles and Chicago.** *Transportation Planning and Technology*, Vol. 25, pp. 1-27.

This study, sponsored by the Natural Resources Defense Council (NRDC), the Center for Neighborhood Technology (CNT) in Chicago, and the Surface Transportation Policy Project in Washington, DC, includes every neighborhood in the San Francisco, LA and Chicago areas. The zones analyzed are the Chicago Area Transportation Study's 316 Dram-Empal model zones covering the Chicago metropolitan area, the Southern California Association of Governments' 1700 Travel Analysis Zones covering the Los Angeles metropolitan area and the Metropolitan Transportation Commission's 1099 Travel Analysis Zones in the San Francisco metropolitan area.

The dependent variables estimated are vehicles available per household and vehicle miles traveled (VMT). Average vehicle availability for each zone is from the 1990 U.S. Census. VMT per vehicle is derived from odometer readings recorded when owners take their vehicles in for emission systems inspections (smog checks) in California and Illinois. Average VMT per household is calculated as the VMT per vehicle times the number of vehicles per household for each zone. The dependent variables were tested against a wide range of potential explanatory variables, including the most important socio-economic factors of household income and household size. Locational variables tested were: density, transit service and access to jobs by transit, availability of local shopping, pedestrian and bicycle friendliness, and proximity to jobs.

The authors predict a household's VMT as a function of home-zone density, transit service and access to jobs by transit, availability of local shopping pedestrian and bicycle "friendliness"; that is, the "attractiveness" of these options as compared to driving, and proximity to jobs. The elasticities for vehicle ownership with respect to density for Chicago, Los Angeles, and San Francisco were -0.33, -0.32, and -0.35. Elasticities for VMT with respect to density were -0.350, -0.4, and -0.43.

- ***Kimley Horn & Associates, with EPS and the Association of Bay Area Governments, for Caltrans (2008). Trip-Generation Rates for Urban Infill Land Uses in California (Phase 1).** http://www.dot.ca.gov/newtech/researchreports/reports/2008/ca_infill_trip_rates-phase_1_final_report_appendices_4-24-08.pdf

The purpose of this study was to provide information regarding the travel characteristics of urban infill development in California. Specifically, the study aimed to: develop a methodology for infill trip generation data collection and analysis; develop trip generation rates for urban infill developments in California; and make these rates available for use in a database that can serve to supplement ITE *Trip Generation* for estimating trip generation rates for infill developments in California. Ultimately, the research team's goal

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was to incorporate data collected into future relevant ITE publications. Land uses examined by this study include commercial and office developments, high density housing and mixed-use and transit-oriented developments. Sites were selected in metropolitan areas based on multi-modal travel options, with the goal of providing a representative sample of different urban areas around the state of California. Methods for collecting data included manual door counts as well as intercept surveys.

Representative site selection was relatively easy compared to obtaining permission to survey the sites, which was the most challenging aspect of the study as of the completion of phase 1. The most effective approach to gaining permission to survey was found to be soliciting permission from those developers or organizations that had prior relationships with members of the research team, or soliciting permission/recognition from larger groups or organizations that represent or are affiliated with multiple developers (e.g. American Planning Association, local Chambers of Commerce, etc.). In addition to counts and intercept surveys, data were collected regarding independent site variables (e.g. building size, number of employees, etc.), and population (i.e. the number of people accessing a site during the study period).

Various methodologies were explored for empirically measuring as well as estimating daily trip generation rates on site. The most viable methodology was determined to be peak-period counts and intercept surveys to estimate daily trip generation rates. Three pilot studies were conducted at infill sites in Oakland and San Francisco to test this methodology. Following these three pilot studies, ten other sites were identified as appropriate for an expanded pilot study. These sites, in the cities of Berkeley, San Diego, and Los Angeles, were mostly residential, though a few commercial/business land uses were included. Based on this small sample, on average residential sites had lower trip rates than ITE estimates. All non-residential sites surveyed, aside from a supermarket in San Diego, demonstrated lower trip rates than the ITE estimates as well. Overall, this report was very informative regarding optimal data collection techniques and methodologies in order to calculate trip generation rates for urban sites.

- *Kimley Horn & Associates, with Economic & Planning Systems and Gene Bregman & Associates, for Caltrans (2009). **Trip-Generation Rates for Urban Infill Land Uses in California (Phase 2)**. http://www.dot.ca.gov/research/researchreports/reports/2009/final_summary_report-calif_infill_trip-generation_rates_study_july_2009.pdf

This is second phase of this project, and provides an overview of the method used for site selection and data collection described in the Phase 1 report. Ten land use types were chosen for data collection to estimate trip generation rates for urban infill developments: high-rise apartment, mid-rise apartment, mid-rise residential condominium/townhouse, high-rise residential condominium/townhouse, hotel, general office building, shopping center/specialty retail, and pharmacy/drug store without drive-through window, quality (sit-down) restaurant, and fast-food restaurant without drive-through window. Based on the sample consisting of 25 sites surveyed during both phase 1 and phase 2, observed trips were lower (by 26% to 40%)

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during peak periods than the ITE trip rates would indicate for all land uses, except: a mid-rise apartment complex in Pasadena, a mid-rise condominium/townhouse site in San Diego, a chain clothing store in San Francisco, and a supermarket in San Diego.

Ultimately, the report concluded that a larger database is needed in order to adequately compare trip generation rates in urban infill developments to those provided by ITE *Trip Generation*. Recommendations for future research include: trip rate validations, development of correlations between specific site characteristics and trip generation rates, and exploring incentives for developers to allow site surveys.

- **Kockelman, Kara, Matt Bomberg, Melissa Thompson, and Charlotte Whitehead (2008) **GHG Emissions Control Options: Opportunities for Conservation**. Report Commissioned by the National Academy of Sciences for the Committee for the Study on the Relationships among Development Patterns, VMT, and Energy Conservation.

