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by Michael G. McNally and Anup Kulkarni

Abstract

This paper presents an empirical assessment of the interaction between the land use - transportation system and travel behavior. A methodology is developed to identify a range of land use-transportation systems using a clustering technique with network and land use inputs. Twenty neighborhoods from Orange County, California were considered in this process. Three groups, or themes, were found to best represent the neighborhoods in the sample area, one each associated with the conventional definition of neotraditional (TND) and planned unit development (PUD) neighborhoods, and one representing neighborhoods which blend characteristics of TND and PUD. Conventional measures of individual travel behavior were compared via an analysis of variance between the themes to identify significant differences, controlling for socio-economic characteristics. Research results include the development of (a) a systematic methodology to identify a more explicit land use and transportation dimension, (b) an estimate of the potential effectiveness of design-oriented solutions to reduce automobile congestion using the developed themes, and (c) a preliminary assessment of the extent to which development themes can be utilized to improve the current modeling framework.

Keywords: neighborhood development patterns, travel behavior

INTRODUCTION

Transportation planners today must deal with a variety of important problems concerning increased automobile congestion on urban networks. Traditionally, such problems are addressed with both supply-side and demand-side initiatives. The former range from the conventional (e.g. infrastructure expansion) to the innovative (Intelligent Transportation Systems), both of which aim to increase transportation system capacity. The later policies range from employer-based travel demand management to telecommuting to other evolving programs. For the most part, both policies have had only marginal success in reducing automobile congestion. As a result, a renewed and more subtle response to combating congestion has emerged: designing the land use-transportation system (LUTS). Since transportation demand derives from our requirement to participate in diverse activities, variations in the basic network and land use structure will to some extent influence revealed travel behavior. Developers and planners in the last century have employed land use strategies in creating the "Garden City", planned unit developments (PUD, the quintessential suburb), traditional and neotraditional neighborhood design (jointly referred to as TND), and transit oriented design (for a summary, see *1*). TND has been popularized in the last decade by urban designers and architects in reaction to the "degraded quality of life in the suburbs [due to] a lack of conveniently assembled land uses and the domination of the automobile" (*1*). **Table 1** provides a more detailed comparison of PUD and TND developments.

Proponents of this approach believe that TND neighborhoods encourage the use of alternatives to automobile travel and promote shorter and fewer trips and, in fact, lead to a better quality of life. Conversely, they believe that PUD neighborhoods support (if not force) auto-dependent travel behavior, promoting longer, drive-alone commutes through their segregated land uses, low residential densities, and lack of nearby employment. In fact, the 1991 Clean Air Act Amendments (CAAA) open the possibility for design-oriented solutions such as TND as an alternate means to satisfy the requirements in reducing automobile congestion and improving air quality. Harvey and Deakin (*2*) state that this "new legislation...retains great latitude for substitution among alternative approaches [including]...land use modifications." Therefore, many transportation planners believe they may address current shortcomings through design-oriented solutions.

Many researchers, however, question whether design-oriented solutions like TND can effectively reduce congestion. Giuliano (*3*) has argued that the land use-transportation connection may be weakening, casting doubt on the belief that travel choices are strongly influenced by the urban system and that land use changes can be an efficient remedy to control automobile use. And even where evidence of a land use-transportation connection exists, some researchers question the notion of causality. That is, residents living in a particular type of community (i.e., TND or PUD) might be predisposed to particular lifestyles and that attitudinal factors or the socio-economic and demographic characteristics of residents, rather than the land use and transportation system itself, may be stronger factors in influencing travel behavior. This paper, therefore, examines the nature of the fundamental relationships between land use-transportation systems and travel behavior in order to assess the effectiveness of policies which advocate land use modifications to promote travel behavior changes.

In addition, this paper will also address the possibility of improving the current transportation modelling practice by including, more explicitly, the land use-transportation system and, in doing so, questions concerning the effectiveness and causality of using design strategies to reduce automobile travel are addressed. The transportation modeling process has been criticized in the past as an outdated process with a limited ability to accurately model traffic. The many shortcomings of the process were for the most part systematically ignored by the profession until the CAAA, the Intermodal Surface Transportation Efficiency Act, and lawsuits dictated that the models be improved. As a way of fueling this improvement, the United States Department of Transportation stepped in on the behalf of state and local transportation authorities and introduced the Travel Model Improvement Program. This program has identified land use and transportation interactions as an area where potentially vast improvements in the planning process can be realized. This paper will examine this relationship in hopes of incorporating this complex dimension into the transportation forecasting process.

A REVIEW OF THE LITERATURE

Design interest within the transportation field began with the introduction of the concepts and the development of traffic engineering standards for TND communities (Lerner-Lam, et al., *4*). Later work with TND tested the performance of the interconnected street networks versus conventional networks. Using simulation studies on certain trip criteria such as network capacity, travel speed, and travel time; Kulash (*5*) and McNally and Ryan (*6*) found that, in general, TND tends to reduce overall trip lengths and reduce automobile travel speeds. Two notable studies built on this work and introduced changes in urban form to more fully simulate TND effects: Stone and Johnson (*7*) and the Middlesex-Somerset-Mercer Regional Council (MSMRC) (*8*). Stone and Johnson compared hypothetical subdivisions and found that TND has less vehicle delay and fewer trips generated than the conventional suburb. The MSMRC study simulated different types of development and identified mixed land uses, a balanced jobs to housing ratio, and increased residential densities as the key factors behind the reduction in automobile trips.

