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A Non-Linear Canonical Correlation

Analysis of Weekly Trip Chaining Behaviour

by

Thomas F. Golob

ABSTRACT

This research concerns the relationships between the patterns of activities pursued in home-based trip chains and the characteristics of the persons making the chains. The data source is a one-week travel diary reported by persons over eleven years of age in the Netherlands in 1984. All home-based trip chains, including both simple two-link chains and more complex ones, were classified on the basis of the sequence of away-from-home activities. Twenty types were distinguished. The presence or absence of these trip-chain types were then explained in terms of the personal and household characteristics of the travellers using non-linear canonical correlation analysis. This analysis technique can accommodate multiple dependent variables and nominally-scaled (categorical) variables in both the independent and dependent variable sets. Determined are the category scores for each independent variable that are optimal in explaining patterns in the dependent chain-type variables. Also determined are the optimal combinations of the two variable sets. These results capture the relationships between the sequences of activities in trip chains and the variables age, sex, working status, household income, stage in the family life cycle, household car ownership, and residential location. The most effective variable was found to be life cycle, followed by age and income.

1.0 OBJECTIVES AND SCOPE

This research focuses on the types of activities pursued in home-based trip chains over the course of a week. In alternative terminology, the focus is on the trip purposes of tours which originate and end at each traveler's home as reported in a seven-day travel diary. These tours can be simple two-link chains (i.e., home to work to home) or more complex chains involving three or more links (such as home to work to shopping to another shopping location to home). The objective is to identify relationships between the activity types and the personal and household characteristics of the travelers. The research is limited in that it addresses the nature of the activities pursued but not the spatial and temporal dimensions of activity patterns.

A secondary objective of this research is to demonstrate the use of non-linear canonical correlation analysis in travel-behaviour research. This method, which is described in Section 3.0, is purported to be a flexible exploratory tool that is relatively easy to apply. It can accommodate multiple dependent variables, whereas, for example, single-equation regression analysis is limited to a single numerical dependent variable, and logit analysis is limited to a single categorical dependent variable. It can also accommodate any number of categorical variables in either the dependent or independent variable sets, whereas linear statistical methods including regression, logit, discriminant analysis, and factor analysis are limited to numerical variables and categorical variables of the 0,1-type (dummy variables) in the independent (explanatory) set. In activity analysis, the multiple dependent variables (activity types, timing, and spatial locations, plus mode of travel, etc.) and categorical independent variables (life cycle, role in the household, etc.) appear to be suited to the application of non-linear canonical correlation analysis.

Non-linear canonical correlation analysis is most applicable as an exploratory technique, and can be used as a preliminary step in model building. Simultaneous-equation regression analyses for continuous variables, or log-linear models for categorical and mixed variables (Nelder and Wedderburn, 1972; Bishop, et al., 1975) can be used as confirmatory techniques in later stages of the analysis.

2.0 RELATED STUDIES OF TRIP CHAINING BEHAVIOUR

Analyses of trip-chaining behaviour fall within the realm of activity-pattern analysis. Comprehensive overviews of this field are provided by Hanson (1979), Root, et al. (1981), Damm (1983), and Golob and Golob (1983); and reviews of specific areas of activity analysis research can be found in Damm (1980), Jones, et al. (1980), Wigan and Morris (1980), Pickup and Town (1981), and Jones (1983).

The first studies specifically addressing relationships between activity patterns and the characteristics of the persons generating the patterns appear to be those of Chapin (1968, 1974) and his colleagues, in which population segmentations were used to explain differences in activity patterns. In particular, Chapin proposed the use of "stage in the family life cycle" (now usually called simply "life cycle"), which incorporates marital status, the number and age distribution of any children, and whether children live at home. These concepts were further developed by Reichman (1976) and have been employed extensively by Jones, et al. (1980) and Allaman, et al. (1981). In the latter study, a constrained simultaneous equation system is used in an attempt to capture allocation of time among different activities for life-cycle segments.

Damm (1980, 1982) and Damm and Lerman (1981) developed a model which described the joint choice of whether or not to participate in an activity, and the duration of the activity. Landau, et al. (1981) specified activity-generation in a multi-stage conditional choice model, and Van der Hoorn (1983) developed a simultaneous, segmented model of choice of type and location of activity. More recently, Kitamura (1984) modelled workers' choices of participation in discretionary activities and the time allocations involved. In all of these modelling efforts, the distinction between compulsory and discretionary activities was critical, and empirical results showed strong relationships between activity pattern parameters and personal and household characteristics such as income and life cycle. Further empirical evidence of relationships between particular socioeconomic characteristics such as age, sex, or life cycle and activity pattern parameters is provided by P. Hanson (1978), Hanson and Hanson (1980), Kitamura et al. (1981), Jones, et al. (1980), Adiv (1983), Godard (1983), Herz (1983), and Pas (1984).