This paper summarizes the magnitude of greenhouse gas (GHG) emissions reductions one can expect from a variety of widely discussed (and often debated) policies and design strategies. These include vehicle technologies, transport modes, fuel types, appliances, home and building design, and land use patterns. Through a detailed review of existing literature, the work strives to identify the greatest opportunities for carbon savings, reflecting, to some extent, cost implications and behavioral shifts needed. Greatest near-term gains mostly emerge in relatively conventional vehicle design shifts, dietary changes, and home weathering. In the medium term, significant energy and emissions savings are likely to come from fuel economy regulations approximating those abroad, appliance upgrades, plug-in hybrid purchases, home heating and cooling practices, and power generation processes. In the longer term, building design practices, carbon capture and sequestration, and a shift towards cellulosic and other fuels appear promising. Ultimately, however, to achieve 50- to 80-percent reductions in GHG emissions, relative to current or past levels, major behavioral shifts are probably needed, motivated by significant fuel economy legislation, energy taxes, household-level carbon budgets, and cooperative behavior in the interest of the global community.

With respect to urban form factors the authors note that these do not appear to be as influential as demographic and economic variables, but are more subject to public policy and regulation. The authors cite Bento et al. (2005) who found that road network and distribution of population throughout the city were the greatest urban form determinants of VMT, while VMT and commute mode were most dependent upon the pattern of residential land use and distribution of employment. The authors note that the 2001 National Household Travel Survey results suggest that VMT per vehicle is rather stable across households owning one to three vehicles. Thus, reducing vehicle ownership may be an important means to reducing VMT. Tables 22, 23, and 24 summarize elasticities of demand for vehicle with respect to parking, density and urban design variables.

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- Lin, J.J. & Yang, A.T. (2009). **Structural Analysis of How Urban Form Impacts Travel Demand: Evidence from Taipei.** *Urban Studies*, 46(9), 1951-1967.

This study analyzes the relationship between the built environment and travel demand in Taipei, Taiwan. The complex relationship between land use variables and travel is discussed, and structural equation modeling is used to clarify this complex relationship. Urban form variables used in the model include density (residential density, building density, and employment density), diversity (land use type mix, housing-job mix, housing-retail mix, retail-job mix, and land use entropy), and design (road density, grid network, and sidewalk density). Travel demand variables included in the model were trip generation and private mode split. Finally, control factors in the model include transit service, private mode facility (e.g. access to automobiles, and parking space density), and socioeconomic variables. Data were obtained at the traffic analysis zone level for the model from the Taipei City Bureau of Transport, and other Taipei City Government Agencies. Based on the model, it was found that density is positively related to trip generation and negatively related to private mode split. Land use mix is negatively associated with trip generation, and indirectly positively related to private mode split. Pedestrian friendly design was found to reduce private mode split. Though most of these findings support findings from studies conducted in the United States, national differences in previous land use patterns may serve to explain any differences.

- Lund, H., Willson, R., and Cervero, R. (2006). **A Re-evaluation of Travel Behavior in California TODs.** *Journal of Architectural and Planning Research*, Vol. 23, No. 3, pp. 247-263.

Building on the authors' prior work (Lund, Cervero & Wilson, 2004) , this reevaluation of survey data from residents living near rail station notes that transit-oriented development (TOD) clearly, but unevenly, encourages walking to transit as well as transit use California region's with rail transit. Survey sites were all located in non-Central Business District (CBD) locations, within walking distance of a transit station with rail service headways of 15 minutes or less, and were intentionally developed as TODs. Surveys were conducted along each of California's major urban rail systems, including: the San Diego Trolley, San Diego Coaster, Los Angeles Blue and Red Lines, Los Angeles Metrolink commuter rail, San Jose VTA light rail, Caltrain commuter rail, the Bay Area Rapid Transit District (BART), and Sacramento Light Rail.

The 2004 study found that residents living near transit stations were around five times more likely to commute by transit as the average resident worker in the same city, while office workers at work sites near transit were three and a half times as likely to use transit as average workers in the same cities. The reevaluation suggests that TOD can reduce per capita automobile travel, but this is only likely to be realized when transit systems reach sufficient coverage and efficiency to provide an attractive alternative to automobile travel.

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- Saelens, B., & Handy, S. (2008). **Built Environment Correlates of Walking: A Review.** *Medicine and Science in Sports and Exercise, Vol 40, No 7S, S550-S566.*

This paper reviews the literature between 2002 and 2006 on the relationship between specific characteristics of the built environment and walking for transportation and recreation. Specifically, this report synthesizes reviews of research, and original research conducted in both the transportation and public health fields regarding the interaction between the built environments and walking. Many reviews found that accessibility, measured as distance to destinations, is associated with walking. Aesthetics were found to be another important indicator of walking in multiple reviews, though factors used to measure aesthetics varied widely across studies. Street connectivity also played an important role as it is closely related to accessibility. Safety attributes were also positively correlated with walking. Most reviews discussed a need for more objective measures of environmental variables, and improved measures of walking, though the authors do mention that recent studies have incorporated more objective measures of the built environment than their predecessors.

The more recent studies found consistent positive relationships between walking for transportation and density, distance to nonresidential destinations, and land use mix. However, the question of causality still poses a problem for those wishing to understand more about the relationship between the built environment and active travel (in this case, walking). The following policies are specifically recommended to shape the built environment, influence aesthetic qualities, and encourage walking: designation of mixed use zoning districts, infill development and redevelopment programs, designation of historic districts, greyfield redevelopment, traffic calming programs, street connectivity ordinances, and requiring developers to provide amenities that make communities more livable.

- ****San Francisco Bay Area Metropolitan Transportation Commission (2006). Characteristics of Rail and Ferry Station Area Residents in the San Francisco Bay Area.** Oakland, CA.
http://www.mtc.ca.gov/planning/smart_growth/stars/

This study was undertaken to characterize the demographic and travel characteristics of station area residents — individuals living within close proximity to stops and/or ferry terminals in the region — compared to residents living elsewhere in the region. Transit Oriented Development (TOD) was defined as development within a one-half-mile *walking* distance (taking account of barriers and walkway circuitry) of a rail or ferry terminal. Demographic and travel data were from MTC’s 2000 Bay Area Travel Survey. This survey compiled travel and demographic data for some 35,000 individuals aged 16 years and above residing in nearly 15,000 Bay Area households.