Puskarev and Zupan (18) found that as urban density increases, more transit trips occur at the expense of auto trips. To examine the impact of TND more realistically, empirical studies using various density measures were conducted. Newman and Kenworthy (*9*) compared different cities around the world with different population densities and their travel behavior. Their analysis indicated that high population density cities seem to be less auto dependent than low density cities. Holtzclaw (*10*) compared five different neighborhoods in the Bay Area using activity density and found that higher activity densities resulted in lower overall vehicle miles traveled. Frank and Pivo (*11*) looked at transit usage for work and shopping trips and found a negative relationship between employment density, population density, and land use mix (collectively) and single occupancy vehicle usage; conversely, a positive relationship was identified between these variables and both transit use and walking. Handy (*12*) used trip distance and trip frequency to compare different urban forms by characterizing a community by local and regional accessibility. Using Bay Area land use and travel survey data, Handy found that shopping travel distance significantly decreases with increasing local and regional access; however, no such relationship was found between either local or regional accessibility and shopping trip frequencies.

Several studies have extended their focus on density measures to more accurately consider the land use-transportation system. Friedman *et al*. (*13*) compared areas of high density, mixed land use, and highly interconnected transportation networks (TND's) against conventional (PUD) communities. Their findings were pronounced: TND communities had substantially lower daily trip generation rates, a lower proportion of drive alone trips, and higher a percentage of public transportation trips. Cervero (*14*) considered "automobile neighborhoods" and "transit neighborhoods" based on certain predefined characteristics and found that auto-orientation produced higher drive alone trip generation and mode split rates than transit neighborhoods. Handy (*15*) identified four Bay Area neighborhoods with comparable regional accessibilities and socio-economics as either typical suburban or traditional based on local accessibilities (which were lower and higher, respectively). Handy found that highly accessible communities possibly encourage walking as a viable option for commercial and other non-work trips. Finally, Ewing *et al*. (*16*) examined the relationship of location and land use to travel patterns and concluded that vehicle hours traveled decreases with increasing neighborhood accessibility and that the travel time savings resulting from trip chaining are greater for communities with less accessibility.

As mentioned earlier, many questions still exist as to the causality of these apparent differences in travel behavior. In a study by Kitamura *et al.* (*17*), the significance of this causal relationship of the land use-transportation system and travel behavior was examined using a series of regression models. The authors hypothesized that certain types of neighborhoods attract "residents with certain demographic and socio-economic attributes, attitudes and values...[which] are the true determinants of their travel behavior." They found that the attitudinal variables tend to explain the most variance in the trips and mode splits and socio-economic variables generally explain more of the variance than neighborhood variables.

RESEARCH HYPOTHESES

Current work in planning and development suggests that two distinct neighborhood themes may be defined: PUD and TND. Such a binary categorization, however, oversimplifies the definition of neighborhood themes. While well-defined PUD and TND neighborhoods exist, they are not exhaustive in their representation. This rigid two-theme format can be expanded to reflect developments indigenous to individual regions which are not necessarily comparable to other regions. Whereas these two major classifications define the extremes of thematic development, it is clear that, in practice, many developments will have attributes of both defined classes, leading to one or more categories of what are referred to as hybrid or mixed developments (MIX). Each of these three (or more) broad themes refers to the overall style of the development pattern which defines density, land use intensity and distribution, and network configuration within the neighborhood.

It is hypothesized that, first, hybrid themes exist, and second, that these network and land use structures can be identified and classified using a vector of network, land use, and accessibility attributes. Third, it is believed that these alternate structures display significant differences in household travel behavior even when controlling for household socio-economic characteristics. These hypotheses will be tested via the development and analysis of relationships between descriptors which identify alternate LUTS profiles (or neighborhood themes) and those which are conventionally used to classify household travel behavior.

APPROACH AND METHODOLOGY

There are few empirical studies which fully encompass the breadth and depth necessary to understand the complex and evolving interaction between the land use-transportation system and travel behavior. The analysis comprised of two sequential aspects. First, the problem of classifying neighborhoods was addressed through a clustering process. The input was a set of attributes that define the neighborhood and the output is the categorization of these neighborhoods into subgroups. Second, a conventional household travel analysis was undertaken to examine travel and socio-economic characteristics of identified neighborhood classifications.

This analysis proposes to contribute an increased understanding of LUTS by explicitly considering the differences of aggregate household travel across varying neighborhood structures. Further, the socio-demographic makeup of the development themes was analyzed to test to what degree any observable differences in travel behavior can be attributed to differences between neighborhoods. Finally, the proposed methodology allowed for an assessment both of policy initiatives which attempt to modify travel behavior and of possible improvements in the current planning process through the explicit incorporation of a LUTS dimension.

DATA

The following sets of data representing Orange County, California provide a comprehensive base for the proposed analysis:

(1) an ARC/INFO land use database from the Orange County Administration Office

(2) 1990 Census Tiger files for the Orange County transportation network

(3) Orange County subset of the Southern California Association of Governments (SCAG) 1991 Origin-Destination Survey

The land use database was utilized with the Census Tiger data files to identify and extract potential classification attributes of the selected neighborhoods while the SCAG survey was used in the travel behavior analysis. The survey includes a 24-hour travel-activity diary for all household members over 5-years of age in addition to conventional household socio-economic and vehicle characteristics.

CLUSTERING NEIGHBORHOODS AND IDENTIFYING THEMES

Neighborhood Selection

In the northern part of Orange County, virtually the entire freeway system was established by 1970, and a predominantly grid-oriented arterial pattern emerged. During the last 25 years, this grid-type development was abandoned in favor of an irregular, circuitous road network and segregated land uses of the PUDs. This type of development occurred primarily in the southern part of the county as well as through in-fill development throughout. Given this variation, study neighborhoods were selected with the goal of capturing these inherent contrasts; the neighborhoods selected met the following criteria:

(1) variation in the transportation network and land use patterns between neighborhoods

(2) consistency in network and land use patterns within neighborhoods

(3) lack of intervening disturbances in neighborhoods

(4) sufficiently high neighborhood response rates to the SCAG survey

Twenty neighborhoods (see **Figure 1** and **Table 2**) were selected for analysis. Note that the initial selection of neighborhoods was determined by the density of responses to the household survey and a subjective assessment of what constitutes a spatially recognizable neighborhood. Therefore, well-developed, established neighborhoods were more likely to appear in the sample. Nevertheless, it is believed that the selected neighborhoods are generally representative of most thematic developments common to Orange County.

