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Land Use - Transportation System and Travel Behavior

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 and more complex measures of individual travel behavior were compared via an analysis of variance between the themes to identify significant differences, controlling for socio-economic differences. Research results included 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.

1. Introduction

Transportation engineers and planners today must deal with a variety of problems which conventional means do not fully address. Perhaps the most important problems concerning transportation are delays and pollution caused by 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, ITS), both of which aim to increase transportation system capacity. While such initiatives remain in practice, enthusiasm for the program has subsided, possibly because of the unpopularity of road building in urban areas and the still questionable benefits of ITS. The demand-side policies range from employer-based travel demand management to telecommuting to other evolving programs. Similarly, these initiatives produce only marginal success and their mandated use causes substantial employer dissatisfaction -- again diminishing the popularity of such programs.

A renewed and more subtle response to combating congestion has emerged: changing 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 Ryan and McNally, 1995). 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" (Ryan and McNally, 1995). TND neighborhoods conventionally display a grid-like transportation network structure, multiple access routes, and a mix of land use types. The mix of integrated land uses reflects the independent nature of the development pattern. PUD -- typified by large suburban, single-family developments common to the post-war growth period -- display hierarchical street arrangements, with cul-de-sacs, collectors, and large arterials providing unique access routes. PUD are also identified by its highly segregated land uses. **Table 1** provides a more detailed comparison of PUD and TND developments.

Table 1 Comparison of PUD and TND Developments

	PUD	**TND**
network	▪circuitous, meandering streets ▪hierarchial street pattern (highways, arterials, collectors) ▪limited access points to the neighborhood ▪wide streets without street parking ▪predominantly auto-based	▪interconnected, grid-like street patterns ▪separate paths (network) for pedestrian and 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 ▪access to a limited number of highly "desirable" land uses ▪low residential densities ▪large home lots	▪mixed land uses ▪close proximity of land uses ▪high residential densities ▪small home lots ▪access to parks, recreation and distinct neighborhood "centers"
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

Proponents of land use measures believe that the land use-transportation system fundamentally affects travel behavior and that, by systematically altering this system, a better qualify of life can result. They believe that TND neighborhoods encourage the use of alternatives to automobile travel and promote shorter and fewer trips. Conversely, they believe that PUD neighborhoods support (if not force) auto-dependent travel behavior. They claim that these neighborhoods promote longer, drive-alone commutes through their segregated land uses, low residential densities, and lack of nearby employment. In fact, the 1990 Amendments to the Clean Air Act allow for land use-transportation systems (particularly for design-oriented solutions such as TND) as alternate means to satisfy the requirements in reducing automobile congestion and improving air quality. Harvey and Deakin (1992) 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 TND can effectively reduce congestion. These researchers doubt the assumption that travel choices are strongly influenced by the urban system and that land use changes are an inefficient remedy to control automobile use in any case, since no conclusive evidence demonstrates nor quantifies such a connection. In fact, Giuliano (1995) has argued that the land use-transportation connection may be weakening. Another concern is whether people who move into new alternative developments will choose to alter their travel behavior following such a move. And assuming 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. Therefore, differences in travel behavior may be due to the attitudinal, socio-economic, and demographic makeup of those residents in addition to the land use and transportation system factor. In any case, one needs to question the nature of the fundamental relationships between land use-transportation systems and travel behavior and the effectiveness of policies which advocate land use modifications to promote travel behavior changes.

This paper examines the fundamental relationship between travel behavior and the land use-transportation system. 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, addresses the questions concerning the effectiveness and causality of using design strategies to reduce automobile travel. The transportation planning process has been criticized in the past as an outdated process with a sketchy record of accurately modeling traffic. The many shortcomings of the process were for the most part systematically ignored by the profession until the 1991 Clean Air Act Amendments (CAAA), the Intermodal Surface Transportation Efficiency Act (ISTEA), 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 (TMIP). The TMIP has identified land use and transportation interactions as an where potentially vast improvements in the planning process. This paper will examine this relationship in hopes of incorporating this complex dimension into the transportation forecasting process.

2. 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 NTND and TOD communities (Lerner-Lam, et al., 1992; ITE Technical Committee 5P-8, 1992). Later work with NTND 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 (1991) and McNally and Ryan (1992) found that, in general, NTND tends to reduce overall trip lengths and reduce automobile travel speeds.

However, these simulation studies failed to account for all aspects of NTND, specifically the changes in land use structure which is an integral part of the NTND concept. Two notable studies which tried to account for this aspect within the simulation format include Stone and Johnson (1992) and the Middlesex-Somerset-Mercer Regional Council (MSMRC) (1992). Stone and Johnson compared hypothetical subdivisions and found that NTND has less vehicle delay and fewer trips generated than the conventional suburb. The MSMRC simulated different types of development and found that mixed land uses, a balanced jobs to housing ratio, and increased residential densities as the key factors behind the reduction in automobile trips.

To model the impact of NTND more realistically, empirical studies were conducted using various density measures were employed. Newman and Kenworthy (1989) 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. Holtsclaw (1990) compared communities in the Bay Area with household density, population density, and activity density, calculated for five fairly different neighborhoods and found that higher activity densities resulted in lower overall vehicle miles traveled (VMT). Frank and Pivo (1994) looked at transit usage for work and shopping trips and found a negative relationship with employment density, population density, land use mix, and single occupancy vehicle usage. Conversely, they found a positive relationship for the same employment density, population density, land use mix, for transit and walking. Handy (1993) used trip distance and trip frequency to compare different urban forms by characterizing a community by two accessibility components: local and regional. Using the 1980 Metropolitan Transportation Commission (MTC) land use data and the 1981 MTC travel survey, regional and local accessibilities were found for 34 super districts and found that (shopping) travel distance significantly decreases with increasing local and regional access. However, there was no relationship between either local and 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.* (1994) 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 much higher proportion of drive alone trips, and lower a percentage of public transportation trips. Cervero (1993) 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 (1995) identified four neighborhoods in the San Francisco Bay Area with comparable regional accessibilities and socio-economic factor as either typical suburban or traditional: suburban communities were more auto-oriented with a limited amount of local accessibility and traditional communities were more pedestrian-oriented with a higher amount of local accessibility. Handy found that highly accessible communities can possibly encourage more walking as a more viable option for commercial and other non-work trips.