Analysis of Bay Area survey results revealed that people living within a half-mile walking distance of a rail transit or ferry station are four times more likely to use transit than those living farther away than a half-mile. The data show that people who live and/or work within a half-mile of major transit or ferry stations

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averaged 42% of their daily trips by transit, walking or biking. Nearly a third of these do not own a vehicle. By comparison, people who live and/or work within a half-mile walking distance of ferry or major transit stations generate about one-half the VMT of suburban and rural residents in the SF Bay Area.

The study also found that the vehicle mode share of residents within a half mile of a rail station or ferry terminal is 28 percent lower than for the region as a whole. The same data also indicate that the transit mode share of residents increased by 14 percent in such areas. This suggests that about half of the reduction in vehicle trips observed for station/terminal area residents may be attributed to the substitution of transit for private vehicle trips.

- **Shay, E. & Khattak, A. (2007). **Autos, Trips, and Neighborhood Type: Comparing Environmental Measures.** Transportation Research Board, 86th Annual Meeting.
http://www.eng.odu.edu/transportation/khattak/New_Clusters_TRB_2007.pdf

This paper examines the relationship between neighborhood design, socio-demographic characteristics, auto ownership, and trip generation. The authors discuss “neo-traditional” development as typically associated with lower auto ownership rates, higher pedestrian/transit trips, and lower VMT, while offering the caveat that this may be due to self-selection. The paper describes a model developed by the authors using survey data from the Charlotte, NC region. In the process of developing this model, the authors used 34 direct measures of the built environment, then derived factors out of these direct measures using factor analysis, and finally performed cluster analysis to group together similar neighborhoods in terms of factors. These factors and clusters were then compared with auto ownership and trip generation. According to the authors, examination of the factors yielded more interesting results than that of the clusters. Factors derived from factor analysis were walkability, accessibility, agglomeration, property value, and level of industrial land use. Based on regression analysis, accessibility was the one land-use factor that was highly correlated with auto ownership (indicating a negative correlation between the two), while both accessibility and walkability were positively correlated with overall trips. The coefficients derived from regression analysis may be of interest in the development of a new trip generation model. However, because this analysis is based on data from North Carolina, it is less applicable in California.

- **Transportation Research Board Special Report 298. (2009). **Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO₂ Emissions.** Washington, D.C.: Transportation Research Board.

This study aimed to establish a scientific basis for analysis of the relationships between development patterns, vehicle miles traveled (VMT), energy consumption, and greenhouse gas (GHG) emissions for the purpose of informing policymakers as they adapt to California's Senate Bill 375. This bill requires the state's metropolitan planning organizations to provide incentives for local jurisdictions to incorporate more compact development and transportation alternatives into their future plans for the purpose of reducing

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GHG emissions by assigned target amounts. A decline in metropolitan density due to suburbanization and its implications for transit use are discussed. The generally accepted density threshold for a successful transit system is noted to be 7 to 15 dwelling units per residential acre, and the typical ½ mile catchment area for transit stations is mentioned. The importance of accounting for the many variables often associated with both density and VMT is discussed. These variables include accessibility, land use mix, development design, connectivity of street network, and demand management policies. Explanations for variability in the findings across studies are explored, including the use of disaggregate versus aggregate data, cross-sectional versus longitudinal studies, the self-selection problem and the uncertainties associated with causality, the measurement and scale of the different variables, and the generalizability of results.

The researchers found that developing at higher population and employment density is likely to reduce VMT rates. Further, evidence from the literature suggests that a doubling of residential density across a metropolitan area may reduce household VMT by 5 percent to 12 percent, and up to 25 percent if combined with other land use practices and policies thought to reduce VMT (e.g. higher employment density, mixed land uses, transit improvements, etc.). Particularly, the effects of land use strategies and transit availability together were found to be considerably greater than those of either one individually.

Chapter four introduces strategies to overcome impediments to compact development. These strategies include a focus on building compact new housing developments, relaxing zoning restrictions to enable more compact and mixed use developments, creating incentives for developers and lenders to invest in compact and mixed use development, and implementing integrated street design and reduced parking requirements in such developments.

Finally, previous national estimates are examined to determine the potential impact of compact development patterns on VMT, and the results of the authors' own development scenarios are presented. One study estimated that shifting growth by 2025 from sprawl to a controlled growth scenario (which moves 11 percent of new housing, and 6 percent of jobs to more urbanized areas) would reduce person miles traveled by 4 percent overall. Another study estimated VMT per capita to be 30 percent less in compact developments than in their conventional counterparts. Results of a scenario study conducted by the authors indicate that a doubling of density in 25 percent of new residential development could reduce VMT by 12 percent in both 2030 and 2050, while a doubling of density in 75 percent of new residential development could reduce VMT by 25 percent in the same time frame. Further benefits and costs of compact development are explored. Noted benefits include improved energy efficiency of buildings, land conservation, and increased physical activity. One potential cost is that of increased necessity for transit investment. Overall, the authors recommend to policymakers that policies in support of more compact, mixed use development should be encouraged.