Index Selection

Index selection required a balanced analysis of attributes which capture salient characteristics of neighborhoods and which are readily calculable from the data. Final indices (see **Table 3**) were selected from a large set of indices developed to quantitatively describe neighborhoods (see **Table 4**); these indices may be classified as (1) network characteristics, (2) land use characteristics, and (3) accessibility aspects of neighborhoods.

The network indices provide information about the pattern of the neighborhood transportation system. These indices captured differences in network structure among the different neighborhoods. The land use indices discriminate neighborhoods along various dimensions which define the land use distribution (in terms of absolute and relative proportion); residential and commercial land uses were primarily selected. Also, measures of accessibility for residential land uses within an identified neighborhood were computed relative to the spatial distribution of residential, commercial, commercial/industrial, and other land uses within a 15 kilometer radius. This construction of network, land use, and accessibility values provided a comprehensive quantitative snapshot of the neighborhood land use-transportation system.

The indices selected for classification required *a priori* judgments regarding the ability of the elements to discriminate among neighborhoods and to provide an understanding of neighborhood structure. Many of the network, land use, and accessibility attributes calculated were considered as a part of the classification, but the final clustering attributes were selected primarily because of (1) their perceived importance in the progression of development patterns as documented by the reviewed literature and (2) their success in identifying distinct themes. This subset of the indices (see **Table 3**) were used to formally group the neighborhoods using cluster analysis. The selected classification attributes included network attributes (ratio of four-way intersections, ratio of cul-de-sacs, ratio of all entrances to the neighborhood perimeter, and density of intersections) and land use attributes (ratio of commercial area and population density to total area). The remaining network, land use, and accessibility attributes calculated will be used in analyzing the clusters rather than for defining them.

Classification Procedure

Clustering is a technique for dividing a set of cases into homogeneous subsets based on similarities. The measure of similarity used here is euclidean distance based on the case's values on each of the k variables under study. A k-means clustering algorithm is used, which maximizes the between group relative to within-group variation of the cluster members. The steps for the clustering are: (1) select a potential range of initial cluster centers, (2) assign objects to the nearest cluster center, (3) update cluster means, (4) repeat steps 2 and 3 until cluster membership is stable, and (5) calculate between and within variations and pseudo F-ratio.

Prior to analysis, values of the indices were standardized to eliminate any bias due to scale. Objects are assigned to initial clusters which are specified by picking seed cases for each cluster, dispersed from the center of all the cases as much as possible. Objects are assigned to the nearest seed and the procedure continues as outlined above. The pseudo F-ratio is defined to measure the statistical significance of the resulting groups. Higher F-ratio values indicate a higher degree of distinction between the resulting groups and a high degree of homogeneity within each individual group; lower

F-ratios indicate a limited amount of group distinction. Further, differences between the resulting clusters can also be identified using the centroids of the clusters with respect to the indices used in the clustering as well as other indices developed.

Classification Results

The neighborhoods were categorized based on standardized classification indices which characterize the salient aspects of each neighborhood. The classification procedure was intended to, first, quantitatively establish measures which discriminate between PUD and TND neighborhood themes, and second, to statistically identify the number and type of MIX themes. The neighborhoods were cluster analyzed for two, three, and four groupings using a k-means clustering algorithm in the computer statistical package SYSTAT. The resulting clusters were judged based on pseudo F-ratios, size of clusters, the relative ability of the clusters to capture the differences among neighborhoods, and the response rate to the SCAG survey. The last condition was introduced to insure that an adequate sample existed in order to measure possible travel behavior differences. The goal was to best capture the distinctive network and land use topology of Orange County while maintaining the homogenous nature of the groups.

Early trials resulted in relatively inconsistent clusters with three outlying neighborhoods: Garden Grove (West A), Newport Beach (West Bay), and Santa Ana (West). Therefore, clustering for the two, three, and four groups were conducted with the three neighborhoods separated. They were subsequently joined in respective fashion to the nearest cluster centroid based on similarities calculated using Euclidean distances. The result was a more stable set of groupings for all three cases. The three group model, consisting of two extreme themes referred to as PUD and TND and a hybrid of the two named MIX, was selected for further analysis (**Table 2**). It was judged to best satisfy the outlined selection criteria and, as a result, best represent the different types of neighborhoods in Orange County. The deviation units from the mean for each utilized attribute were calculated for each theme and are presented in **Table 3**; other network, land use and accessibility mean statistics are provided in **Table 4**. The groups TND, MIX, and PUD contained five, eight, and seven neighborhoods, respectively.

Identified Themes

When the neighborhoods were clustered into three groups, the primary and secondary differentiating factors were those associated with transportation and land use, respectively. The PUD theme is composed of neighborhoods which have circuitous transportation networks with many cul-de-sacs, a very limited number of access points in the neighborhood, very segregated land uses, and low residential densities. TND neighborhoods tend to possess grid-like transportation networks with little or no cul-de-sacs, a large number of access points into the neighborhood, and high population densities. Further, they tend to have lower than average values for all residential land areas while maintaining larger than average commercial land uses (strip and overall). MIX neighborhoods have land use-transportation systems that possess the amenities of both the TND and PUD themes. For instance, MIX neighborhoods have many cul-de-sacs and a large ratio of land devoted to single family housing like the PUD, but also maintain an overall grid structure on major arterials. MIX also have integrated land uses similar to that of TND with much land zoned for commercial and general development. Population densities are between those of PUD and TND as are all the accessibilities. Representative network patterns are depicted in **Figure 2** for each of the identified neighborhood themes.

Overall, it is believed that the method described in this section represents a significant first step in the understanding of the land use-transportation system in that it quantitatively distinguishes among different systems. Further, the results are not only statistically significant, but are representative of real developments and the design movements which inspired them.