Ewing *et al.* (1994) examined the relationship of location and land use to travel patterns in communities possessing diverse land use-transportation patterns (as demonstrated by calculated attributes such as residential and employment density, jobs-housing ratio, accessibility, and the percentage of multifamily dwellings). Although the study did not classify communities as PUD or TND, such a link was implied through variations in their respective accessibility measures. They 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.

While much of the reviewed literature focused on the conventional aspects of travel behavior, a limited number of studies have looked into more complex characteristics of travel behavior such as trip chaining. In fact, results comparing trip chaining in different land use-transportation systems have been somewhat perplexing. Some studies have found lower density, suburban areas (the PUD range as defined here) to produce more chaining of trips (Kumar and Levinson, 1995). Others have found that traditional inner city areas encourage multiple chaining (Goulias and Kitamura, 1989). Compounding these results is the identification of a multitude of factors which influence trip chaining behavior. Socio-economic factors are considered distinctively important in influencing the degree of trip chaining: income and gender are among the more important. Studies have examined chaining behavior by incomes and have found that workers in higher income households tend to trip chain more then low income households (Strathman et al., 1994). Further, women tend to chain more than men (Kumar and Levinson, 1995 and Strathman et al., 1994). Researchers have additionally documented the differences in chaining associated with the type of activity in which an individual is engaged; notably, work activities are more likely to be included on complex tours.

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.* (1995), 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 blocks tend to explain more of the variance in the trips and mode splits than socio-economic blocks which generally explain more of the variance than neighborhood blocks.

3. Research Hypotheses

Current work in planning and development suggests that two distinct neighborhood themes may be defined: planned unit development and traditional neighborhood development. 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 either defined class, 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.

4. Approach and Methodology

There are few empirical studies which fully encompass the breath and depth necessary to understand the complex and evolving interaction between the land use-transportation system and travel behavior. This analysis proposes to contribute to this understanding by relating travel behavior to the nature of residential developments which generate that behavior. Analysis of household travel behavior will explicitly consider the differences of aggregate household travel across varying neighborhood structures. Further, the socio-demographic makeup of the development themes will be analyzed to test to what degree any observable differences in travel behavior can be attributed to differences between neighborhoods.

The proposed analysis comprises two sequential aspects. First, the problem of classifying neighborhoods will be addressed though a clustering process. The input is a set of attributes that define the neighborhood and the output is the categorization of these neighborhoods into subgroups. Second, an expanded version of conventional household travel analysis, including trip chaining, will be undertaken to examine the aggregate travel patterns which result from differences in network and land use structures. Adequate controls for socio-economic differences between the identified themes will be taken. The goal of this investigation is to provide further information concerning the impact of alternative land use-transportation systems on travel behavior. Moreover, the methodology allows for an assessment of policy initiatives which attempt to modify travel behavior through changes in the land use-transportation system as well as identify possible improvements in the current planning process through the explicit incorporation of a new LUTS dimension.

5. Data

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

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

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

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

The land use database is 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.

6. 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 infill 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, and (4) sufficiently high neighborhood response rates to the SCAG survey. Twenty neighborhoods (**Figure 1**) 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 requires a balanced analysis of attributes which capture salient characteristics of neighborhoods and which are readily calculable from the data. A large set of indices were developed to quantitatively describe neighborhoods both as individuals and as groups (summarized in **Table 2**). These indices are 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.

Figure 1: Selected Neighborhoods

Table 2: Classification Indices

Index	Description
	Network Indices
INT1	number of cul-de-sacs
INT3	number of 3-way intersections
INT4	number of 4-way intersections
INT	total number of intersections
D-INT*	**intersection density (intersections/acre)**
ENT	number of access points
ENTM	number of major access points
R-INT1*	**ratio of INT1 to INT**
R-INT3	ratio of INT3 to INT
R-INT4*	**ratio of INT4 to INT**
R-INT43	ratio of INT4 to INT3
PERIM	development perimeter
R-ENT*	**ratio of ENT to PERIM**
R-ENTM	ratio of ENTM to PERIM
	Land Use Indices
SFRES	single family residential area to total area
MFRES	multi-family residential area to total area
RES	residential area to total area
MALL	shopping complex area to total area
STRIP	strip commercial area to total area
GENC	general commercial area to total area
OFFIC	office-commercial area to total area
COM*	**commercial area to total area**
DENS*	**population density**
PI	public/institutional to total area
T	transportation to total area
U	uncommitted to total area
	Accessibility Indices
ACR	access to residential land uses
ACC	access to commercial land uses
ACO	access to other land uses
R-ACR	ratio of ACR to area
R-ACC	ratio of ACC to area
R-ACO	ratio of ACO to area

*** Indicates Indices Used in Clustering**

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 (a) their perceived importance in the progression of development patterns as documented by the reviewed literature and (b) their success in identifying distinct themes. This subset of the indices (indicated with an asterisk in **Table 2**) 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.

Clustering Procedure

Clustering is a technique for dividing a set of cases into homogeneous subsets based on similarities or distances. The measure of similarity used here is euclidean distance based on the case's values on each of the k variables under study. The clustering procedure used in the project is a k-means clustering algorithm which maximizes the between group relative to within-group variation. 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 2-3 until cluster membership is stable, and (5) calculate between and within variations and pseudo F-ratio.

Prior to analysis, values of the indices are 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.

Clustering Results

The neighborhoods were categorized based on the standard 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 3**). 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 attribute were calculated for all groupings and are presented and graphically depicted in **Table 4** and **Figure 2** while the network, land use and accessibility mean statistics are provided in **Table 5**. The groups TND, MIX, and PUD contained five, eight, and seven neighborhoods, respectively.

