A Markovian Analysis of Urban Travel Behavior: Pattern Response by Socioeconomic-Occupational Groups

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Knowledge concerning urban movement patterns is relevant in the expansion of planning principles that relate provision of transportation facilities to user demands. The purpose of this paper is to analyze the urban travel behavior of individuals grouped into categories of similar socioeconomic-occupational class. Socioeconomic neighborhood groups are formed vis-a-vis the application of a statistical grouping procedure to socioeconomic variables reflecting household status. Four types of residential areas are defined. However, it cannot be assumed that all people in a given census tract have the same class standing. Therefore, the occupation of the household head was used as a measure to isolate individual variation in socioeconomic status. Ten occupational groups are included. This resulted in 40 combinations of socioeconomic-occupation class groups based on neighborhood and occupation. Principal components analysis was applied to a matrix of trip linkages based on trip purpose for each of the groups. A modified Ward's grouping procedure was applied to a matrix of trip linkages based on trip purpose for each of the groups, resulting in three travel behavior sets.

Each travel behavior set was then analyzed using trip linkage distributions generated by Markov chain analysis. Equilibrium vectors for each of the three groups were examined to elicit the trip pattern differences. The resulting analysis defined significant differences between travel patterns of the three groups. Results indicate that the trip behavior varies significantly in purpose, linkages, and length. A similar analysis was applied to an examination of zonal interchanges for each socioeconomic-occupational group.

•OF major interest to urban transportation planners, urban planners, and transportation geographers is the study of urban travel flows. Knowledge concerning urban movement patterns is relevant to the expansion of planning principles that relate provision of transportation facilities to the user's demands. In recent years increasing attention has been placed on the analysis of individual urban travel behavior in an attempt to find ordering factors with which urban planners, transportation planners, and others can better understand and forecast travel patterns in the city.

The variations in trip movement of individuals may be considered to reflect personal preferences in their travel. Similar preferences arise for like groups of people, providing a basis for general models of intraurban travel patterns (5, chapters 4 and 5).

The purpose of this paper is to analyze the urban travel behavior of sets of individuals having similar socioeconomic characteristics. The first phase deals with the problem of defining socioeconomic groups. Those groups having similar trip structure are then defined. Using a time-dependent probabilistic model to describe trip movements of individuals within each group, differences and similarities between these

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groups are identified. This investigation deals with variation based on trip purposes, variation in CBD versus non-CBD trips, and variation in zonal interchange.

METHOD OF INVESTIGATION

It should be apparent that the first and most important step is to determine an accurate measure of space preferences, as reflected by socioeconomic status, because this is the delineating factor in grouping individuals with similar travel patterns. To accomplish this, socioeconomic data were gathered from the 1960 census for each census tract in Waco, Texas. After converting the data into percentage form, principal components analysis was applied to group those variables covarying; that is, those variables whose percentages varied in approximately the same manner for each of the census tracts. Based on this analysis, each census tract was classified as a particular type of residential neighborhood within the city. In order to link those census tracts of similar residential type, a modified Ward's grouping routine was applied to the component groups—the program utilized in this analysis was CONGROUP (4). Four groups of residential areas in Waco were identified.

The variables used in identifying socioeconomic groups included those measuring household, ethnic, occupational, and economic characteristics of each zone. The principal components analysis yielded four significant clusters of variables. The first was interpreted as representing upper socioeconomic characteristics, while the second exhibited lower socioeconomic characteristics. The third component identified middle class neighborhoods, and the fourth component strongly reflected ethnic characteristics.

Based on the grouping analysis, four groups of census tracts were identified. The first was characterized by high income, quality housing, and white collar occupations. The majority of the tracts were grouped into the middle class socioeconomic group, as might be expected. Two lower socioeconomic residential groups were recognized, differentiated by ethnic affiliation.

It cannot be assumed that all people in a given census tract have the same socioeconomic standing. Therefore, the occupation of the household head was used as a further measure of socioeconomic status to decrease within group variance. Thus, the combination of social area analysis and occupational position was used to measure socioeconomic status, which presumably reflects individual space preferences (6).