SOCIO-ECONOMIC MAKEUP OF THE THREE-GROUP THEMES

Household and individual socio-economic information (both absolute numbers and relative proportions) provided by the respondents of the SCAG 1991 travel survey were compared by theme. Notable individual and household socio-economic differences among themes are apparent from **Table 5**. TND neighborhoods tend to have lower income households, smaller household membership sizes, younger adults or families with young children, and are less likely to own as many vehicles or have as many individuals with driver's license as MIX or PUD neighborhoods. Further, households in TND are more likely to live in an apartment or condo rather than a single family house. In contrast, PUD households are most likely to live in single family houses. Moreover, they tend to have higher incomes, a larger number of household members, families with school aged and older children, and are more likely to own more vehicles and have more licensed drivers than households in the other themes. Finally, MIX households for the large part tend to have socio-economic characteristics which are hybrids of the two extreme neighborhoods. This is particularly true for the number of household members, number of automobiles, and driver's license holders. In addition, MIX households tend to be live in single family houses and are comprised mainly of single adults, families with very young children, and a very high ratio of families with older children, no children, or retirees.

Comparisons revealed that clear socio-economic differences among the themes did exist. Therefore, it is necessary to control for these identified differences. In order to do so, income groups will be used as a proxy for the socio-economic differences between the themes to determine the degree to which they affect travel behavior. Three income groups were identified from the SCAG survey: low (households whose gross annual income was below $30K), middle (household income between $30K and $75K), and high (household income greater than $75K). Those households who did not answer the income question were not used in any analysis involving income.

CONVENTIONAL TRAVEL BEHAVIOR DIFFERENCES

Household travel behavior was analyzed by total trips as well as by mode, trip purpose, travel time, and time of day. First, differences in travel behavior among the themes were tested using an ANOVA design with theme as a factor. With the exception of total trips, all tests used mean shares as the dependent variable and a significance level of five percent. Results showed that with themes as the factor, only total household trips and mode choice were significantly different at the required level. Accordingly, these two travel categories are examined in greater detail.

Total Household Trips

The results show that households in TND neighborhoods produce the lowest mean number of total trips, followed by MIX, and then PUD neighborhoods (**Table 6**). ANOVA results on total trips with themes as a factor indicates that the differences between the theme groups are significant (**Table 7**). Pair-wise comparison of the theme group means demonstrates this further by identifying particularly significant differences between the individual themes: TND and MIX households were found to make significantly less trips than PUD households (**Table 7**).

The results of the income group breakdowns show trip-making to be highly correlated to income: low income households average 6.5 trips, middle income households average 9.9 trips, and high income households 12.5 trips (**Table 6**). To test the significance of this relationship, income was used as a factor in a similar ANOVA approach as before (**Table 7**). A very strong relationship between income and total household travel was found, where the mean total trips for the income groups were significantly different. All pair-wise comparisons of total trips between the income group means were also found to be significantly different from each other. In comparing the two experimental designs (theme and income), the larger F-statistic value for the design with income as a factor indicates that more of the variance is explained in the income design than in the theme design. The outcome of the trip rate mean's pair-wise comparisons also seem to confirm this outcome.

Next, two-factor (income and theme) ANOVA tests of total household trips (see **Table 7**) indicated that income groups are significant in explaining the total variance while theme groups and joint income-theme groups were not. Subsequently, the interaction effect between theme and income was examined; a strong relationship between travel and income was confirmed, with higher incomes in each theme associated with an increased household trip rate. Total household trips were analyzed in greater detail using a pair-wise comparison of all possible income-theme groups. The values indicate that high income PUD and MIX households have significantly higher trip rates than most low and middle income households. Similarly, middle income PUD households have higher trip rates than those in low income MIX and TND communities.

The analysis of total household trips seems to demonstrate that income is more significant in determining the total household trip rate than the themes. This outcome suggests that income, as a proxy for socio-economic characteristics, explains more of the variance in trip generation than the themes. No significant interaction was found between theme and income (the effect of income is approximately the same regardless of the theme). Data limitations and associated large variances may mask these interactions. Furthermore, additional variables such as stage in household life cycle or household size, if introduced, could control for some of this variance and reveal interaction effects. However, since the results show that households make progressively more trips in TND, MIX, and PUD neighborhoods, respectively, this may indicate a decreasing propensity to chain trips from TND to MIX to PUD neighborhoods. A more detailed analysis of trip chaining needs be undertaken to test this hypothesis.

Comparisons by Mode

Household trips were analyzed by mode in terms of rates and shares (**Table 6**). By mode use, the TND and MIX households only produce slightly higher ratios of transit use and pedestrian activity than PUD households. PUD households exhibit higher use of the automobile and correspondingly lower use of transit or pedestrian modes. This seems to suggest that the more integrated land uses and gridiron street network of TND (and MIX to a lesser degree) do increase the attractiveness of alternative modes to the automobile, but only slightly. To test the significance of these differences between themes and mode choice, each mode share (automobile, transit, and pedestrian) was tested separately in an ANOVA model to determine if it was influenced by the factor theme. The F-scores and pair-wise comparisons of each mode's mean share suggest that differences in automobile, transit, and pedestrian mode shares between the theme groups were statistically insignificant (**Table 7**).

Mode trip rate and trip share breakdowns by income (**Table 6**) revealed basically the same pattern between low, middle, and high income groups which existed between TND, MIX, and PUD, though the distinction between the auto trip rates and trip shares are much larger when separated by income than by theme. ANOVA and pair-wise comparisons between the income groups were then conducted for auto share, transit share, and pedestrian share (**Table 7**). When comparing ANOVA results for the one factor test on mode shares, income groups tend to explain more of the variance than the theme groups. This is particularly apparent for the auto and pedestrian shares, with the former being statistically significant. Pair-wise comparisons of the individual mode shares by income groups showed that there were significantly lower automobile mode shares in low versus high income groups. Other key differences (though not significant), occurred between low and middle income groups in automobile shares and between low income groups and both middle and high income groups in pedestrian shares.