Table 3: Neighborhood Composition of the 3-Theme Case

TND	MIX	PUD
Anaheim (East)	Fullerton (A)	Fullerton (C)
Huntington Beach (South)	Fullerton (B)	Irvine (Turtle Rock)
Newport Beach (West Bay)	Fullerton (D)	Irvine (Woodbridge)
Santa Ana (East)	Fullerton (E)	Mission Viejo (Lake)
Santa Ana (West)	Garden Grove (East)	Newport Beach (East Bay)
	Garden Grove (West A)	Orange (North)
	Garden Grove (West B)	Orange (South)
	Orange (Central)	

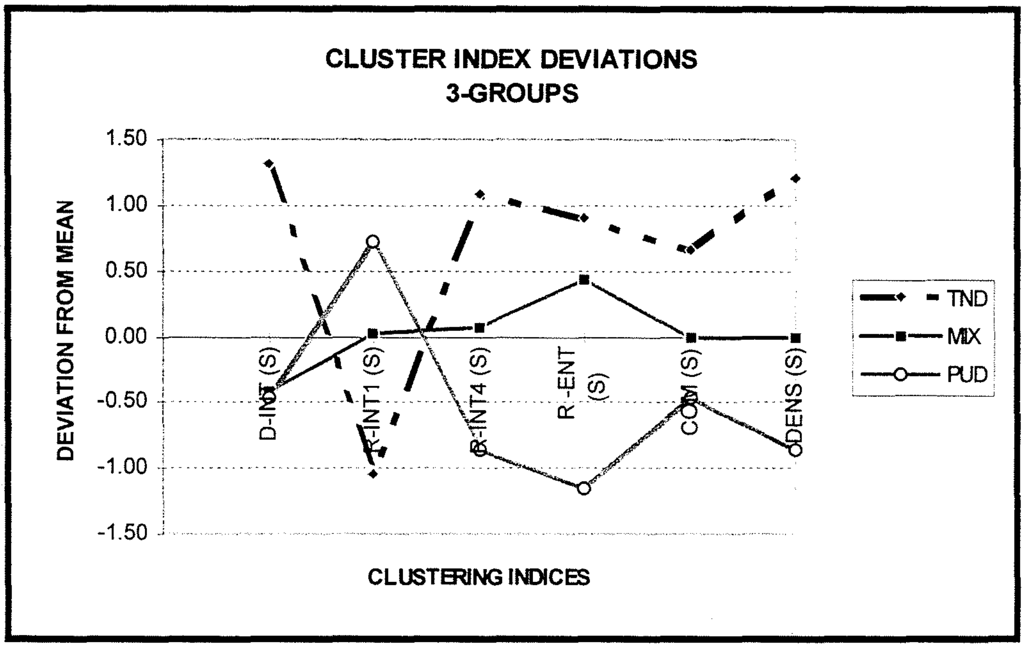

Figure 2: Cluster Index Deviations From the Mean for the 3-Theme Case

Table 4: Standardized Values of the Neighborhood Classification Indices Used for the 3-Theme Case

Index	TND	MIX	PUD
R-INT1	-1.05 (0.43)	0.02 (0.43)	0.73 (1.14)
R-INT4	1.10 (0.96)	0.07 (0.73)	-0.87 (0.24)
D-INT	1.32 (0.79)	-.042 (0.58)	-0.46 (0.65)
R-ENT	0.91 (0.59)	0.44 (0.53)	-1.15 (0.35)
COM	0.67 (1.36)	-0.02 (0.83)	-0.46 (0.72)
DENS	1.21 (0.88)	0.00 (0.44)	-0.87 (0.57)

Table 5: Transportation, Land Use, and Accessibility Mean Statistics for the 3-Theme Case

Index	TND	MIX	PUD
INT1	83.2	81.1	167.3
INT3	298.0	235.1	445.3
INT4	207.2	100.8	88.0
INT	588.4	417.4	700.6
ENT	56.4	39.8	17.9
ENTM	7.8	8.5	6.7
R-INT1*	**0.14**	**0.20**	**0.24**
R-INT3	0.50	0.56	0.63
R-INT4*	**0.36**	**0.24**	**0.13**
R-INT43	0.77	0.45	0.21
D-INT*	**278.01**	**184.54**	**182.75**
R-ENT*	**0.47**	**0.39**	**0.10**
R-ENTM	0.07	0.17	0.04
SFRES	0.16	0.22	0.10
MFRES	0.14	0.16	0.16
RES	0.30	0.38	0.26
MALL	0.00	0.02	0.00
STRIP	0.18	0.08	0.04
GENC	0.04	0.05	0.03
OFFIC	0.03	0.04	0.06
COM*	**0.25**	**0.18**	**0.14**
PI	0.09	0.14	0.12
T	0.01	0.06	0.01
U	0.14	0.04	0.32
DENS*	**13285.51**	**8292.01**	**4729.41**
ACR	81.8	41.6	53.1
ACC	87.0	46.6	43.4
ACO	170.7	100.9	105.6
R-ACR	42.06	17.74	16.40
R-ACC	46.11	20.05	12.90
R-ACO	94.64	42.43	30.61

*** Indicates Indices Used in Clustering**

Identified Groups

When the neighborhoods were clustered into three groups, the primary and secondary differentiating factors were those associated with transportation and land use, respectively (see **Figure 3**). The PUD theme is composed of neighborhoods which have transportation networks which are circuitous 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 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 (mall) and general development. Population densities are between those of PUD and TND as are all the accessibilities.

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 world developments and the design movements which inspired them. Further, the themes developed will be used to understand the travel behavior consequences of different land use-transportation systems and the claims which have been attached to them.