In the Waco Transportation Study (7), ten occupational groups were listed, including a miscellaneous category consisting primarily of housewives and students. Coupled with the four residential area types, there were 40 combinations of socioeconomic class groups based on neighborhood and occupation. In order to define those class groups with similar travel patterns, a matrix of trip linkages based on trip purpose for each of the groups was subjected to the modified Ward's grouping routine after being converted to percentages to reduce the influence of varying sample sizes. Table 1 defines the form of the data matrix that was operated on to delineate three classes of trip makers.

VARIATION IN TRIP PURPOSE

Preliminary Analysis

The grouping of the 40 socioeconomic-occupational groups according to similar trip purpose structure resulted in a reduction to three classes. The socioeconomic-occupational groups found in each class are given in Table 2. The first consisted of those people employed in professional and white collar occupations regardless of neighborhood, as well as middle-status workers from better residential areas. Also included were housewives living in upper socioeconomic neighborhoods.

Individuals with blue collar occupations, particularly those living in lower socioeconomic residential areas, made up the majority of the second class. Predominant were the service workers in all areas and the laborers in the low-status areas of the city.

The last class embodied the miscellaneous occupation category of all but the upper-status residential areas. This category consisted primarily of housewives and students, and therefore may be termed nonworkers.

TABLE 1

SOCIOECONOMIC-OCCUPATIONAL–TRIP LINKAGE INPUT MATRIX

Trip Linkages		S (1) RA (1) OC (1)	S (2) RA (1) OC (2)	S (3) RA (1) OC (3)	.... S (10) .... RA (1) OC(10)	S (11) RA (2) OC (1)	.... S (J) .... RA (K) OC (L)	.... S (40) .... RA (4) OC(10)	$\sum_j X_{ij}$
T(1)	P(1) to P(1)	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$	.... $X_{1,10}$	$X_{1,11}$	.... $X_{1,j}$	.... $X_{1,40}$	$\sum_j X_{1j}$
T(2)	P(1) to P(2)	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$	.... $X_{2,10}$	$X_{2,11}$	.... $X_{2,j}$	.... $X_{2,40}$	$\sum_j X_{2j}$
T(3)	P(1) to P(3)	$X_{3,1}$	$X_{3,2}$	$X_{3,3}$	.... $X_{3,10}$	$X_{3,11}$	.... $X_{3,j}$	.... $X_{3,40}$	$\sum_j X_{3j}$
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
T(11)	P(2) to P(1)	$X_{11,1}$	$X_{11,2}$	$X_{11,3}$	.... $X_{11,10}$	$X_{11,11}$	.... $X_{11,j}$	.... $X_{11,40}$	$\sum_j X_{11,j}$
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
T(I)	P(M) to P(N)	$X_{i,1}$	$X_{i,2}$	$X_{i,3}$	.... $X_{i,10}$	$X_{i,11}$	.... X_{ij}	.... $X_{i,40}$	$\sum_j X_{ij}$
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
T(100)	P(10) to P(10)	$X_{100,1}$	$X_{100,2}$	$X_{100,3}$	.... $X_{100,10}$	$X_{100,11}$	.... $X_{100,j}$	.... $X_{100,40}$	$\sum_j X_{100,j}$
		$\sum_i X_{ij}$	$\sum_i X_{i1}$	$\sum_i X_{i2}$	$\sum_i$ i3 .... $\sum_i$ i,10	$\sum_i$ i,11	.... $\sum_i X_{1j}$	.... $\sum_i X_{1,40}$	

RA - Residential Area

OC - Occupational Classification

P - Purpose of Trip

$\sum_{i=1}^{100} X_{ij}$ = Total number of trips by the j^{th} social class.

$\sum_{j=1}^{40} X_{ij}$ = Total number of trips in the i^{th} trip linkage.

$X_{ij} \Big/ \sum_{i=1}^{100} X_{ij}$ = Percentage of trips in the i^{th} trip link by the j^{th} social class group.

The original data matrices were transformed into transition probability matrices as shown in Tables 3, 4, and 5 (2, p. 24-42). That is, each entry represents the probability that a person within that group will move from an origin purpose (row) to a destination purpose (column) during some time period.