In two groups of studies, there has been an attempt to develop an activity-pattern typology by clustering diverse trip chains into homogeneous groups. Highly complex methodologies are involved in both groups of studies. Recker, et al. (1983, 1985a, 1985b) and Recker and McNally (1985) employed pattern recognition techniques of the type used for physical character recognition and image analysis, while Pas (1982, 1983) calculated geometrical similarity indices based on a hierarchy of activity pattern attributes. Earlier efforts at classifying activity patterns are documented in Kansky (1967), Hanson and Marble (1971), and Oppenheim (1975).

In the present study, there is a finer distinction of activity types (trip purposes) than in these previous studies, but the temporal and spatial parameters of the patterns are excluded from analysis. The present methodology, described in the next section, is quite simple and direct when compared to many of the methodologies employed in the previous studies; a simple classification of activity patterns together with a single multivariate statistical analysis technique is implemented in place of the complex sequences of techniques used in the previous studies.

3.0 METHODOLOGY

Canonical correlation analysis deals with two variable sets, one of which is usually considered to be a dependent set while the other is considered to be an independent set. The objective is to find the linear combinations of each set which are maximally correlated. These linear combinations are known as canonical variates, and the correlation between the variates for each set is called the canonical correlation. If there are two or more variables in each set, then a second canonical variate can usually be found for which there is maximum correlation between the variable sets, with the condition that it is orthogonal (statistically independent of) the first canonical variate. The possible number of canonical variates is equal to the number of variables in the smaller of the two variable sets; but in pratical applications the number of variates is often limited to one or two for purposes of interpretation. Canonical correlation analysis can be viewed as a generalisation of regression analysis to more than one dependent variable. Canonical correlation analysis does in fact reduce to regression analysis when there is only one variable in the dependent set.

Conventionally, canonical correlation analysis is a linear statistical method: results are invariant under any linear tranformations of the variables. Thus, the variables must be at least intervally-scaled (numerical or cardinal variables) or must be of the dichotomous 0,1-type (dummy variables). The solution is then a closed-form eigenvalue problem. This restriction to interval-scaled (or 0,1-type) variables severely limits the usefulness of conventional canonical correlation analysis (and regression analysis) in investigations of trip-chaining behaviour.

Recently, non-linear (or, non-metric) versions of canonical correlation analysis have been developed. These techniques are designed for use with nominally-scaled (categorical) variables, and with ordinal variables. The results produced are invariant under any non-linear, category-preserving transformations of the variables (or, in the case of ordinal variables, invariant under monotonic transformations). Most of these techniques are based on the principle of optimal scaling; the catagorical variables are transformed into quantitive data by assigning scores (scale values) to each category of each categorical variable (Keller and Wansbeek, 1983).

These scores are optimal in the sense that the relationships between the variable sets are the best possible (in, say, a least-squares sense). The solution algorithms are no longer closed-form, because both the category scores and variable weights (coefficients) must be determined. This generally requires an iterative solution.

The non-linear canonical correlation analysis technique used in the present research, called CANALS, was developed at the University of Leiden, Department of Data Theory (De Leeuw, 1973) and is documented in Gifi (1981), Van der Burg (1983), and Van der Burg and De Leeuw (1983). The solution algorithm is known as alternating least squares (De Leeuw, et. al., 1976; Young, et al., 1976; Young, 1981). The algorithm operates by minimising a loss function that is a measure of the sum of squared differences between the linear combinations of the rescaled dependent and rescaled independent variable sets. Category scores and variable weights are successively adjusted for each data set, and the algorithm iterates between the two variable sets. Certain constraints relating to the opposite variable set (that is, the variable set not being adjusted at a given iteration) must be observed at each iteration, and the Gram-Schmidt technique is used. The algorithm is convergent because the objective loss function is never increased in any rescaling. The results provided in a CANALS output include, for each canonical variate requested, the canonical correlation between the variable sets, the weights (coefficients) for each variable, and the correlations between each variable and the canonical variate for each variable set. The number of canonical variates is generally determined by inspection of the canonical correlations, unless otherwise dictated by theory. The category scores (defining the optimal scales) are also computed for each variable and three types of variables are distinguished: numerical (for which the category scores are linearly related), ordinal (for which the scores are monotonically increasing or decreasing) and categorical (for which the scores can take any values).