7. 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 6**. TND neighborhoods tend to have poorer households, smaller household membership sizes, younger adults or families with young children, and are less likely to own as

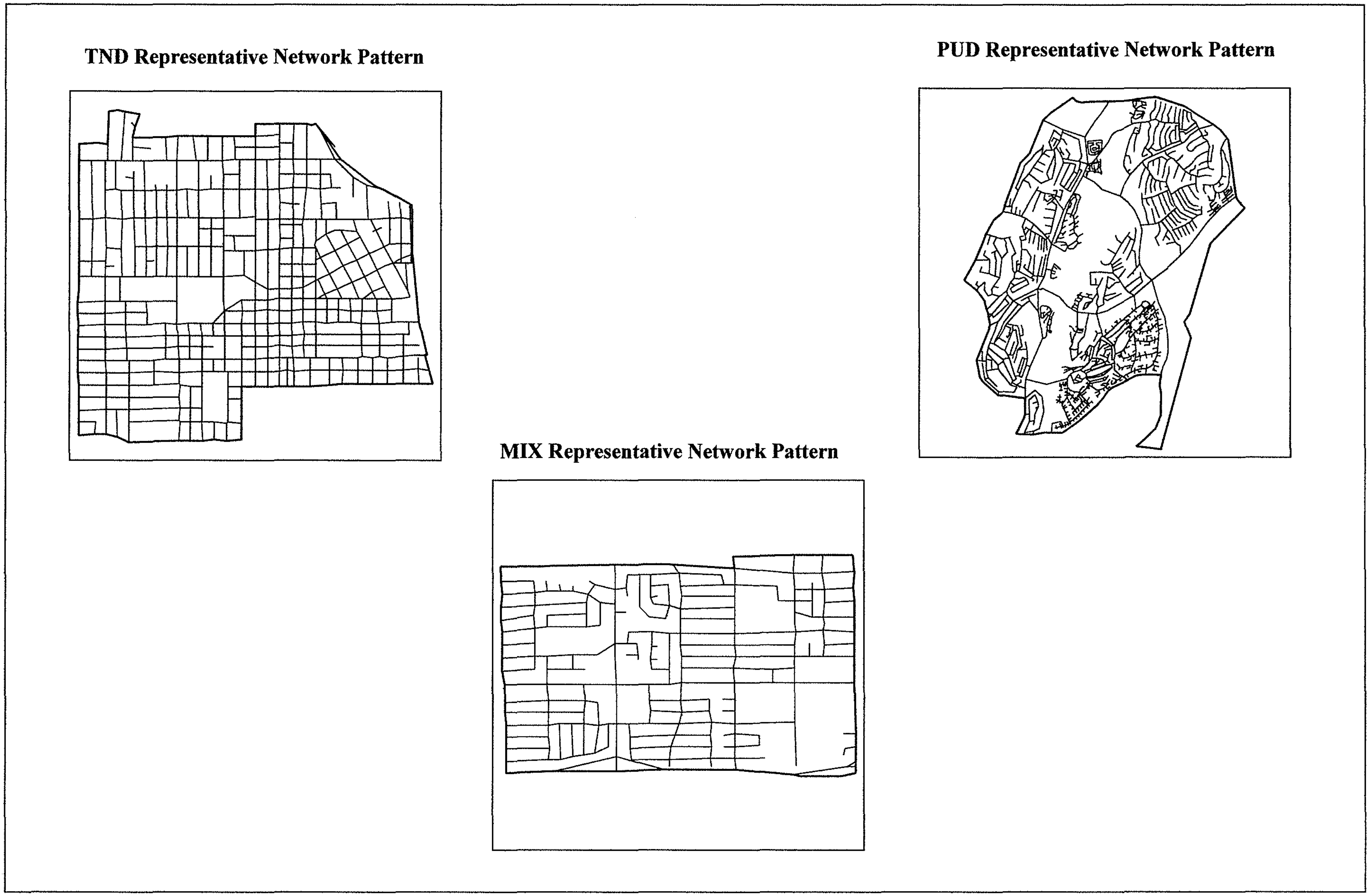

Figure 3: Representative Network Patterns of the Three Themes

Table 6: 3-Theme Household and Individual Data

	TND	MIX	PUD	TOTAL
Households	118	195	211	524
HH Size *(Percent)*				
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 *(Percent)*				
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 *(Percent)*				
Single Family	39	61	67	59
Apt/Condo	50	32	30	36
Other	11	7	2	6
Income *(Percent)*				
< $30K	36	37	11	26
$30K - $75K	49	52	52	51
> $75K	15	11	36	23
Individuals	249	452	556	1257
Males *(Percent)*	48	48	48	48
Employment (Percent)				
FT	57	47	48	49
PT	10	11	10	10
Self	10	8	10	9
None	23	34	31	31
License *(Percent)*				
Yes	83	90	95	90
No	16	10	5	10
Student Status *(Percent)*				
No	73	75	72	73
Part Time	15	18	25	21
Full Time	11	7	3	6
Age *(Percent)*				
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 *(Percent)*				
Head	.64	67	64	65
Child	14	17	24	19
Other	22	16	14	16

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, and 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 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.

8. 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 the mean shares as the dependent variable and were considered significant at the five percent level. 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 7**). ANOVA results on total trips with themes as a factor indicates that the differences between the theme groups are significant (**Table 8**). Pairwise 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 8**).

The results of the income group breakdowns show tripmaking 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 7**). In order to test the significance of this relationship, income was used as a factor in a similar ANOVA approach as before (**Table 8**). A very strong relationship between income and total household travel was found, where the mean total trips for the income groups were significantly different. Pairwise comparisons of total trips between *all* the income group means (**Table 8**) 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 pairwise comparisons also seem to confirm this outcome. Next, the interaction effect between the themes and income was examined (**Table 8**) confirming the strong relationship between travel and income as higher incomes among all themes resulted in increased household trip making. ANOVA tests of total household trips (**Table 8**) indicate that income groups are significant in explaining the total variance while theme or joint income-theme groups are not. Total household trips were analyzed in greater detail using a pairwise comparison of all possible income-theme groups (**Table 8**). 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. Moreover, as a proxy for the socio-

Table 7: Mean (Standard Deviation) Trip Rates and Mode Shares by Theme, Income, and Theme-Income Groups

	TOTAL TRIPS	*AUTO TRIPS*	*AUTO SHARES*	*TRANSIT TRIPS*	*TRANSIT SHARES*	*PED TRIPS*	*PED SHARES*
1. 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)
2. 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)
• MIDDLE	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)
3. 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)
• MIDDLE	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)
• MIDDLE	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 (10.75)	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)
• MIDDLE	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)
4. 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 8: ANOVA Results for Conventional Travel Behavior Statistics

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

economic characteristics, the outcome suggests that the socio-economic variables such as income, household size and car ownership explain more of the variance in trip generation than the themes. Clearly, this is an important outcome of the study. However, the results still seem to demonstrate that a relationship does exist (though as not statistically significant) between the themes and trip generation, and that TND, MIX, and PUD households do make progressively more trips. A possible explanation for this behavior may be that the propensity to trip chain progressively decreases for TND, MIX, and PUD neighborhoods. A more detailed analysis of trip chaining will be undertaken to test this hypothesis.