An examination of the three transition probability matrices revealed several class differences. In the high occupation class, people who began their trip at home had a probability of 0.38 that they were leaving for work. Other destinations from home with high probabilities were those serving passenger (0.16), social-recreation (0.15), and

TABLE 2

ELEMENTS OF TRIP CLASSES

Occupational Categories	Residential Area I by Group (lower white)	Residential Area II by Group (middle white)	Residential Area III by Group (lower Negro)	Residential Area IV by Group (upper white)
Professional	1	1	1	1
Administrative	1	1	1	1
Clerical	1	1	1	1
Sales	1	1	1	1
Skilled laborers	1	1	2	1
Semiskilled laborers	2	1	1	1
Unskilled laborers	2	1	2	1
Protective services	2	1	2	2
Personal services	2	2	2	2
Miscellaneous (housewives and students)	3	3	3	1

TABLE 3

CLASS 1—HIGH OCCUPATIONAL STATUS PREDOMINANT
9 x 9 TRIP PURPOSE MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5	6	7	8	9
Home	0.00[a]	0.38	0.09	0.01	0.06	0.15	0.02	0.12	0.16
Work	0.55	0.18	0.05	0.00[a]	0.00[a]	0.02	0.11	0.04	0.05
Personal business	0.44	0.12	0.18	0.01	0.01	0.06	0.03	0.11	0.04
Medical-dental	0.57	0.09	0.05	0.03	0.00	0.05	0.05	0.11	0.04
School	0.78	0.03	0.01	0.02	0.01	0.07	0.03	0.03	0.02
Social-recreation	0.68	0.03	0.03	0.00[a]	0.00[a]	0.14	0.02	0.05	0.04
Eat meal	0.23	0.56	0.04	0.00	0.01	0.04	0.01	0.05	0.05
Shop	0.64	0.03	0.05	0.00[a]	0.00[a]	0.05	0.02	0.18	0.03
Serve passenger	0.46	0.18	0.03	0.01	0.01	0.04	0.03	0.05	0.20

[a]Less than 0.005

TABLE 4

CLASS 2—LOW OCCUPATIONAL STATUS PREDOMINANT
9 x 9 TRIP PURPOSE MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5	6	7	8	9
Home	0.00	0.59	0.06	0.01	0.00[a]	0.08	0.01	0.09	0.15
Work	0.78	0.03	0.02	0.00[a]	0.00	0.01	0.04	0.05	0.06
Personal business	0.56	0.06	0.13	0.00	0.00	0.05	0.02	0.12	0.05
Medical-dental	0.69	0.00	0.13	0.00	0.00	0.00	0.00	0.06	0.12
School	0.67	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Social-recreation	0.69	0.01	0.05	0.00	0.00	0.10	0.02	0.07	0.05
Eat meal	0.20	0.56	0.02	0.00	0.00	0.04	0.04	0.08	0.06
Shop	0.68	0.07	0.05	0.01	0.00	0.04	0.02	0.13	0.02
Serve passenger	0.48	0.19	0.03	0.01	0.00	0.03	0.00[a]	0.03	0.23

[a]Less than 0.005

TABLE 5

CLASS 3—HOUSEWIVES AND STUDENTS
9 x 9 TRIP PURPOSE MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5	6	7	8	9
Home	0.00[a]	0.03	0.10	0.02	0.27	0.24	0.02	0.17	0.15
Work	0.74	0.02	0.03	0.00	0.03	0.04	0.08	0.02	0.04
Personal business	0.49	0.00[a]	0.21	0.01	0.01	0.07	0.02	0.16	0.04
Medical-dental	0.55	0.01	0.06	0.01	0.02	0.11	0.01	0.18	0.04
School	0.80	0.01	0.01	0.00[a]	0.02	0.07	0.03	0.04	0.02
Social-recreation	0.65	0.00[a]	0.03	0.01	0.02	0.17	0.02	0.07	0.04
Eat meal	0.51	0.04	0.06	0.00	0.10	0.15	0.01	0.09	0.04
Shop	0.62	0.01	0.05	0.00[a]	0.00[a]	0.07	0.02	0.19	0.04
Serve passenger	0.55	0.01	0.04	0.01	0.03	0.06	0.01	0.08	0.20

[a]Less than 0.005

shopping (0.12). The majority of trips have the home as a destination. An exception is the purpose of eat meal, which has only a 0.23 probability of going home but has a 0.56 probability of going to work. The other highly linked trip purposes for this class include (a) work with work and eat meal; (b) personal business with itself, work, and shop; (c) medical-dental with shop; (d) social-recreation with itself; (e) shop with shop; and (f) serve passenger with itself and with work.