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- ****Wallace, B., Mannering, F., & Rutherford, G.S. (1999). Evaluating Effects of Transportation Demand Management Strategies on Trip Generation by Using Poisson and Negative Binomial Regression. *Transportation Research Record, 1682, 70-77.***

This paper examines how various travel demand management (TDM) strategies can be incorporated into trip generation models for planning purposes. Using multi-modal travel survey data from the Puget Sound Transportation Panel (PSTP), the authors use Poisson regression techniques to analyze the effects of five TDM strategies on home-based work trip generation. The five strategies examined are as follows: (1) telecommunications strategies (i.e. telecommuting), (2) alternative work schedules (i.e. compressed work weeks), (3) on-site amenities at work, (4) pricing strategies (i.e. parking charges), and (5) land use strategies (i.e. urban center vs. non-urban, and distance from home to work). The results from the regression analysis are provided in the paper, including correlation coefficients for each of the variables examined. Variables of interest to the Smart Growth Trip Generation Rates spreadsheet effort include the two land-use variables of urban center vs. non-urban, and distance from home to work. Distance from home to work is negatively correlated with home-based work trips, while living in an urban center is much more highly (and positively) correlated with home-based work trips. The authors speculate that this may be due to trip-chaining: those living in urban centers (which tend to incorporate a mix of land uses, higher density, etc.) are less likely to feel the need to trip-chain between work and home, as making personal trips independent from their commute is presumably not as difficult for these people as it is for those living outside urban areas. This could also provide an explanation for the negative correlation between distance from home to work and home-based work trips: if trip-chaining occurs on the way to or from work, this trip is no longer counted as a home-based work trip. Finally, the authors discuss the differences between land-use strategies and other TDM strategies, and it is determined that perhaps instead of treating land-use strategies as variables within a trip generation model, separate trip generation models should be created for distinct land-use types.

- ****Zhang, M. (2005). Intercity Variations in the Relationship Between Urban Form and Automobile Dependence: Disaggregate Analyses of Boston, Massachusetts; Portland, Oregon; and Houston, Texas. *Transportation Research Record, 1902, 55-62.***

This study focuses on improving understanding of the relationship between urban form, access to a variety of travel mode choices, and the shift in mode choice from automobile travel to non-automobile travel. This is done through a modeling of mode availability and mode choice in three distinct cities: Portland, Oregon; Boston, Massachusetts; and Houston, Texas. Trip diary surveys were used as the primary source of data for all three cities. Based on the model, it was found that vehicle ownership and home distance to transit tend to influence whether people consider non-automobile modes feasible, with increased automobile ownership and poor transit service both correlated with high automobile dependence. When socioeconomic and transit supply variables are controlled for, population density was associated with a lower probability of automobile dependence in both Portland and Boston. However, no such association

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was found in Houston. After completion of the modeling phase, the authors estimated disaggregate elasticities of automobile dependence and driving choice with respect to density, transit access, and vehicle ownership. Houston, which is quite automobile dependent, demonstrated the smallest elasticities. The authors speculate that this may indicate that places with established high levels of automobile dependence will have a harder time overcoming this automobile dependence through improvements in density and transit access and decreased vehicle ownership. Overall, the authors found that land use densification and improved access to transit can help to increase travel options and encourage modal shifts from driving to non-driving.

B. Applied Methods

- **California Department of Transportation (Caltrans). (2010). **Smart Mobility 2010: A Call to Action for the New Decade**. February 2010. <http://www.dot.ca.gov/hq/tpp/offices/ocp/smf.html>

In this guidebook, “Smart Mobility” is defined as the provision of a safe, efficient, and equitable transportation system that facilitates reductions in auto use and greenhouse gas emissions. Keys to Smart Mobility are the principles of location efficiency, reliable mobility, health and safety, environmental stewardship, social equity, and robust economy. The concept of location efficiency includes coordinating land use and transportation decisions to facilitate multi-modal travel while improving accessibility. Many features that can be categorized under the concept of the “Ds”: mixed land uses, high quality urban design, increased density, distribution of public facilities, and quality transit service. Next, reliable mobility emphasizes efficient congestion response, provision of multi-modal options, and avoidance of capacity increases that may induce vehicle travel. Important to the concept of health and safety is the promotion of “active” travel modes (e.g. walking, biking), system optimization to reduce injuries and fatalities, and reduction of public exposure to transportation related pollutants.

Environmental stewardship, from a Smart Mobility perspective, consists of preserving current infrastructure and development, enhancing the natural and built environment through transportation programs that encourage their preservation, and contribution to climate and energy sustainability through improved land use and transportation planning. The concept of social equity is discussed as focusing on efficient access to non-vehicular travel modes, and developing performance measures that evaluate the impacts of land use and transportation decisions on diverse population groups. Finally, a robust economy can be cultivated through Smart Mobility through improved freight operations, minimized transportation costs, and maximized public return on transportation investments through improved project foresight.

Seven “Place Types” are introduced, which are distinguished based on community design and regional accessibility, both of which have been shown to affect travel behavior. Priorities in each of these place

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types are defined for the advancement of Smart Mobility. Priorities in Urban Centers include: provision of efficient multi-modal travel, re-investment in existing roadways, and pricing strategies to optimize roadway and parking capacity.

Priorities in compact communities and compact communities in close proximity to urban centers include: improved transit and enhanced connectivity to foster non-motorized travel modes. Priorities in suburban areas include: increased connectivity to reduce average trip length, improved bicycle and pedestrian infrastructure, and investments to increase the efficiency of existing roadways. Included in the many performance measures proposed to determine the success of Smart Mobility implementation are transit mode share, and pedestrian and bicycle mode share.

- ****Cervero, R. (2006). *Alternative Approaches to Modeling the Travel-Demand Impacts of Smart Growth*. *Journal of the American Planning Association*, Vol. 72, No. 3, pp. 285-295.**

This study begins by noting that four-step trip-based travel demand forecasting models were not developed to estimate the travel impacts of neighborhood-level smart growth initiatives like transit villages, but rather to guide regional highway and major transit investments. It notes that while progress has been made in enhancing large-scale models to make them more sensitive to local, small-scale elements of smart growth, some analysts have turned to post-processing and direct models to reduce modeling time and cost, and to better capture the travel impacts of neighborhood-scale land use strategies.

This article presents examples of direct or off-line modeling of rail and transit-oriented land uses for greater Charlotte, the San Francisco Bay Area exurbs, and south St. Louis County. These alternative approaches provided a useful platform for scenario testing, and their results revealed that concentrating development near rail stations produced an appreciable ridership bonus. The study deems these alternative models are appropriate as **sketch-planning** supplements to, but not substitutes for, traditional travel models.