Non-linear canonical correlation analysis in general, and CANALS in particular, reduces to conventional (linear) canonical correlation analysis when all variables are defined to be numerical or dichotomous. (The conventional linear solution is in fact used as the initial solution in the CANALS algorithm.) If there is one categorical variable in the dependent variable set, it is similar to conventional discriminant analysis; if the independent variable set is specified as a design matrix, analysis-of-variance is the result.

For travel behaviour analysis in general, the technique has two major advantages. First, categorical independent variables can be accommodated without the necessity of breaking such variables into dichotomous dummy variables or employing population segmentations. Thus, important variables such as life cycle, occupation, and household role structure can be directly included as explanatory variables in models of behaviour. (It still might be useful to employ segmentations, however, if there are significant interactions between certain categories of the variable in question and other independent variables.) When the categorical variables are included in non-linear canonical correlation analysis, the computed category scores will indicate whether or not certain categories can be considered together because of their similarity in explaining the dependent behavioural variables. There is no need in these analyses to exclude observations which have missing data on variables such as income; a category is simply established for missing data and the optimal scales will indicate how this category relates to the other, non-missing, categories. In applications with one multinomial choice variable in the dependent variable set, the optimal scaling of this variable will indicate which choice alternatives are uniquely different from one another and which choice alternatives cannot be distinguished by the explanatory variables.

A second advantage is the capability to accommodate multiple dependent variables. Results generally will indicate the degree to which each of these dependent variables is correlated with the canonical variate(s) of the independent variable set, and thus with each independent variable itself.

There are also certain drawbacks in using the technique. First, numerical variables must be categorised when they are included in the analysis. This can lead to difficult subjective decisions, particularly when there are a number of outlying observations for a variable, and this was a motivation for considering trip chain generations as dichotomous rather than numerical variables in the present study. A second major disadvantage is that there are fundamental difficulties in conducting significance tests. For this reason, non-linear canonical correlation analysis and related techniques are more appropriate as exploratory rather than confirmatory analysis tools.

4.0 DATA

Data for analysis were drawn from the first wave of the Dutch National Mobility Panel (J.M. Golob, et al., 1985). The surveys, which took place in March, 1984, involved seven-day travel diaries for all household members over eleven years of age. The sample was clustered in twenty communities throughout the Netherlands and consisted of over 1,700 households, with travel diary data for over 3,800 persons. A quota sampling procedure was used, based on life cycle and income criteria, and the sample was weighted to national statistics using a random-sample national travel survey. In the travel diary, away-from-home activities were distinguished on the basis of twelve trip purpose categories (plus a thirteenth "other" category).

An attempt was made to take specific advantage of the multi-day aspect of the travel data. This was done by defining a relatively large number of complex trip chains, as described in the next section of this paper. With seven-day diaries, there is a high probability of observing a mix of different types of activity patterns for each individual, because patterns which typically occur on a weekly basis are likely to be reported (Hanson, 1979). Thus, for the present objective of relating activity patterns to person and household characteristics, there is a high information content in each observation (person) in the sample. (It is not within the scope of this paper to debate the merits of multi-day diary data sets.)

Previous studies, reviewed in the second section of this paper, have identified the overwhelming effect of compulsory travel (particularly for work and school) on activity pattern formation. Consequently, separate analyses were conducted in the present study for three population segments: "workers" (both full-time and part-time), "students" (full-time only), and "others" who are neither workers nor students. The sample sizes were 1,481 "workers", 667 "students", and 1,582 "others". (The population characteristics of the "others" segment are discussed in the course of defining the explanatory variables in Section 5.2.) These 3,730 persons were found to make more than 35,000 home-based trip chains during their seven-day diary periods.

In the course of the analysis it was determined that the relationship between the population segmentation and the activities "work" and "school" was not direct. Some workers were part-time students, and some students were part-time workers. Also, some persons classified into the "others" segment reported work and school trips. Apparently they were engaged in incidental work or were part-time students. In some cases they may have confused the diary category "serve-passenger" with the diary category relating to the activity of the passenger; this appears to be a common problem with conventional travel diaries.