Finally, for completeness, mode shares were analyzed jointly by theme and income groups (**Table 6**). Two factor ANOVA tests and pair-wise comparisons were performed for auto share, transit share, and pedestrian share (**Table 7**). At the two factor level, both main factors as well as the joint factor were insignificant. Pair-wise comparisons of all possible income-theme group means for all three mode shares confirmed the insignificant nature of the interactions as no comparisons were statistically significant. No clear pattern emerged between mode choice, themes, and income.

Overall, the results are somewhat surprising. While **Table 6** seems to illustrate that themes matter in automobile use (mode choice), the ANOVA analysis demonstrates that these differences attributable to themes are statistically insignificant relative to income, which again seems to be a more important factor, demonstrating that socio-economics may be an overriding factor in determining conventional travel behavior as demonstrated by the significant differences ascribed to income in mode choice. Clearly, this is an important result since it suggests that conventional mode choice behavior may be only marginally affected by the LUTS.

CONCLUSIONS

The study examined the effects of land use and network characteristics on travel behavior for twenty neighborhoods and over 500 households in Orange County. The three research hypotheses, that hybrid themes exist, that these themes can be identified and classified, and that these themes display significant differences in household travel behavior, were verified. By exploring a number of neighborhoods at the theme level rather than analyzing a few case studies, these findings reveal important aspects of the relationship between travel behavior and the land use-transportation system. These results have two main effects.

First, they seem to dissipate some of the enthusiasm for design-oriented solutions to the problems of congestion and air pollution given the relationships documented between the LUTS and conventional travel behavior: it seems that income (as a proxy for other socio-economic factors) has a more significant relationship to travel behavior. While trip rate did vary significantly over neighborhood themes, the income variable was more successful in capturing their differences. Further, design-oriented solutions may still prove effective in reducing overall travel by possibly inducing the chaining of multiple trips, but further analysis, currently underway, needs to be completed.

Second, at an operational level, this study seems to offer some hope in improving the transportation modelling process. Given that differences in travel behavior among income groups can be alternately explained by neighborhood theme, it may be advantageous to include theme groups instead of income groups in transportation models. Income and other socio-economic variables tend to be very difficult and expensive to collect while network and land use data is both readily available and more accurate (particularly with the advent of GIS). Although there are some questions about the transferability of these results to other regions, themes may be a good proxy for a number of socio-economic and LUTS variables used in transportation models. It must be noted that full disaggregate data is preferable to aggregate variables such as theme (or aggregated socio-economics); it is in the absence of this data where theme could be utilized. Care should be exercised to consider the variation of socio-economic variables within each theme.

To make the themes more transferable, several steps would need to be taken. First, it would be necessary to expand the breadth and depth of the sample neighborhoods to more adequately reflect those found in Southern California and possibly those throughout the United States. Second, the scope of the cluster analysis with the new data should be expanded, possibly with a new set of indices reflecting more commonly available data. A taxonomy of themes could be developed whereby statistical techniques (e.g., discriminant analysis) could be introduced to assign new neighborhoods into the established taxonomy.

Clearly these findings support recent claims which point to a weakening link between land use-transportation systems and travel behavior. Further study may be needed to determine whether the findings are an artifact of Southern California region selected. Nonetheless, the implication is that care should be taken when considering design-oriented solutions as an alternative measure to address the automobile congestion and air quality improvement issues. It is important to note that while some of the travel behavior results may not be statistically attributed to the TND, MIX, and PUD classifications, this does not necessarily invalidate the merits (and perhaps the need) of TND. That is, TND relates to more than just travel behavior numbers: it is also a movement about the quality of life and the more intangible aspects of community. Proponents of TND hope to raise the level of these intangibles. On such a foundation, perhaps further evidence is needed to fully evaluate the merits of such design-oriented solutions.

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TABLE 1. Comparison Of PUD And TND Developments

	PUD	TND
Network	▪ Circuitous, meandering streets ▪ Hierarchical street pattern ▪ Limited access points to the neighborhood ▪ Wide streets without street parking ▪ Predominantly auto-based	▪ Interconnected, grid-like street patterns ▪ Separate paths for pedestrians & bicycles ▪ Narrow streets ▪ On street parking ▪ Green spaces and tree lining ▪ Access points to the neighborhoods ▪ Many modes successful
Land use	▪ Segregated, clustered land uses ▪ Low residential densities ▪ Large home lots ▪ Access to a limited number of highly "desirable" land uses	▪ Mixed land uses in close proximity ▪ High residential densities ▪ Small home lots ▪ Access to neighborhood amenities
Design	▪ Missing sidewalks ▪ Less shaded sidewalks ▪ Homogenous housing ▪ Dominating garages and driveways	▪ Shaded sidewalks ▪ Variation in housing design and size ▪ Shallow setbacks ▪ Front porches ▪ Detached garages

TABLE 2. Neighborhood Composition: Three-Theme Case

TND	MIX	PUD
1. Anaheim (East) 2. Huntington Beach (South) 3. Newport Beach (West Bay) 4. Santa Ana (East) 5. Santa Ana (West)	6. Fullerton (A) 7. Fullerton (B) 8. Fullerton (D) 9. Fullerton (E) 10. Garden Grove (East) 11. Garden Grove (West A) 12. Garden Grove (West B) 13. Orange (Central)	14. Fullerton (C) 15. Irvine (Turtle Rock) 16. Irvine (Woodbridge) 17. Mission Viejo (Lake) 18. Newport Beach (East Bay) 19. Orange (North) 20. Orange (South)

TABLE 3. Standardized Means (Stdev) of Neighborhood Classification Indices: Three-Theme Case