- **Chang, T. (2005). *Memorandum re: INFORMATION – Level of Service Technical Working Group Update*. San Francisco County Transportation Authority.**

This memorandum discusses the Transportation Authority Board's adoption of the Transportation Level of Service (LOS) Methodologies Strategic Analysis Report (SAR), which recommends adjustments to the measurement of transportation impacts as well as the review of transportation impacts under CEQA. Specifically, the SAR recommends that LOS be replaced with vehicle trips generated as an indicator of traffic impact. This ensures that improvements to transit, pedestrian, and bicycle infrastructure are not adversely impacted by unnecessary mitigation fees. In order to determine vehicle trips generated, the methodology outlined in the San Francisco Planning Department's Guidelines for Environmental Review is suggested. Additionally, the SAR recommends that mitigation fees for various projects should be combined in order to fund multi-modal transportation projects to mitigate growth at the system-wide level. The

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methodology mentioned for estimating vehicle trip generation will be examined in more detail as a part of our project's tools search.

- ****DKS Associates, the University of California, Irvine & Santa Barbara, and Utah State University (2007) Assessment of Local Models and Tools for Analyzing Smart-Growth Strategies – Final Report** (for Caltrans) http://www.dot.ca.gov/newtech/researchreports/reports/2007/local_models_tools.pdf

Objectives of this project were to: review existing local travel models in California, assess their ability to analyze the effects of smart growth strategies on travel behavior, and examine the availability of techniques and tools that can contribute to the overall sensitivity of travel models. More specifically, this paper discusses the extent to which the “4D” elasticities (density, diversity, design, and destinations) contribute to the sensitivity of travel models to smart growth strategies. The many limitations of the Urban Transportation Modeling System (UTMS), or the “traditional four-step travel demand model” as it is commonly known, are discussed regarding sensitivity to smart growth. Methods to overcome these limitations are introduced, which can be divided into four categories: (1) post-processor to UTMS for application of smart growth trip and VMT elasticities, (2) stand-alone tools for aggregate application of smart growth trip and VMT elasticities, (3) enhancement of UTMS models, and (4) integrated land-use, economic, and transportation models.

Next, the 4D elasticities are introduced, which measure the interactions between the characteristics of built environments, vehicle trips, and VMT. Included in the discussion of these elasticities is an overview of “Do's and Don'ts” provided by Fehr and Peers Consultants, which outline conditions for optimal use of 4D elasticities. Among other restrictions, they “indicate that the 4D elasticities were not appropriate for use in analysis of small-scale developments (below 200 acres) and/or in CEQA analyses. An overview of a few existing tools that utilize these elasticities includes: PLACE3S/I-PLACE3S, INDEX (both of which are “stand-alone tools for aggregate application of smart growth trip and VMT elasticities”), and URBEMIS. PLACE3S is a software tool for assessing and comparing planning scenarios. I-PLACE3S is an internet-based version of PLACE3S that the Sacramento Area Council of Governments (SACOG) developed and used in its regional Blueprint planning program. INDEX is a GIS-based sketch-planning tool developed by Criterion Engineering in Portland, Oregon that incorporates a 5th D (distance to heavy rail transit stations). Also discussed is URBEMIS, a primarily air-quality impact assessment tool that estimates multi-modal trip generation, VMT, and related air quality impacts of land uses up to 50 acres in size.

Next, the state of the practice of travel modeling in California is discussed. Though many smaller metropolitan planning organizations (MPOs) and regional transportation planning agencies (RTPAs) rely on travel demand models that lack sensitivity to smart growth, some of the larger MPOs and local jurisdictions have improved their models including: the San Francisco Transportation Authority, SACOG, MTC, SLOCOG, Contra Costa County, Humboldt County, Fresno and Madera Councils of Government, the City and the

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County of Sacramento, among others. To expand upon this analysis, case studies were presented of six cities in California regarding their plans to improve the sensitivity of their travel models, including four cities that use multi-modal travel models: (1) San Diego, whose model tests smart growth developments and transit focused areas, (2) San Jose, whose model incorporates certain socio-demographic variables (auto ownership and income), (3) Fresno, and (4) West Sacramento, both of latter two cities' models use a 4D post-processor. Other jurisdictions identified in the case studies were: the City of Irvine, which plans to incorporate the 4Ds in its travel model; and the City of San Luis Obispo, which has tested the potential use of 4Ds elasticities for planning.

- Ercolano, J.M., Olson, J.S., & Spring, D.M. (1997). **Sketch-Plan Method for Estimating Pedestrian Traffic for Central Business Districts and Suburban Growth Corridors.** *Transportation Research Record*, 1578, 38-47.

This paper analyzes a method to determine future peak-hour pedestrian-trip volumes in central business districts and suburban growth corridors. The method consists of three steps: 1) Estimating sources of pedestrian trips (i.e. determining potential sources of pedestrian trips from motor vehicle, transit, and walk and bike-only trips), 2) Estimating average peak pedestrian-per-hour (pph) trip rates per person (i.e. estimating peak pph using vehicles-per-hour (vph) and other mode data), and 3) Determining pph trip distribution and assignment. The second step is of particular interest for this analysis. These steps were tested using two different methodologies for the estimation of peak pph trip rates in the town of Plattsburgh, NY. The first of these methodologies is a mode-based estimation for pedestrian trip generation rates. In this methodology, pedestrian trips are divided into three types: 1) Car-walk linked person-trips (CWL trips – estimated at 90% of total mode share), 2) Walk-only and bike-only person-trips (WBO trips – estimated from census data for the state of NY to be 7%), and 3) Transit-walk linked person-trips (TWL trips – estimated from census data to be 3%). The peak pph for the first type of pedestrian trips (WBO trips) is calculated using the following methodology, taking into account through-trips and vehicle occupancy:

$$\text{Peak pph} = (\text{Peak vph} - \text{through-movement trips}) = [(\text{vph turning movements}) \times (1.5 \text{ default average vehicle occupancy}) \times (5 \text{ trips per person}) \times (20 \text{ percent drive-through, etc.})]$$