Comparisons by Mode

Household trips were analyzed by mode in terms of rates and shares (**Table 7**). 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 (of the order of only one or two percentage points). To test the significance of the 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 ANOVA F-scores and pairwise 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 8**).

Mode trip rate and trip share breakdowns by income (**Table 7**) revealed basically the same pattern between low, middle, and high income groups which existed between TND, MIX, and PUD. Some differences do exist when grouping with income; for instance, the distinction between the auto trip rates and trip shares are much larger when separated by income than by theme. ANOVA and pairwise comparisons between the income groups were then conducted for auto share, transit share, and pedestrian share (**Table 8**). 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. Pairwise 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, mode shares were analyzed jointly by theme and income groups (**Table 7**). Two factor ANOVA tests and pairwise comparisons were performed for auto share, transit share, and pedestrian share (**Table 8**). At the two factor level, both main factors as well as the joint factor were insignificant. Pairwise 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.

These were rather surprising results and tend to suggest that even when controlling for socio-economics (income), themes do not seem to affect mode choice, at least for the predominantly auto-oriented neighborhoods in Orange County. Rather, income again seems to be a more important factor demonstrating that socio-economics may be an overriding factor in determining mode choice. Clearly, this is an important result as it suggests that mode choice may be at best marginally affected by the LUTS.

9. Comparisons of Trip Chaining Behavior

The identified themes were investigated to determine any differences in trip chaining. The primary unit of analysis will be the tour (or chain) defined as a set of trips beginning and ending at a respondents home. Recall, a multitude of socio-economic factors including income and gender have been identified as influencing trip chaining behavior. Therefore, this analysis controlled for income and gender in order to test the themes. Further controls included assigning a type to each tour was assigned based on the destination activity of the trip. The SCAG activity types were consolidated into three purposes: (1) work (comprising of work or work-related activities), (2) maintenance (comprising of at home, pick up/drop off, school, shopping, personal business, or eating out), and (3) discretionary (consisting of social, recreation, out of town, or other activities). Tours were defined by their component activities in an hierarchical fashion as follows. Work tours were tours which contained any work activities as well as any ancillary maintenance or discretionary activities. Maintenance tours may include discretionary activities, but no work activities. Discretionary tours consisted of only discretionary activities. The advantage of this hierarchial classification of tours being the ability to control for the tour purpose when comparing the themes. Trip chaining behavior was analyzed by total tours, work tours, maintenance tours, and discretionary tours. Again, differences in travel behavior among the themes were tested using an ANOVA design with theme as a factor in addition to income and gender. All tests used the mean number of activities as the dependent variable and were considered significant only at the five percent level. The decision to analyze chaining by tour purpose was influenced by previous work suggesting it to be an important factor in chaining. Further, because limited data was available for exclusive discretionary touring, only work and maintenance touring were examined in greater detail.

Tour Statistics

First, basic differences in tour composition were determined (**Table 9**) by theme. TND residents take a majority of work tours (51 percent), the largest among the three themes, and the correspondingly lowest proportion of maintenance tours (40 percent). PUD residents have the opposite pattern with a majority of maintenance tours (51 percent) and the lowest ratio of work tours (38 percent). MIX residents seem to behave similar to PUD residents though its proportion of maintenance tours is not a majority (47 percent).

By income, it seems that a majority of total tours were performed by middle income residents, followed by high income residents, and finally low income residents. The ratio of total tours which are work tours is the same at 44 percent in middle and high incomes while low income residents take the least at 36 percent. Conversely, low income residents make a majority of maintenance tours (55 percent) followed by middle (47 percent) and finally high income residents. Discretionary tours make up 9 percent of both low and middle income residents tours while 12 percent of high income resident tours.

By gender, it seems that females make slightly more of the total tours than males (51 percent to 49 percent) as seen in **Table 9**. However, males make a larger ratio of work tours than

Table 9: Tour Frequency (Percentage) for Select Theme, Income, and Gender Groups

	TOTAL TOURS	*WORK TOURS*	*MAINT TOURS*	*DISC TOURS*
1. THEME				
• TND	309	156 (50)	124 (40)	29 (9)
• MIX	618	257 (42)	292 (47)	69 (11)
• PUD	779	295 (38)	400 (51)	84 (11)
2. INCOME				
• LOW	273	97 (36)	151 (55)	25 (9)
• MIDDLE	757	334 (44)	355 (47)	68 (9)
• HIGH	407	180 (44)	180 (44)	47 (12)
3. GENDER				
• MALE	829	383 (46)	351 (42)	95 (12)
• FEMALE	877	325 (37)	465 (53)	87 (10)
4. THEME-INCOME				
TND				
• LOW	76	34 (45)	41 (54)	1 (1)
• MIDDLE	139	82 (59)	44 (32)	13 (9)
• HIGH	46	22 (48)	19 (41)	5 (11)
MIX				
• LOW	145	48 (33)	75 (52)	22 (15)
• MIDDLE	273	132 (48)	121 (44)	20 (7)
• HIGH	87	44 (51)	34 (39)	9 (10)
PUD				
• LOW	52	15 (29)	35 (67)	2 (4)
• MIDDLE	345	120 (35)	190 (55)	35 (10)
• HIGH	274	114 (42)	127 (46)	33 (12)
5. THEME-GENDER				
TND				
• MALE	155	84 (54)	54 (35)	17 (11)
• FEMALE	154	72 (47)	70 (45)	12 (8)
MIX				
• MALE	300	136 (45)	130 (43)	34 (12)
• FEMALE	318	121 (38)	162 (51)	35 (11)
PUD				
• MALE	374	163 (44)	167 (45)	44 (12)
• FEMALE	405	132 (33)	233 (58)	40 (10)

females (46 percent to 37 percent). Conversely, females make a majority of maintenance tours compared to males (53 percent to 42 percent). Finally, males make relatively more (2 percent) discretionary tours than females.