The individuals in the blue collar-service occupation class (2) have a greater probability of leaving for work (0.59) than the first group. This group also has a higher probability of returning home than Class 1. This seems to imply more singularity in trip purpose when compared to Class 1. There is also a smaller proportion of trips for medical-dental purposes, possibly for economic reasons. Other important linkages include (a) personal business with itself and shop; (b) medical-dental with itself and serve passenger; (c) social-recreation with itself; (d) eat meal with work; (e) shop with shop; and (f) serve passenger with itself and work.

The third class, consisting mainly of housewives and students, has a unique trip structure in that the purpose to work is of little importance. The purpose of home continues to dominate as the primary destination, but from home trips are primarily for the purposes of school (0.27), social-recreation (0.24), and shopping (0.17), rather than for work (0.03). The purposes of shopping and social-recreation exhibit high linkages with most of the other purposes when compared to the other classes. The major linkages other than with home purpose are (a) personal business with itself and shop; (b) medical-dental with shop and social-recreation; (c) social-recreation with itself; (d) eat meal with social-recreation, school, and shop; (e) shop with shop; and (f) serve passenger with itself.

When examining all classes, it is clear that home and work purposes dominate for both origin and destination purposes. The averages for the three groups were 59, 69, and 41 percent, respectively, for both to and from home and work purposes. All three groups had over one-third of their origin and destination purposes related to the home, pointing out its significance as a base for the daily trips of the people regardless of their occupation.

Simple Markov Chain Analysis

To further examine the trip structure of the three groups, their urban travel movements were conceptualized as satisfying the conditions of a Markovian process. It may be assumed that the trip purposes within the urban system represent states that a tripmaker may choose as a trip goal. It is also logical to posit that given a tripmaker in a particular state i, there is an associated probability, P_{ij}, that he will move to another state j, in some time period t, and this movement is independent of where he was in any previous time period. Given these assumptions, the transition matrices may be used as a basic input to the Markov model, with the purposes viewed as states and the actual trip linkages as the associated probabilities of moving between states (1, 3).

The Markov chain model also yields the limiting matrix. This matrix may be interpreted as the percentage of trips that on the average have the given purpose as their destination. In other words, it gives the probability of being in a given state after many trips have taken place. Because all rows are similar in the limiting matrix, a row of the matrix is generally termed the equilibrium vector.

The equilibrium vectors for the three classes and the aggregate data are given in Table 6. All three have the home as the purpose state most likely to be occupied, but the high occupation class has a lower percentage than the others. It is also lower than Class 2 in the expected percentage at the work purpose, and higher for such purposes as personal business, social-recreation, eat meal, and shop. This suggests that individuals in the middle-to-high socioeconomic group have a more diverse trip pattern in relation to purpose than do those people in the lower socioeconomic groups, where the home and work states predominate. The people in the housewife-student class are found primarily in the school, social-recreation, personal business, and shop states, and have very few people in the work state.

TABLE 6

EQUILIBRIUM VECTORS FOR TRIP PURPOSE BY CLASS

Purpose	Class 1 High Occupation (percent)	Class 2 Low Occupation (percent)	Class 3 Housewives (percent)	Cumulative[a] (percent)
Home	34.7	38.7	38.2	37.3
Work	22.8	28.8	1.5	14.4
Personal business	6.7	4.6	6.9	6.7
Medical-dental	0.7	0.6	1.0	0.8
School	2.5	0.0[b]	11.5	6.3
Social-recreation	8.6	5.1	14.8	11.3
Eat meal	4.3	2.8	2.3	3.3
Shop	8.7	7.0	12.6	10.2
Serve passenger	10.0	11.0	9.4	9.5

[a]From Horton and Shuldiner (1). [b]Less than 0.05

Thus, the low socioeconomic class is more oriented towards the basic activities of home and work, whereas the medium-to-high occupation class is not only concerned with work, but also with activities such as shopping, personal business, and social-recreation. Another influencing factor might be that white collar and professional occupations often require more interpersonal or face-to-face contact, thus increasing the probability of the purposes of personal business and eat meal as related to their work. In the third class, housewives are more concerned with the purchasing of goods and services, whereas the students pursue their education.

It is interesting to note the consistency of the serve passenger state over all groups. This seems to indicate that approximately 10 percent of all trips, regardless of occupation or class, are concerned with serving the needs of other people. Also, the state of medical-dental is most frequented by members of the housewife-student group, probably because mothers often accompany their children to doctor's offices, and receive more regular medical attention themselves.