The second methodology used to estimate peak pph trip rates is based on land-use. The first step in this methodology was to estimate the on-site trip rate average, which is assumed to equal the local trip rate times 93 m². This will be of greater significance in the final step of the methodology. The second step is to adjust this data for various land uses. The adjustment factors are as follows: 0.67 for urban areas with populations up to 50,000, 2) 1.0 for urban areas with populations from 50,000 to 500,000, and 3) 1.33 for urban areas with populations from 500,000 to +1,000,000. Third, a peak-hour adjustment factor was determined based on historical pedestrian-peaking characteristics and variations in peak demand by land use types. This factor was determined to be 1.5 times the average hourly volume for peak hours (to be

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applied to the average trip rate during peak hours). Finally, in order to calculate the total peak pedestrians per hour walk trips as generated by land use, the following formula was used:

$$\text{Total peak pph (for each TAZ by land-use type)} = (\text{total m}^2 \text{ per TAZ} / 93 \text{ m}^2) \times (\text{av. trip rate as calculated above})$$

When these two methods were compared, the mode-based pedestrian trip generation model was found to be 9% less on average than the land-use pedestrian trip generation model. Although this methodology is simple and straightforward, the methodology for deriving the adjustment factors and numbers is not provided.

- Fulton, W. & Aubry, R. (2005) **Utilizing GIS to Help Both Cities and Developers Analyze Infill Development Potential**. Solimar Research Group, Inc.
http://www.esri.com/industries/planning/docs/solimar_gis.pdf

This paper outlines the creation of and potential uses for the Infill Analysis Tool created by Solimar Research Group. This tool uses GIS software and Microsoft Excel to analyze which areas within a city would be appropriate for infill development. Since its creation, the tool has been used by housing developers in New York, New Jersey, and California. The tool relies on a combination of parcel-level data (e.g. parcel vector data, assessor attribute data, and zoning data) and block- or district-level data (e.g. census data, employment data, environmental constraints, transportation data, infrastructure capacity and scheduled capital improvements, etc.). In the transportation sector, the tool can be used to identify where infill sites would best be located in order to take advantage of existing transportation infrastructure, as well as to better forecast the environmental impacts of infill policy proposals under CEQA. This is the case as the tool allows policymakers to focus specifically on the parcels eligible for redevelopment under a given policy, instead of assuming all parcels would be eligible. Though no direct examples were provided regarding the ability of the tool to estimate the environmental (or traffic) impacts of infill development, this paper provides an interesting overview of the process used to develop a user-friendly tool using software that is readily available for most practitioners.

- **Johnston, R. (2008) **Review of U.S. and European Regional Modeling Studies of Policies Intended to Reduce Transportation Greenhouse Gas Emissions**. *Institute of Transportation Studies*, University of California, Davis, Research Report UCD-ITS-RR-08-12.
http://pubs.its.ucdavis.edu/publication_detail.php?id=1166.

With the enactment of new federal transportation legislation in 2005, State and regional transportation plans and programs are for the first time required to achieve the objectives of the SAFETEA-LU planning process, which focus on enhancing mobility and supporting economic development, while minimizing conventional emissions and greenhouse gas emissions. In 2007, the U.S. Supreme Court held that greenhouse gases are a pollutant and so are covered by the Clean Air Act and, consequently, the USEPA can

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regulate them. California and 13 other states are now attempting to regulate the emissions of greenhouse gases from vehicles.

The results from over 40 long-range regional scenario exercises performed in the U.S. and Europe demonstrate that substantial reductions in vehicle-miles of travel (VMT), fuel use, and emissions of both criteria pollutants and greenhouse gases are possible using transportation pricing policies and investment priorities that have been demonstrated as acceptable and effective in a modest but growing number of metropolitan areas and regions around the world. These studies show that substantial reductions in travel and emissions of pollutants and greenhouse gases are possible (10%-30%, compared to the future base case), but only with combined transportation investment, land use, and travel pricing policies.

- ****Matley, T., Goldman, L., & Fineman, B. (2000). Pedestrian Travel Potential in Northern New Jersey: A Metropolitan Planning Organization's Approach to Identifying Investment Priorities. *Transportation Research Record*, 1705, 1-8.**

This paper outlines the development of a “pedestrian potential index” (PPI) by the New Jersey Transportation Planning Authority (NJTPA). The NJTPA developed this tool in order to determine where increased pedestrian trips may take place if the proper infrastructure were developed. The PPI is based on the relationship between land use mix, density, and urban design, with a strong emphasis on the importance of proximity and connectivity. Census tract level data were used to measure gross employment density, gross population density, and land use mix as indicators of proximity, in addition to street network density as an indicator of connectivity. Employment density and population density were calculated per square mile, using only census information. In order to measure land use mix, an entropy formula was used to determine how evenly land areas in each tract were distributed among different land use types. Finally, street network density was measured in street miles per square mile using GIS and census tract land areas. All of these indicators were verified through a comparison with cities of three distinct land use types (urban, suburban, and rural). A low and high threshold was set for each indicator, and a census tract had to pass three of the four thresholds in order to be considered a “high potential” pedestrian area. Those tracts passing the higher threshold were considered high priority areas for improved pedestrian infrastructure. Though this process does not directly estimate pedestrian trips generated, it is an effective method of using readily available data to produce indicators of walkability at the census tract level.

- ***Muldoon, D., & Bloomberg, L. (2008). Development of Best Practices for Traffic Impact Studies. *Transportation Research Record*, 2077, 32-38.**

The Oregon Department of Transportation (ODOT) completed a Best Practices for Traffic Impact Studies (TISs) in response to concerns that TISs are typically not as accurate as they could be. As a part of the research for this project, case studies for actual developments were conducted to verify estimated traffic impacts, in addition to a literature review regarding the state of the practice. Based on verification of case

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studies, trip generation estimates tended to overestimate peak-hour trip generation. It was determined that this overestimation is in part due to confusion regarding the proper use of ITE's *Trip Generation*. Cited sources for such errors include improper land use code selection, inadequate assessment of pass-by trip reductions, failure to consider seasonal variations in traffic counts, and lack of multi-modal evaluation. Although this project seems to do little more than advise practitioners to exercise caution when using ITE's *Trip Generation* estimates, it certainly supports arguments in favor of a context-sensitive trip generation tool to for Traffic Impact Studies.