Next, two distinctive touring patterns emerged when joint theme-income groups were explored (see **Table 9**). First, as expected, low income residents in all themes tend to have the least ratio of work tours and the highest ratios of maintenance tours across the themes. Second, the highest ratio of work tours occur in middle income TND neighborhoods.

Finally, it seems from the results in **Table 9** that total tours are evenly split between gender and theme groups. Further, work tours appear to make a progressively lower proportion of total tours going from TND to MIX to PUD for both males and females. In addition, males tend to make a larger portion of work tours than females across the themes, while the reverse pattern exists for maintenance tours. Finally, males and females make up a progressively larger amount of total tours from TND to MIX to PUD. For the most part, discretionary tours appear to be insensitive with respect to theme. Though, they tend to make up a slightly large ratio of tours for males across themes.

Work Tours

When work tours were arranged by number of activities (**Table 10**), large differences between the themes are evident. MIX residents have the highest ratio of one activity work tours (58 percent) followed by TND (50 percent) and finally PUD (43 percent). Correspondingly, PUD has the highest ratio of two activity work tours, followed by TND, and MIX has the lowest. Second, when the average number of activities in work tours are examined by theme, the rank in decreasing order is PUD, TND, and MIX (2.5, 2.3, and 2.1 activities, see **Table 10**). ANOVA test results (summarized in **Table 11**) for average activities per tour indicated significant differences (5 percent) for the work tour category by themes. Pairwise comparisons show that MIX theme residents behaved significantly different than both PUD and TND. These relationships seem to confirm those of the average activities per work tour showing greater chaining *at both extremes* of the land use-transportation system.

Table 10 indicates that income is correlated with the average number of activities per

Table 10: Mean Activities (Standard Deviation) by Tour Purpose for Selected Theme, Income, and Gender Groups

	ALL TOURS	*WORK TOURS*	*MAINT TOURS*	*DISC TOURS*
1. THEME				
• TND	2.1 (1.72)	2.3 (1.87)	2.0 (1.67)	1.1 (0.31)
• MIX	1.8 (1.39)	2.1 (1.72)	1.7 (1.12)	1.1 (0.31)
• PUD	1.9 (1.48)	2.5 (1.80)	1.7 (1.19)	1.1 (0.48)
2. INCOME				
• LOW	1.8 (1.48)	2.0 (1.68)	1.8 (1.48)	1.2 (0.37)
• MIDDLE	1.9 (1.43)	2.2 (1.69)	1.7 (1.19)	1.2 (0.52)
• HIGH	1.9 (1.51)	2.6 (1.88)	1.6 (0.95)	1.0 (0.17)
3. GENDER				
• MALE	1.7 (1.28)	2.0 (1.51)	1.6 (1.07)	1.1 (0.31)
• FEMALE	2.0 (1.67)	2.6 (2.03)	1.8 (1.37)	1.1 (0.47)
4. THEME-INCOME				
TND				
• LOW	2.1 (1.55)	2.5 (1.80)	1.8 (1.26)	1.0 (n/a)
• MIDDLE	2.0 (1.57)	2.2 (1.61)	2.0 (1.66)	1.2 (0.44)
• HIGH	2.4 (2.14)	3.2 (2.71)	1.9 (1.10)	1.0 (0.00)
MIX				
• LOW	1.7 (1.44)	1.8 (1.74)	1.7 (1.41)	1.1 (0.35)
• MIDDLE	1.9 (1.43)	2.2 (1.73)	1.6 (1.06)	1.1 (0.45)
• HIGH	1.7 (1.06)	1.8 (1.24)	1.7 (0.91)	1.0 (0.00)
PUD				
• LOW	1.8 (1.49)	1.5 (0.83)	1.9 (1.73)	1.5 (0.71)
• MIDDLE	1.8 (1.37)	2.3 (1.70)	1.7 (1.14)	1.2 (0.58)
• HIGH	1.9 (1.50)	2.7 (1.82)	1.5 (0.93)	1.0 (0.17)
5. THEME-GENDER				
TND				
• MALE	1.9 (1.90)	2.2 (1.63)	1.8 (1.29)	1.2 (0.39)
• FEMALE	2.2 (1.81)	2.5 (1.82)	2.2 (1.89)	1.0 (0.0)
MIX				
• MALE	1.6 (1.04)	1.7 (1.14)	1.6 (1.02)	1.0 (0.17)
• FEMALE	2.0 (1.63)	2.5 (2.10)	1.7 (1.20)	1.1 (0.40)
PUD				
• MALE	1.8 (1.29)	2.2 (1.52)	1.6 (1.03)	1.1 (0.31)
• FEMALE	2.0 (1.62)	2.7 (2.06)	1.8 (1.28)	1.1 (0.47)

work tour while **Table 11** ANOVA results confirm the significance of these findings. Pairwise comparison of the income group averages reveals significant differences occurred only between the low and high income groups. Next, the interactions between the income-theme groups were analyzed (**Table 10**) revealing that no consistent pattern emerges between income and themes. Rather, each income group reacts separately to the themes. This is confirmed in the income-theme ANOVA test, as the theme main effect, the income main effect, and the income-theme interaction effect were all significant for work tours.

The results for the gender groupings show that females consistently engage in more complex trip chaining for work tours than their male counterparts (**Table 10**). The differences are particularly large as women averaged 30 percent (or 0.6 more activities) greater activities than men. The ANOVA with gender verified the statistical significance of this difference (**Table 11**). Work tour differences of note indicate females tend to conform to the prescribed notions of chaining more activities in PUD neighborhoods compared to MIX and TND neighborhoods. Males seem to display a pattern of increased chaining of work tours in both TND and PUD compared to MIX for work tours. The gender-theme ANOVA associations are not as significant as those for the income-theme groups. The results do show that the main effects for the work tours are significant, but none of the interaction effects are. There were significant differences when means were compared, though in all cases but one they were between gender rather than the theme groups.