Absorbing Chain Analysis

Urban trip movements may be viewed as a closed-circuit system, with the trip-maker leaving home, making one or more stops, and then returning to the home base. By setting the probability of moving from the home state equal to unity (i.e., once a person returns home, he may not leave), an absorbing Markov chain is formed and it is possible to study the movements made before returning to the home (1).

Computation of the fundamental matrix yields the expected number of times the trip-maker will be in a particular transient state before returning to the absorbing state (home), provided that he starts in a given transient state. Tables 7, 8, and 9 give the

TABLE 7

CLASS 1—HIGH OCCUPATIONAL STATUS
EXPECTED NUMBER OF STOPS BY FIRST PURPOSE AND TYPE OF STOP

First Purpose \ Stops at	1	2	3	4	5	6	7	8
1. Work	1.37	0.10	0.01	0.01	0.06	0.16	0.10	0.11
2. Personal business	0.28	1.26	0.01	0.01	0.11	0.08	0.21	0.10
3. Medical-dental	0.22	0.10	1.04	0.00[a]	0.10	0.08	0.18	0.09
4. School	0.09	0.03	0.02	1.01	0.10	0.04	0.07	0.05
5. Social-recreation	0.10	0.05	0.01	0.01	1.18	0.05	0.09	0.08
6. Eat meal	0.82	0.12	0.01	0.02	0.10	1.11	0.14	0.14
7. Shop	0.10	0.09	0.00[a]	0.00[a]	0.09	0.04	1.25	0.07
8. Serve passenger	0.36	0.08	0.01	0.02	0.09	0.08	0.12	1.29

[a]Less than 0.005

TABLE 8

CLASS 2—LOW OCCUPATIONAL STATUS
EXPECTED NUMBER OF STOPS BY FIRST PURPOSE AND TYPE OF STOP

First Purpose \ Stops at	1	2	3	4	5	6	7	8
1. Work	1.09	0.03	0.00[a]	0.00	0.03	0.05	0.08	0.10
2. Personal business	0.13	1.17	0.00[a]	0.00	0.09	0.03	0.19	0.10
3. Medical-dental	0.06	0.16	1.00	0.00	0.02	0.01	0.11	0.18
4. School	0.04	0.39	0.00[a]	1.00	0.03	0.01	0.06	0.03
5. Social-recreation	0.06	0.07	0.00[a]	0.00	1.13	0.03	0.11	0.09
6. Eat meal	0.67	0.06	0.00[a]	0.00	0.07	1.08	0.16	0.15
7. Shop	0.11	0.07	0.01	0.00	0.06	0.03	1.18	0.04
8. Serve passenger	0.28	0.07	0.01	0.00	0.06	0.02	0.07	1.33

[a]Less than 0.005

mean number of times a person is in a transient state for each possible transient starting state for each of the three classes of tripmakers.

From a study of the two working class matrices, it appears that in general, Class 1 has a greater likelihood of stopping in the various states than Class 2. Some exceptions occur in the medical-dental and school trips, but they are probably caused by the small sample sizes for the blue collar-service occupation class. The other exception is that of serving passengers consecutively, implying that more individuals in the low occupation class depend upon rides from others.

In both classes, there is a high expected number of stops from eat meal to work, giving evidence that many workers go to their jobs after eating a meal somewhere other than home. The high occupation class also has a strong linkage of work with work, supporting an earlier contention that such occupations require more interpersonal contact with others in their work, resulting in a higher number of trips in the work category.

As might be expected, the housewife and student group exhibits a higher mean number of stops in the social-recreation, shop, and personal business purposes than the working groups. Women usually make a series of stops when shopping for both goods and services, and are more likely to undertake such trips.