Index	Description	TND	MIX	PUD
R-INT1	cul-de-sacs to total intersections ratio	-1.05 (0.43)	0.02 (0.43)	0.73 (1.14)
R-INT4	4-way to total intersections ratio	1.10 (0.96)	0.07 (0.73)	-0.87 (0.24)
D-INT	intersection density (number/acre)	1.32 (0.79)	-0.42 (0.58)	-0.46 (0.65)
R-ENT	ratio of access points to area perimeter	0.91 (0.59)	0.44 (0.53)	-1.15 (0.35)
COM	commercial area to total area	0.67 (1.36)	-0.02 (0.83)	-0.46 (0.72)
DENS	population density	1.21 (0.88)	0.00 (0.44)	-0.87 (0.57)

TABLE 4. Transportation, Land Use, And Accessibility Mean Statistics: Three-Theme Case

Index	Description	TND	MIX	PUD
INT1	number of cul-de-sacs	83.20	81.10	167.30
INT3	number of 3-way intersections	298.00	235.10	445.30
INT4	number of 4-way intersections	207.20	100.80	88.00
INT	total number of intersections	588.40	417.40	700.60
ENT	number of access points	56.40	39.80	17.90
ENTM	number of major access points	7.80	8.50	6.70
R-INT1[a]	**ratio of INT1 to INT**	**0.14**	**0.20**	**0.24**
R-INT3	ratio of INT3 to INT	0.50	0.56	0.63
R-INT4[a]	**ratio of INT4 to INT**	**0.36**	**0.24**	**0.13**
R-INT43	ratio of INT4 to INT3	0.77	0.45	0.21
D-INT[a]	**intersection density (intersections/acre)**	**278.01**	**184.54**	**182.75**
R-ENT[a]	**ratio of ENT to development perimeter**	**0.47**	**0.39**	**0.10**
R-ENTM	ratio of ENTM to development perimeter	0.07	0.17	0.04
SFRES	single family residential area to total area	0.16	0.22	0.10
MFRES	multi-family residential area to total area	0.14	0.16	0.16
RES	residential area to total area	0.30	0.38	0.26
MALL	shopping complex area to total area	0.00	0.02	0.00
STRIP	strip commercial area to total area	0.18	0.08	0.04
GENC	general commercial area to total area	0.04	0.05	0.03
OFFICE	office-commercial area to total area	0.03	0.04	0.06
COM[a]	**commercial area to total area**	**0.25**	**0.18**	**0.14**
PI	public/institutional to total area	0.09	0.14	0.12
T	transportation to total area	0.01	0.06	0.01
U	uncommitted to total area	0.14	0.04	0.32
DENS[a]	**population density**	**13285.51**	**8292.01**	**4729.41**
ACR	access to residential land uses	81.80	41.60	53.10
ACC	access to commercial land uses	87.00	46.60	43.40
ACO	access to other land uses	170.70	100.90	105.60
R-ACR	ratio of ACR to area	42.06	17.74	16.40
R-ACC	ratio of ACC to area	46.11	20.05	12.90
R-ACO	ratio of ACO to area	94.64	42.43	30.61

[a] Indicates Indices Used in Clustering

TABLE 5. Household And Individual Data: Three-Theme Case

	TND	MIX	PUD	TOTAL
Households	118	195	211	524
HH Size (%)				
1	19	17	10	15
2	38	39	32	36
3	20	17	24	20
4	12	14	25	18
5+	10	13	9	11
Mean (Stdev)	2.6 (1.32)	2.7 (1.47)	3.0 (1.33)	2.8 (1.38)
Autos (%)				
0	6	6	0	4
1	34	24	19	24
2	36	49	52	47
3	18	14	19	17
4	3	6	8	6
5+	3	1	1	2
Mean (Stdev)	1.9 (1.32)	1.9 (1.00)	2.2 (0.20)	2.0 (0.99)
Housing (%)				
Single Family	39	61	67	59
Apt/Condo	50	32	30	36
Other	11	7	2	6
Income (%)				
LOW: < $30k	36	37	11	26
MED: $30k - $75k	49	52	52	51
HIGH: > $75k	15	11	36	23
Individuals	249	452	556	1257
Males (%)	48	48	48	48
Employment (%)				
Full Time	57	47	48	49
Part Time	10	11	10	10
Self	10	8	10	9
None	23	34	31	31
License (%)				
Yes	83	90	95	90
No	16	10	5	10
Student Status (%)				
No	73	75	72	73
Part Time	15	18	25	21
Full Time	11	7	3	6
Age (%)				
0-15	12	11	17	14
16-24	12	12	12	12
25-44	49	39	42	42
45-64	18	23	22	22
65+	8	15	8	11
Relation (%)				
Head	64	67	64	65
Child	14	17	24	19
Other	22	16	14	16

TABLE 6. Mean (Stdev) Trip Rates And Mode Shares By Theme, Income, And Theme-Income Groups: Three-Theme Case