First, the results seem to, again, limitations in classifying land use-transportation systems as a binary system. Second, they show that residents of PUD themes chain more non-work activities to work tours than TND residents and particularly MIX residents. A possible explanation for this behavior may be that PUD residents are suspected to have longer commutes and limited accessibilities to non-work activities given the relatively isolated nature of its development compared to TND and MIX. Therefore, PUD residents may find substantial time savings in adding non-work activities to their work tour as do TND residents, though to a lesser degree. Finally, it seems that MIX theme residents may not receive such time savings as they do not engage in as many complex tours or have as many non-work activities attached to their work tours.

Table 11: Anova Test Results On Mean Number Of Activities By Tour Purpose

	FACTORS	F-RATIO	P	SIGNIFICANT PAIRWISE DIFFERENCES (5%)
I. ALL TOURS	1. THEME	4.568	0.011	(TND & MIX)
	2. INCOME	0.721	0.487	(NONE)
	3. GENDER	17.634	0.000	(MALE & FEMALE)
	4. THEME-INCOME			(NONE)
	THEME	0.413	0.002	
	INCOME	0.799	0.450	
	JOINT	1.045	0.382	
	5. THEME-GENDER			(TND-FEMALE & MIX-MALE,
	THEME	4.593	0.010	TND-FEMALE & PUD-MALE,
	GENDER	15.966	0.000	MIX-FEMALE & MIX-MALE,
	JOINT	0.408	0.665	PUD-FEMALE & MIX-MALE)
II. WORK TOURS	1. THEME	3.910	0.021	(MIX & PUD)
	2. INCOME	3.439	0.033	(HIGH & LOW)
	3. GENDER	19.661	0.000	(MALE & FEMALE)
	4. THEME-INCOME			(MIX-HIGH & TND-HIGH,
	THEME	5.040	0.007	PUD-HIGH & MIX-HIGH)
	INCOME	3.103	0.046	
	JOINT	2.916	0.021	
	5. THEME-GENDER			(MIX-MALE & TND-FEMALE,
	THEME	3.167	0.043	MIX-MALE & MIX-FEMALE,
	GENDER	16.723	0.000	MIX-MALE & PUD-FEMALE)
	JOINT	1.307	0.271	
III. MAINTENANCE TOURS	1. THEME	1.896	0.151	NONE
	2. INCOME	1.181	0.308	NONE
	3. GENDER	4.947	0.026	(MALE & FEMALE)
	4. THEME-INCOME			NONE
	THEME	0.217	0.805	
	INCOME	1.049	0.351	
	JOINT	0.718	0.580	
	5. THEME-GENDER			(TND-FEMALE & MIX-MALE,
	THEME	3.478	0.031	TND-FEMALE & PUD-MALE)
	GENDER	5.734	0.017	
	JOINT	0.638	0.528	
IV. DISCRETIONARY TOURS	(NOT ENOUGH DATA TO TEST DISCRETIONARY TOURS)			

Maintenance Tours

Differences in maintenance touring (**Table 10**) by theme are consistent with theme differences. TND had the highest number of average activities in maintenance tours (2.0) with MIX and PUD following with an equal number of average activities (1.7). The results seem to be intuitive of the land use structure of the themes, although neither the ANOVA (**Table 11**) results nor pairwise comparisons of average activities indicated statistically significant differences. Maintenance tours were then arranged by frequency of activities (**Table 12**) and the findings seem to indicate that while TND residents make the lowest ratio of one activity maintenance tours (58 percent compared to 61 percent for PUD and MIX). TND residents also make the lowest ratio of two activity maintenance tours (19 percent) followed by PUD and MIX residents (24 percent and 25 percent). It seems that TND residents make relatively more complex tours while MIX and PUD residents tend to make more simple maintenance tours.

Differences between chaining activities and incomes (see **Table 10**) were examined next and, surprisingly, an inverse pattern emerged for maintenance tours (though neither the ANOVA tests or pairwise comparisons revealed the differences to be statistically significant). Income-theme groups were also analyzed, though the ANOVA test for joint income-theme groups, again, did not reveal any significant differences in average activities for maintenance tours.

The results for the average activities by gender show (**Table 10**) that females consistently engage in more complex maintenance tours (roughly fifteen percent more activities) than their male counterparts. The one-way ANOVA with gender verifies that it is a significant factor (**Table 11**). Gender-theme interaction results are summarized in **Table 12**. The gender-theme ANOVA associations show that the main effects for maintenance tours are significant, but that the interaction effects are not. Significant differences when pairwise average activities were compared exist only in one case: between females in MIX and TND. Overall, maintenance tour results for both females and males show females tend to chain more than males regardless of theme and that, in TND, they both genders chain more trips than their PUD and MIX counterparts.

Table 12: Activity Count Frequencies (Percentage) by Tour Purpose

	TND	MIX	PUD	ALL
ALL TOURS				
1 ACTIVITY	176 (57)	391 (63)	448 (58)	1015 (60)
2 ACTIVITIES	53 (17)	105 (17)	154 (20)	312 (18)
3 ACTIVITIES	33 (11)	68 (11)	80 (10)	181 (11)
4 ACTIVITIES	17 (6)	28 (5)	40 (5)	85 (5)
5+ ACTIVITIES	30 (10)	26 (4)	57 (7)	113 (7)
WORK TOURS				
1 ACTIVITY	78 (50)	149 (58)	127 (43)	354 (50)
2 ACTIVITIES	27 (17)	30 (12)	55 (19)	112 (16)
3 ACTIVITIES	23 (15)	41 (16)	49 (17)	113 (16)
4 ACTIVITIES	9 (6)	17 (7)	22 (8)	48 (7)
5+ ACTIVITIES	19 (12)	20 (8)	42 (14)	81 (11)
MAINTENANCE TOURS				
1 ACTIVITY	72 (58)	177 (61)	245 (61)	494 (61)
2 ACTIVITIES	23 (19)	72 (25)	97 (24)	192 (24)
3 ACTIVITIES	10 (8)	26 (9)	27 (7)	63 (8)
4 ACTIVITIES	8 (6)	11 (4)	18 (5)	37 (5)
5+ ACTIVITIES	11 (9)	6 (2)	13 (3)	30 (4)
DISCRETIONARY TOURS				
1 ACTIVITY	26 (90)	65 (94)	76 (90)	176 (92)
2 ACTIVITIES	3 (10)	3 (4)	2 (2)	8 (4)
3 ACTIVITIES	0 (0)	1 (1)	4 (5)	5 (3)
4 ACTIVITIES	0 (0)	0 (0)	0 (0)	0 (0)
5+ ACTIVITIES	0 (0)	0 (0)	0 (0)	0 (0)