By summing across the rows of the matrix of the expected number of stops by first purpose, the average number of stops for each purpose as a starting state may be computed. In other words, the length of multipurpose trips, measured in frequency of stops,

TABLE 9

CLASS 3—HOUSEWIVES AND STUDENTS
EXPECTED NUMBER OF STOPS BY FIRST PURPOSE AND TYPE OF STOP

First Purpose \ Stops at	1	2	3	4	5	6	7	8
1. Work	1.02	0.05	0.00[a]	0.05	0.09	0.09	0.07	0.06
2. Personal business	0.01	1.29	0.01	0.03	0.15	0.04	0.28	0.09
3. Medical-dental	0.01	0.11	1.02	0.03	0.18	0.03	0.28	0.08
4. School	0.02	0.03	0.01	1.02	0.10	0.04	0.07	0.04
5. Social-recreation	0.01	0.06	0.01	0.03	1.24	0.03	0.13	0.07
6. Eat meal	0.05	0.11	0.00[a]	0.11	0.23	1.03	0.16	0.08
7. Shop	0.00[a]	0.10	0.01	0.01	0.13	0.03	1.27	0.08
8. Serve passenger	0.02	0.08	0.01	0.05	0.13	0.03	0.17	1.27

[a]Less than 0.005

TABLE 10

PREDICTED NUMBER OF STOPS FOR WACO PERSON TRIPS BY CLASS

First Purpose	High Occupation Class	Low Occupation Class	Housewife and Student Class	Cumulative Classes[a]
Work	1.92	1.38	1.44	1.8
Personal business	2.06	1.71	1.90	1.9
Medical-dental	1.80	1.54	1.74	1.8
School	1.41	1.57	1.33	1.3
Social-recreation	1.57	1.49	1.58	1.6
Eat meal	2.45	2.19	1.77	2.2
Shop	1.65	1.50	1.64	1.7
Serve passenger	2.04	1.84	1.76	1.9
System	1.84	1.50	1.58	1.7

[a]From Horton and Shuldiner (1).

TABLE 11

VARIANCE IN NUMBER OF STOPS FOR WACO PERSON TRIPS BY CLASS

First Purpose	High Occupation Class	Low Occupation Class	Housewife and Student Class	Cumulative Classes[a]
Work	1.89	0.75	0.82	1.4
Personal business	1.87	1.07	1.39	1.5
Medical-dental	1.60	0.98	1.18	1.3
School	0.94	1.01	0.64	0.7
Social-recreation	1.19	0.85	0.99	1.1
Eat meal	2.03	1.04	1.13	1.6
Shop	1.30	0.83	1.11	1.2
Serve passenger	1.90	1.19	1.22	1.5
System	1.71	0.90	1.03	1.3

[a]Horton and Shuldiner (1).

can be found for each non-home starting state and for the system (Table 10). The variation in trip length can also be calculated (Table 11).

As suggested by previous results, the high occupation class has the highest expected number of stops in most of the starting states, and in the system as a whole, indicating that the majority of trips are multipurpose in nature. The low occupation class has a low frequency of trip stops in comparison with the other classes, implying that most trips are singular in purpose. There is a larger number of stops when starting at the eat meal and serve passenger states for both working classes. Surprisingly, the expected number of stops in the shopping state is small when starting from shopping, whereas personal business is relatively high.

VARIATION IN CBD VERSUS NON-CBD TRIPS

To further study the variation in the travel patterns of the three classes, trips were divided by CBD versus non-CBD origins and destinations. Initially, each category was

TABLE 12

CBD/NON-CBD TRIP BREAKDOWN BY CLASS

Trip End	Class 1		Class 2		Class 3	
	CBD	Non-CBD	CBD	Non-CBD	CBD	Non-CBD
CBD	417	1989	86	319	268	1146
Non-CBD	1932	14, 491	331	2052	1169	11, 342
CBD	0.173	0.827	0.212	0.788	0.190	0.810
Non-CBD	0.118	0.882	0.139	0.861	0.093	0.907

TABLE 13

HIGH OCCUPATIONAL CLASS (1)
5 x 5 ZONAL MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5
1. CBD	0.192	0.080	0.069	0.355	0.304
2. Northeast	0.156	0.498	0.038	0.144	0.164
3. Southeast	0.169	0.061	0.269	0.326	0.175
4. Southwest	0.125	0.029	0.055	0.529	0.262
5. Northwest	0.126	0.031	0.024	0.272	0.547

classified by trip purpose, but the resultant matrices had too few observations to warrant Markovian analysis.

However, some observations were possible. For trips leaving the CBD, approximately 60 percent were bound for home, regardless of group affiliation. Yet for trips starting and ending outside the CBD, the average was only 38 percent returning to home. The high percentage of the former can probably be attributed to the central function of the downtown area, with many specialized services and jobs drawing people who return home after their purpose has been accomplished. Also, the CBD has few trips from home to some other purpose in comparison with other areas.