	TOTAL TRIPS	AUTO TRIPS	AUTO SHARES	TRANSIT TRIPS	TRANSIT SHARES	PED TRIPS	PED SHARES
Theme							
TND	8.2 (6.1)	7.0 (5.8)	0.86 (0.25)	0.3 (1.1)	0.04 (0.14)	0.8 (1.8)	0.09 (0.19)
MIX	8.9 (7.2)	8.1 (7.0)	0.87 (0.22)	0.3 (0.7)	0.03 (0.12)	0.6 (1.3)	0.08 (0.18)
PUD	10.9 (7.0)	9.8 (6.4)	0.91 (0.15)	0.2 (0.6)	0.02 (0.05)	0.9 (1.6)	0.07 (0.14)
Income							
LOW	6.5 (5.4)	5.6 (4.8)	0.86 (0.26)	0.2 (0.6)	0.03 (0.15)	0.8 (1.6)	0.11 (0.22)
MED	9.9 (6.1)	8.8 (5.6)	0.90 (0.16)	0.2 (0.7)	0.02 (0.07)	0.8 (1.5)	0.07 (0.15)
HIGH	12.5 (7.9)	11.6 (7.6)	0.92 (0.15)	0.2 (0.6)	0.01 (0.05)	0.7 (1.3)	0.07 (0.14)
Theme-Income							
TND							
LOW	6.4 (4.9)	5.1 (4.43)	0.80 (0.31)	0.3 (0.73)	0.06 (0.19)	1.0 (2.16)	0.15 (0.25)
MED	8.8 (4.6)	8.0 (4.40)	0.91 (0.18)	0.2 (0.56)	0.02 (0.07)	0.6 (1.38)	0.07 (0.17)
HIGH	10.8 (8.3)	10.2 (8.36)	0.94 (0.10)	0.1 (0.77)	0.01 (0.04)	0.5 (0.59)	0.05 (0.10)
MIX							
LOW	6.5 (5.6)	5.7 (4.41)	0.87 (0.25)	0.2 (0.61)	0.03 (0.14)	0.6 (1.19)	0.09 (0.21)
MED	9.6 (5.9)	8.6 (5.99)	0.90 (0.17)	0.3 (0.77)	0.03 (0.08)	0.7 (1.49)	0.07 (0.15)
HIGH	14.6 (10.6)	12.8 (10.8)	0.88 (0.25)	0.2 (0.48)	0.01 (0.09)	1.6 (1.45)	0.11 (0.25)
PUD							
LOW	7.2 (5.8)	6.6 (5.25)	0.91 (0.16)	0.0 (0.22)	0.00 (0.01)	0.6 (1.55)	0.08 (0.16)
MED	10.7 (6.6)	9.7 (6.12)	0.91 (0.14)	0.2 (0.71)	0.02 (0.06)	0.7 (0.96)	0.07 (0.13)
HIGH	12.3 (6.9)	11.3 (6.50)	0.92 (0.12)	0.1 (0.57)	0.01 (0.05)	0.7 (1.25)	0.06 (0.11)
ALL	9.6 (7.0)	8.5 (6.59)	0.89 (0.20)	0.3 (0.85)	0.03 (0.10)	0.8 (1.54)	0.08 (0.17)

TABLE 7. ANOVA Results For Conventional Travel Behavior Statistics: Three-Theme Case

ANOVA TESTS	FACTORS	F-RATIO	P	SIGNIFICANT PAIRWISE DIFFERENCES (5%)
TOTAL HOUSEHOLD TRIP RATES	1. THEME	6.732	0.001	(PUD & TND, PUD & MIX)
	2. INCOME	23.1735	0.000	(LOW & MED, LOW & HIGH, MED & HIGH)
	3. THEME-INCOME	1.617	0.200	
	THEME	17.014	0.000	(LOW-MIX & HIGH-PUD, LOW-PUD & HIGH-PUD, LOW-TND & HIGH-PUD, LOW-MIX & HIGH-MIX, LOW-PUD & HIGH-MIX, LOW-TND & HIGH-MIX, MED-TND & HIGH-MIX, MED-PUD & LOW-MIX, MED-PUD & LOW-TND)
	INCOME	0.899	0.465	
	JOINT			
AUTO SHARE	1. THEME	1.629	0.197	NONE
	2. INCOME	3.247	0.040	(LOW & HIGH)
	3. THEME-INCOME	0.899	0.408	NONE
	THEME	1.985	0.139	
	INCOME	1.218	0.302	
	JOINT			
TRANSIT SHARE	1. THEME	1.285	0.278	NONE
	2. INCOME	1.541	0.215	NONE
	3. THEME-INCOME	0.871	0.419	NONE
	THEME	0.865	0.422	
	INCOME	0.873	0.480	
	JOINT			
PEDESTRIAN SHARE	1. THEME	0.690	0.690	NONE
	2. INCOME	2.025	0.133	NONE
	3. THEME-INCOME	0.358	0.699	NONE
	THEME	1.474	0.230	
	INCOME	0.825	0.510	
	JOINT			