- ****Replogle, M. (1993). Land Use/Transportation Scenario Testing: A Tool for the 1990s.** Transportation Research Board 72nd Annual Meeting.
<http://tmip.fhwa.dot.gov/resources/clearinghouse/docs/landuse/luts/luts.pdf>

This paper begins by discussing the need for alternative analysis methods for land use and transportation scenarios. In particular, scenarios that do not favor automobile oriented development are emphasized. The author discusses the inadequacies of standard methods used to determine transportation impact fees for new developments (particularly their insensitivity to urban design factors). Next, advancements in modeling efforts which include more long-range planning scenarios are discussed. Of particular focus are planning efforts that were underway in Montgomery County, Maryland at the time. Montgomery County crafted various planning scenarios incorporating different growth levels and jobs/housing mixes, in addition to different types of growth in transportation infrastructure. These scenarios were tested in particular for their effects on VMT. Ultimately, based on the Montgomery County scenarios, the author concludes that VMT and mode share can be influenced by transportation incentives and enhancements, urban design, and changes in land use patterns that complement transportation investments. Though this paper is somewhat outdated, it serves as an interesting indicator that the issues inherent in current transportation impact analysis methods have been recognized as significant impediments for decades.

- ****Rodier, C.J. (2009). An International Review of the Modeling Evidence on the Effectiveness of Transit, Land Use, and Auto Pricing Strategies.** *Transportation Research Record*, 2132, 1-12.

With an eye toward recent greenhouse gas (GHG) reduction legislation in California, this paper reviews the international modeling literature on land use, transit, and auto pricing policies. Modeling-based studies in California, elsewhere in the US, and in Europe are analyzed to suggest a range of VKT and GHG reduction that regions might achieve if such policies were implemented separately or in combination. To account for the fact the three types of policies examined have different time frames for full implementation and effectiveness (e.g., land use changes take longer to be effective than pricing changes), the author develops order of magnitude estimates for 10-, 20-, 30-, and 40-year time horizons.

The review concludes that land-use-only policy packages can potentially reduce VKT by up to 2% in the 10-year time horizon. The effectiveness of land use strategies may increase by approximately 2 to 3

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percentage points to a higher reduction level at 10-year increments. Land use plus transit scenarios may reduce VKT by 2% to 6% during a 10-year time horizon, and these figures may increase by approximately 2 to 5 percentage points for each future 10-year increment. Combined land use, transit, and pricing policy measures would bring significantly greater reductions in both the shorter- and the longer-term time horizons. The review also concludes that even improved calibrated travel models are likely to underestimate VKT reductions from land use, transit, and pricing policies. Most California models are not yet suited for the policy analysis demands in the era of global climate change.

- Samdahl, D.R. (2009). **Multi-Modal Impact Fees**. *Washington State ITE Newsletter* Vol. 19, No. 8, 9-13. <http://www.westernite.org/Sections/washington/newsletters/Samdahl%20multimodal%20impact%20fees.pdf>

This article outlines the process used by the cities of Seattle and Portland, OR to assess appropriate multi-modal allocation of revenue generated by traffic impact fees. In order to do this, the cities had to develop methods of determining multi-modal trip generation rates. Seattle's method utilized data from the regional household activity survey in order to determine the typical person trips to vehicle trips ratio. This allowed them to convert ITE's vehicle trip generation rates to person trip generation rates. Then modal split factors from the same survey were used to determine the total person trips per mode. Portland took a similar approach to determine multi-modal trip generation rates. Again, ITE vehicle trip generations rates were converted to person trip generation rates. In this case, two factors were combined to determine person trips from vehicle trips. These factors were (1) average vehicle occupancy for Portland, based on a region-wide traffic count, and (2) a motorized mode share determined for geographic conditions such as those on which the ITE trip generation rates are based (90%). Once person trips were determined from vehicle trips, they were split into modes using 2017 travel forecasting data for Portland.

Additionally, the number of vehicle trips was multiplied by an unspecified trip length adjustment factor. The assumption behind this effort is that a method for assessing multi-modal impact fees will be necessary as urban areas will no longer be able to accommodate further road development and growth of vehicle infrastructure. Thus, the enhancement of multi-modal infrastructure to accommodate increased trip rates associated with new development projects will be a better investment of revenue collected from traffic impact fees. Overall, this paper provides a fairly simple method for deriving multi-modal trip generation estimates from ITE estimates. However, this methodology may not be ideal to incorporate into a tool for widespread use as it relies heavily on local travel data.

- *San Francisco Planning Department. (2002). **Transportation Impact Analysis Guidelines for Environmental Review**. <http://www.sf-planning.org/Modules/ShowDocument.aspx?documented=6753>

This document introduces guidelines for conducting traffic impact analyses (TIAs) in the City and County of San Francisco. Included in these guidelines are estimates of person-trip generation rates for different land

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use types. The land uses included in these estimates are representative of most of the current developments in San Francisco. If a particular land use is not listed in the document, the planning department encourages the use of the SANDAG tool or ITE's *Trip Generation*, using average auto occupancy to convert vehicle trips to person-trips. The trip generation table provided in this document provides estimates of person-trips generated per square feet, in addition to percentage splits between work and non-work trips for a 24-hour period, as well as the PM peak period. Sources of these estimates include data from the Citywide Travel Behavior Survey, various environmental impact reports (EIRs) including Mission Bay 1990 FEIR, 525 Golden Gate FEIR, and 1000 Van Ness FEIR, as well as ITE *Trip Generation*, 6th edition. Although this trip generation table is simple and user-friendly, the methodology used to estimate the numbers provided in the table is not well documented in this paper.