For movements within non-CBD areas, 20 percent of the high occupation class trips were destined for work, whereas for the low occupation class, 29 percent of the trips had a similar destination. If the trip was to the CBD from the outer area, the percentage of trips for work for the high and low occupation groups was 54 and 46 percent, respectively. It therefore seems reasonable that a greater portion of high-status workers are employed in the CBD where higher order functions are located.

Work was the dominant trip purpose for within-CBD movements for both high and low occupation classes, with 40 and 31 percent, respectively. Both made approximately 19 percent of their trips for personal business purposes.

The housewife-student group made relatively fewer trips to the downtown area. Their first stop was divided with 20 percent of the trips for personal business, 19 percent for social-recreation, 15 percent for shopping, and 14 percent for school purposes. Once in the CBD, 35 percent of their trips within the CBD were for personal business, 20 percent for shopping, and 9 percent for social-recreation purposes.

By eliminating the trip purpose breakdown, three matrices of total trip ends were given based on the CBD versus non-CBD dichotomy. The totals and the corresponding percentages are shown in Table 12. A possible explanation for the higher percentage of CBD destinations for Class 2 may be the close proximity of low socioeconomic neighborhoods to the CBD, resulting in a greater potential interaction for various trip purposes.

VARIATION IN ZONAL INTERCHANGE

Because a better differentiation of zonal movements between the three classes was desired, the non-CBD area was subdivided into four sectors. Although the zones were chosen primarily on the criterion of dividing the city into quadrants of approximately equal area, it may be of interest to note the general socioeconomic composition of each. The southeast zone consists of poor whites and Mexicans with middle class whites in the outer tracts of the zone. But the southwest and northwest sectors are predominantly middle-to-upper income white households, although the latter includes some households in the lower socioeconomic group. The northeast quadrant is com-

TABLE 14

LOW OCCUPATIONAL CLASS (2)
5 x 5 ZONAL MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5
1. CBD	0.218	0.206	0.188	0.134	0.254
2. Northeast	0.131	0.483	0.052	0.155	0.179
3. Southeast	0.210	0.126	0.250	0.200	0.214
4. Southwest	0.118	0.227	0.134	0.261	0.261
5. Northwest	0.141	0.134	0.062	0.173	0.490

TABLE 15

HOUSEWIFE AND STUDENT CLASS (3)
5 x 5 ZONAL MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5
1. CBD	0.196	0.083	0.127	0.309	0.285
2. Northeast	0.087	0.684	0.042	0.076	0.112
3. Southeast	0.121	0.052	0.423	0.243	0.162
4. Southwest	0.093	0.026	0.080	0.590	0.211
5. Northwest	0.116	0.029	0.030	0.234	0.591

TABLE 16

EQUILIBRIUM VECTORS FOR ZONAL INTERCHANGE

Zone	Class 1 High Occupation	Class 2 Low Occupation	Class 3 Housewife-Student
CBD	0.139	0.154	0.115
Northeast	0.073	0.247	0.106
Southeast	0.057	0.113	0.098
Southwest	0.373	0.182	0.352
Northwest	0.358	0.304	0.329

TABLE 17

HIGH OCCUPATIONAL CLASS (1)
EXPECTED NUMBER OF STOPS BY ORIGIN ZONE AND DESTINATIONS

Zone Origin \ Stops at	NE	SE	SW	NW
Northeast	2.31	0.37	2.29	2.30
Southeast	0.51	1.68	2.69	2.39
Southwest	0.46	0.42	4.12	2.71
Northwest	0.46	0.37	2.77	4.12

posed of Negro and white neighborhoods, mostly blue collar workers, with middle class whites residing in the eastern sections of the area. The northeast zone is separated from the rest of Waco by the Brazos River, making it subject to a barrier effect. The transition matrices for each class are displayed in Tables 13, 14, and 15.

Common to all three classes is a high intrazonal percentage of movement, except in the CBD area. The high occupational class has relatively little movement to the northeast and southeast sectors. Two possible factors contributing to this movement pattern are that both zones are primarily lower socioeconomic class neighborhoods, and that the northeast zone is separated from the city by the Brazos River. Greater interaction exists with those zones characterized by middle and high income residential areas.