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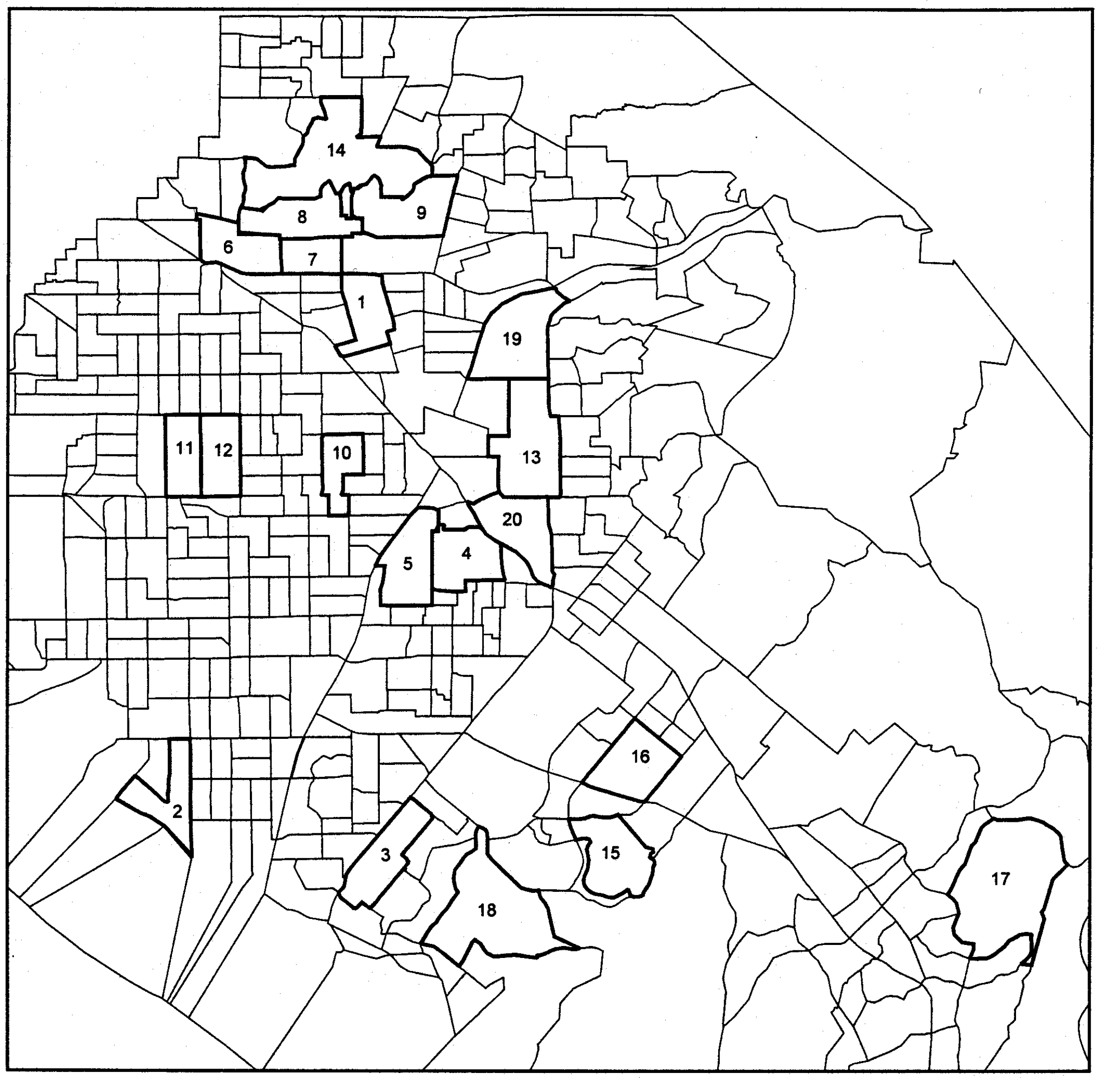

FIGURE 1 Selected Neighborhoods (Numbers Refer To TABLE 2)

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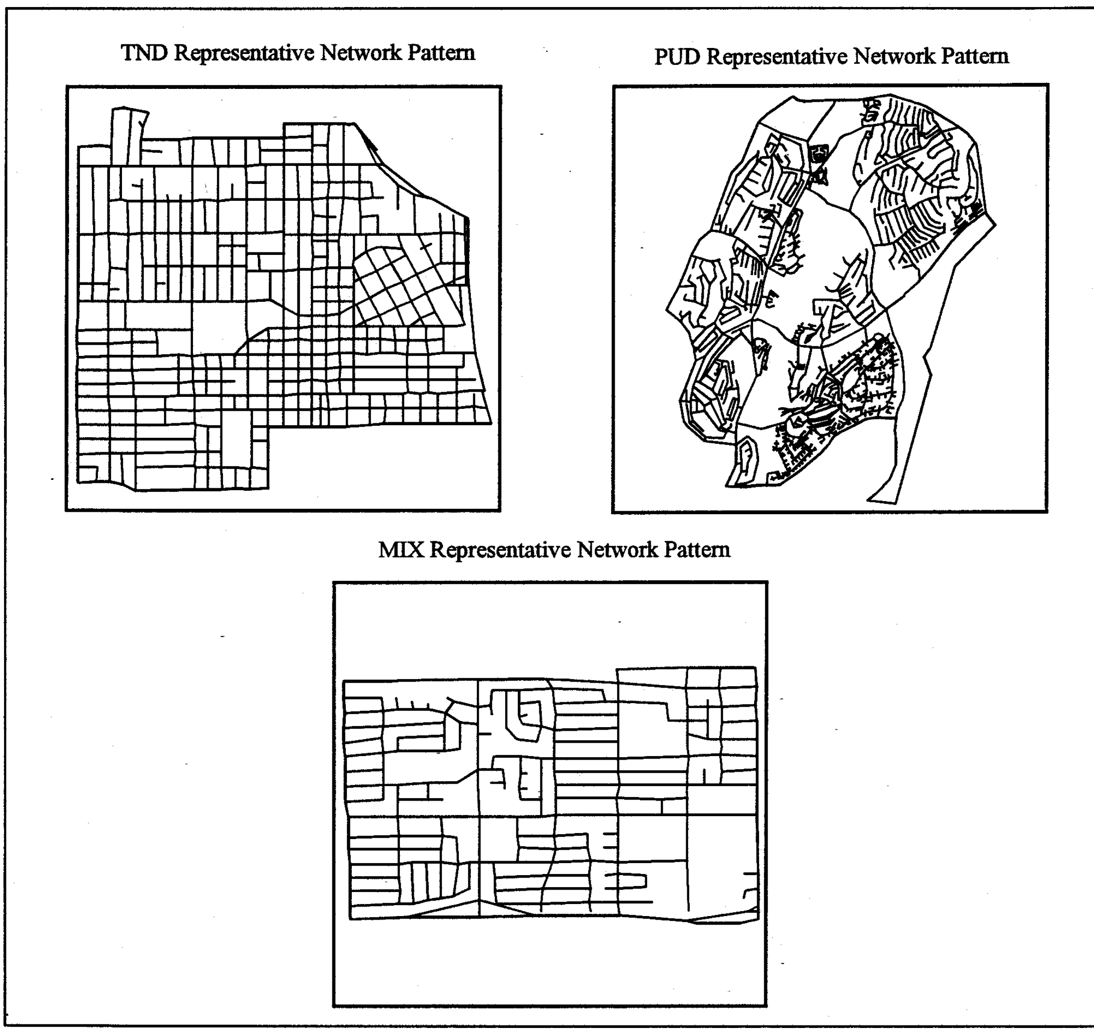

FIGURE 2 Representative Network Patterns of the Three Themes