- **Turner, S., Hottenstein, A., & Shunk, G. (1997). **Bicycle and Pedestrian Travel Demand Forecasting: Literature Review.** Texas Transportation Institute. <http://tti.tamu.edu/documents/1723-1.pdf>

Researchers from the State of Texas Department of Transportation (DOT) performed a review of the literature regarding current practices in bicycle and pedestrian travel demand forecasting techniques, as a preliminary step in the development of a methodology of forecasting bicycle and pedestrian travel demand in Texas. This review identifies four basic categories of bicycle and pedestrian demand forecasting models: (1) aggregate or simplified trip generation models (using survey data at the zonal level to predict the extent of bicycle and pedestrian travel demand at this level); (2) facility locator or “market travelshed” models, which treat bicycle and pedestrian facilities as trip destinations; (3) sequential stand-alone bicycle and pedestrian demand models similar to current four-step traffic models; and (4) four-step traffic models modified to account for bicycle and pedestrian environments.

Many of the models discussed are not entirely relevant to site-specific trip generation, as they are estimated at the zonal-level (e.g. TAZ, census tract, etc.). One model used bicycle trip generation rates per capita in order to estimate new bicycle trips generated by a bike path in Rhode Island. This model used rates developed previously by planners in the state of Pennsylvania for a similar project, which were later compared to actual trip counts and were found to overestimate bicycle trips by about 10 to 15 percent. These rates are provided in Table 1 of the paper; however, they are based on relatively old data from the 1980s. Of further interest are the models that provide correlations for variables thought to affect bicycle and pedestrian trips (i.e. Dade County Demand Models, North Central Texas Council of Governments' (NCTCG) Bicycle Needs Index, and NCTCG's Pedestrian Needs Index). Though these correlations are based on somewhat newer survey data (1990s) they are still outdated.

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- University of North Carolina, Highway Safety Research Center. (1994). **A Compendium of Available Bicycle and Pedestrian Trip Generation Data in the United States.**
<http://drusilla.hsrrc.unc.edu/cms/downloads/BikePedTripGenerationData1994.pdf>

This report summarizes the findings of bicycle and pedestrian counts, surveys, and studies conducted in various cities to estimate the effects of bicycle and pedestrian facilities. The document includes many charts and tables displaying various bicycle and pedestrian counts conducted in cities throughout the United States. Overall, this document is a rich source of data (albeit quite old) and methodologies for bicycle and pedestrian trip data collection. As this research was focused on trip generation counts and estimates for bicycle and pedestrian facilities (e.g. bike lanes, sidewalks, recreational paths, etc.), it is not directly applicable to trip generation estimates for developments, but it provides an interesting assessment of what environmental factors influence biking and walking trips.

Of particular interest is a methodology for assessing pedestrian level of service (A through F) based on square feet per pedestrian, average speed, and flow rate taken from the Transportation Research Board's *Highway Capacity Manual*. However, other researchers (Seneviratne and Morrall, 1985) have argued that this is not an appropriate method of analyzing pedestrian level of service as it does not take into account enough environmental captures to account for an area's "walkability." Also of interest is Table 7-1 in this document, which presents rates of bicycle and walking for major trip purposes in large urban areas (>1 million) with rail transit, large urban areas without rail transit, and small urban areas (<1 million).

One interesting finding demonstrated in this table is that levels of biking and walking are usually similar between small urban areas and large urban areas without rail transit. Ultimately, this study found that data for bicycle trips were more readily available than data for pedestrian trips, potentially due to the relative ease of collecting bicycle data as opposed to collecting pedestrian data. Unfortunately no studies were found that assigned bicycle and pedestrian trip generation rates to a wide range of land uses. Thus, the authors recommend using local modal split data to convert ITE *Trip Generation* estimates into multi-modal trip generation rates

- Vernez Moudon, A., Kavage, S.E., Mabry, J.E., & Sohn, D.W. (2005). **A Transportation-Efficient Land Use Mapping Index.** *Transportation Research Record*, 1902, 134-144.

This paper explores a Transportation-Efficient Land Use Mapping Index (TELUMI) that was developed by the Washington State Department of Transportation (WSDOT) in order to better-evaluate the effects of land use patterns on Level of Service (LOS). The idea of Land Use Level of Service (LULOS) is introduced as a more comprehensive, less mode-specific alternative to traditional LOS. In a LULOS the capacity and characteristics of the entire transportation network for a given area would be examined relative to the total number network users, regardless of mode-choice. The result would be a multi-modal travel behavior model as opposed to models looking at LOS for single modes.

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WSDOT's TELUMI is an instrument which incorporates the concept of LULOS. TELUMI takes into account multi-modal networks, in addition to context-sensitive trip generation. Land use variables that relate to travel behavior are established, and then Cartographic Modeling (CM) techniques are used to explore the relationship between these variables and different levels of transportation-efficient land use. Then, different levels of transportation efficiency are identified, which correspond to standard LOS levels. The result is a tool which can receive a variety of different types and quantities of input and in turn produce a visual and quantitative output that is a better indicator of an area's true LOS for all network users. This tool also incorporates context-sensitive trip generation rates derived from ITE rates, but the methodology for doing so is not provided.

- Walters, G., Ewing, R., & Schroerer, W. (2000). **Adjusting Computer Modeling Tools to Capture Effects of Smart Growth: Or “Poking at the Project Like a Lab Rat.”** *Transportation Research Record*, 1722, 17-26.

This paper describes the application of travel forecasting methods to determine the air quality impacts of a mixed-use, infill development centrally located in Atlanta that required construction of a bridge in order to make it a viable project. Many design and travel demand management variables known to affect travel demand (i.e. the “Ds”) were taken into account in the analysis of this project, in order to determine whether such a project would have less environmental impact than a similar project in a less central, undeveloped area.

The literature on the Ds was used to develop adjustment factors, and analysis of the site was facilitated by the “INDEX” GIS-based scenario-planning tool. Ultimately it was determined that regional location and site design can be used to foster multi-modalism, which in turn can lead to reduced emissions and environmental impacts. Specifically, travel reductions for the mixed use, infill site were found to be 14 to 52 percent compared to development at greenfield locations. Such findings indicate a need for tools that analysts can use in order to determine reductions in trip generation from site location and design.

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