The pattern in Class 2 (blue collar-service workers) is not as clear. It appears that they are more likely to move between zones regardless of neighborhood type. The zonal interchanges most likely represent flows to various low-skill employment centers within the sectors.

The housewife-student class shows an even greater tendency to restrict movement to within zones. Only a small percentage of trips from without are destined to the low income eastern sectors. Trips originating in the two upper socioeconomic neighborhood quadrants tend to remain in the same type of area. On the average, 10 percent of the housewife-student trips are destined for the CBD, whereas the working groups averaged nearer to 15 percent, illustrating the downtown area's strength as both a shopping and work center.

The equilibrium vectors (Table 16) give the probability of being in a given zone after a larger number of transitions have taken place. The blue collar-service occupation group differs from the other groups in that a greater proportion of trips end in the northeast sector while fewer travel to the southwest sector. One factor is the existence of a large number of laborer and semiskilled jobs in factories in the northeast sector, and another is that many of the neighborhoods in that sector are in the lower socioeconomic class. The high occupational class and housewife-student class trip distributions appear to be similar.

The CBD is of primary importance in that it is the focal point for a large number of trips for both work and non-work purposes. Hence, it was used as the absorbing state

TABLE 18

LOW OCCUPATIONAL CLASS (2)
EXPECTED NUMBER OF STOPS BY ORIGIN ZONE AND DESTINATIONS

Zone Origin \ Stops at	NE	SE	SW	NW
Northeast	3.21	0.63	1.33	2.07
Southeast	1.50	1.82	1.26	1.94
Southwest	1.84	0.75	2.46	2.22
Northwest	1.65	0.64	1.34	3.50

TABLE 19

HOUSEWIFE AND STUDENT CLASS (3)
EXPECTED NUMBER OF STOPS BY ORIGIN ZONE AND DESTINATIONS

Zone Origin \ Stops at	NE	SE	SW	NW
Northeast	3.78	0.79	2.74	2.76
Southeast	0.92	2.39	3.22	2.86
Southwest	0.84	0.90	4.90	3.11
Northwest	0.82	0.75	3.24	4.63

TABLE 20

PREDICTED NUMBER OF STOPS FOR WACO INTERZONAL TRIPS BY CLASS

Origin Zone	Class 1 High Occupation	Class 2 Low Occupation	Class 3 Housewife-Student
Northeast	7.28	7.24	10.06
Southeast	7.26	6.53	9.39
Southwest	7.71	7.27	9.75
Northwest	7.72	7.13	9.43
System	6.17	5.50	7.73

in an absorbing Markov chain analysis to study the movements made before arriving there. Tables 17, 18, and 19 display the fundamental matrices of the three classes. Each entry represents the probable number of times that a tripmaker will be in a certain zone before traveling to the CBD, given that he begins in a particular non-CBD zone.

For the professional-white collar worker, the majority of the trips are destined to the high socioeconomic neighborhoods in the western sectors of the city, even if they start their trip in the eastern sectors. The same is true to a lesser extent for the blue collar-service workers, although they also have regular stops in the northeast sector. For both groups, there are few stops in the southeast sector. This is most likely caused by the lack of employment opportunities in this area.

The non-working class of housewives and students has a pattern comparable to the professional and white collar workers, but with a greater frequency of stops at all zones. This appears reasonable because tripmakers in this class do not travel to the CBD for work trips, but rather for occasional shopping and business trips. The majority of their trips are local. The frequency of stops in the southeast zone is increased, possibly because of the presence of Baylor University.

The expected number of stops in non-CBD zones before stopping downtown is given for each starting zone in Table 20. Class 2 has the fewest stops before entering the CBD, especially if the origin zone is the southeast sector. The housewife-student group visits the CBD the least often, in that at least 9 non-CBD trips are made, on the average, before a downtown trip is undertaken.

CONCLUSIONS

The results indicate that the travel behavior of various socioeconomic-occupational groups varies considerably in trip purpose, linkages, and length. These groups also appear to differ in their spatial distribution of trip ends within the city. As a result, research in the development of trip generation and distribution models utilizing this information would appear worthwhile. Also of importance is the application of the Markovian process and models in analyzing the travel behavior of urban households. Research is currently being undertaken to utilize the probability matrices generated in the analyses discussed in this paper as basic input to a simulation model of urban travel behavior which will define movement behavior of the three groups under different environmental conditions.

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