10. Conclusion

The study examined the effects of land use and network characteristics on travel behavior for twenty neighborhoods in Orange County. 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 much of the enthusiasm for design-oriented solutions to the problems of congestion and air pollution given the effectively weak relationship between the LUTS and both mode choice and trip travel times. Rather, it seems that income and other socio-economic factors have a much more significant relationship to travel behavior than the LUTS, an exception being that total household travel may be influenced by urban form. There may still be hope that design-oriented solutions still may be effective in reducing overall travel by possibly inducing the chaining of multiple trips, but further analysis needs to be done on this subject. An objection to this research may be that design-oriented solutions may not be effective unless they are implemented at a regional level. However, given the political and economic nature of development, such a large scale application of design-solutions appears implausible. Therefore, the results do bring into question the use, especially in regions where design-oriented solutions only affect infill developments, of encouraging initiatives which attempt to tweak the land use-transportation system to reduce automobile congestion.

Second, at an operational level, this study seems to offer some hope in improving the transportation modelling process. Given that differences in travel behavior in income groups can largely be 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 from respondents 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, it is concluded that themes can be a good proxy for a number of socio-economic and LUTS variables used in transportation models.

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. But, the implications may be that care should be taken when considering design-oriented solutions as an alternative measure to address the automobile congestion and air quality improvement issues. However,it is important to note here that while much 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 a traditional neighborhood development movement. That is, the movement is not just a set of travel behavior numbers. It is also a movement about the quality of life and the more intangible aspects of community, intangibles are inherently immeasurable (quality of life, safety, and sense of community among neighbors). TND proponents hope to raise the level of these intangibles. And, in that same breadth, they believe, rightly or wrongly, that TND will do so through its enhancement of pedestrian activity. This idea reaches as far back as Jane Jacobs (1961) seminal work. On such a foundation, perhaps further evidence is needed to fully evaluate the merits of such design-oriented solutions.

11. References

Cervero, R. (1993). Transit-supportive Development in the United States: Experiences and Prospects. USDOT, Washington, D.C.

Deakin, E. and Harvey, G. (1991). "CO2 Emissions Reductions from Transportation and Land Use Strategies: A Case Study of the San Francisco Bay Area". Paper Prepared for the Peder Sather Symposium.

Ewing, R. (1994). "Getting Around a Traditional City, a Suburban Planned Unit Development, and Everything in Between". Transportation Research Record, 1466: 53-62.

Frank, L.D. and Pivo, G. (1994). "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking". Transportation Research Record, 1466: 44-52.

Friedman,B. et al. (1994). "Effect of Neotraditional Neighborhood Design on Travel Characteristics". Transportation Research Record, 1466: 63-70.

Giuliano, G. (1995). "The Weakening Transportation-Land Use Connection". Access, 6: 3-11.

Goulias, K. and Kitamura, R. (1989). "Recursive Model System for Trip Generation and Trip Chaining". Transportation Research Record. 1236.

Harvey, G. and Deakin E. (1992). "Air Quality and Transportation Planning: An Assessment of Recent Developments". ITS Working Paper.

Handy, S. (1993). "Regional Versus Local Accessibility: Implications for Nonwork Travel". Transportation Research Record. 1400.

Handy, S. (1995). "Understanding the Link Between Urban Form and Travel Behavior". Paper presented at the 74th Annual Meeting of the Transportation Research Board, Washington DC, January 1995.

Holtzclaw, J. (1990). Explaining Urban Density and Transit Impacts on Auto Use. State of California Energy Resources Conservation and Development Commission.

Jacobs, Jane (1961). The Death and Life of Great American Cities. Random House. New York, 1961.

Kitamura, (1990) "Trip Chaining Behaviour by Central City Commuters: A Causal Analysis of Time-Space Constraints". In Developments in Dynamic and Activity-based Approaches to Travel Analysis. Gower Publishers, Brookfield, Vermont.

Kitamura, R. et al. (1995). "A Micro-analysis of Land Use and Travel in Five Neighborhoods in the San Francisco Bay Area". Paper presented at the 74th Annual Meeting of the Transportation Research Board, Washington D.C., January 1995.

Kulash, (1990). "Traditional Neighborhood Development: Will the Traffic Work?" presented at the 11th International Pedestrian Conference, Bellevue, Washington, 1990.

Kulkarni, A., R.M. Wang, and McNally, M.G. (1995). "Interactions Between the Land Use-Transportation System and Travel Behavior." Presented at the 50th Annual ITE Conference, Denver, Colorado.

Kumar, A. and Levinson, D. (1995). "Chained Trips in Montgomery County, Maryland". ITE Journal. 65.

Lerner-Lam, et. al. (1992). ITE Technical Committee 5P-8.

McNally and Ryan (1992). "Accessibility of Neotraditional Neighborhoods: a Review of Design Concepts, Policies, and Recent Literature." University of California, Institute of Transportation Studies.

Middlesex-Somerset-Mercer Regional Council (1992). The Impact of Various Land Use Strategies on Suburban Mobility. Federal Transit Administration. Washington D.C.

Newman, P. and Kenworthy, J. (1989). "Gasoline Consumption and Cities: A Comparison of U.S. Cities with a Global Survey". APA Journal 55 (1): 23-39.

Ryan, S. and McNally, M.G. (1995). "Accessibility of Neotraditional Neighborhoods: A Review of Design Concepts, Policies, and Recent Literature". Transportation Research A, 29A (2): 87-196.

Stone, and Johnson (1992). "Neotraditional Neighborhoods: A Solution to Traffic Congestion? in Paasweel, R. (ed.) Site Impact Traffic Assessment: Problems and Solutions. ASCE, New York, New York, 72-76.

Strathman, J. et al. (1994). "Effects of Household Structure and Selected Travel Characteristics on Trip Chaining". Transportation, 21: 23-45.