5.0 THE VARIABLES

5.1 The Dependent (Chain-Type) Variables

A typology of home-based trip chains was developed by analysing the transitions between activities (trip purposes). The procedure is described in Golob (1984) and is an extension of the transition analysis developed in Kitamura (1983). Nineteen activity sequences were identified which accounted for at least 0.7 % of all home-based trip chains. These are listed, together with a twentieth residual type, in Table 1. The typology is arbitrary but was guided by certain planning criteria. For instance, a distinction was made between trip types 3 and 4 because of the possible importance of type 3 to working female household heads.

Seven of the chain types involved only one non-home activity. These simple two-link chains together account for 78.4 % of all home-based chains. The remaining thirteen chain types (including the twentieth type) involve three or more links. It was not deemed necessary to distinguish between home and non-home destinations for the third link, because less than forty percent of all third destinations are non-home. Thus, three-link and four-or-more-link chains are not distinguished from one another, but no chains are excluded from the analyses.

These twenty dependent variables were coded dichotomously. For each chain type, the value "2" was assigned if a person was observed to make a chain of the type during the diary week; the value "1" was assigned if no such chain type was made. This dichotomous treatment of the dependent variables represents a major simplification in the analysis that was motivated by three considerations. First, a

Chain type defined by activity sequence*	Number of links	Observed number	Percent of all chains
Dependent (chain-type) variable set			
1. H-Work-H	2	5,277	15.3
2. H-Work-Work-	3 or more	616	1.8
3. H-Work-Shop-	3 or more	241	0.7
4. H-Work-Other than Work or Shop-	3 or more	585	1.7
5. H-School-H	2	2,834	8.2
6. H-School-Other than Home-	3 or more	514	1.5
7. H-P. Bus.-H	2	1,205	3.5
8. H-Serve P.-H	2	1,935	5.6
9. H-P. Bus/Serve P.-Other than Shop or S. Rec.-	3 or more	432	1.3
10. H-P. Bus/Serve P.-Shop-	3 or more	333	1.0
11. H-P. Bus/Serve P.-S. Rec.-	3 or more	351	1.0
12. H-Shop-H	2	5,211	15.1
13. H-Shop-Shop-	3 or more	474	1.4
14. H- Shop-S. Rec.-	3 or more	330	1.0
15. H-S. Rec.-H	2	8,971	26.0
16. H-S. Rec.-S. Rec.-	3 or more	1,100	3.2
17. H-S. Rec.-Shop-	3 or more	351	1.0
18. H-Other-H	2	1,615	4.7
19. H-Other-Other-	3 or more	1,003	2.9
20. Anyting else	3 or more	1,118	3.2
Total observed number of chains		34,496	100.0

* Abbreviations: H = home, P. Bus = personal business, Serve P. = serve passenger
S. Rec. = social or recreational

TABLE 1: A TYPOLOGY OF HOME-BASED TRIP CHAINS RECORDED IN DUTCH NATIONAL MOBILITY PANEL WAVE I (MARCH, 1984)

judgement was made that results should be in terms of whether or not a certain activity sequence was generated over the course of a week, rather than in terms of the frequency of generation of each sequence. For instance, it was judged to be important to distinguish workers who make a stop for shopping after work from those who do not, but not to distinguish workers who work one day a week from those who work five days a week, all else held constant. Second, to facilitate interpretation of the results, only the explanatory (population characteristic) variables are optimally scaled in such an analysis, because the scaling of a dichotomous variable cannot be distinguished from its coefficient (and is thus equivalent to a numerical variable). Third and finally, for practical reasons, only the simple two-link work, school, and shopping chains exhibited substantial numbers of persons making more than one chain per week.

5.2 The Explanatory Variables

Seven explanatory variables were used in the analysis. One of these variables, working hours, was only relevant for the "workers" segment. The other six variables were used in all three analyses. However, categories were collapsed for some variables and segments. The category definitions are listed in Table 2 for each of the segments. It can been seen from Table 2 that the "others" segment is composed largely of females (73 %) from middle-income households with young children.

The intention was to use explanatory variables which are commonly available in travel surveys. Missing data were handled internally within the CANALS program: each missing case was quantified uniquely. If there had been large numbers of missing observations for any particular variable, then a separate category could have been defined and an optimal score computed for this missing category. However, this was not necessary due to the relatively small number of missing observations in the present analysis.

Explanatory variable	Workers	Students	Others
Household life cycle	(1) couples ≦ 35, no child at home (199) (2) with children, all < 12 yrs. (552) (3) with at least one child ≧ 12 yrs. (396) (4) couples > 35, no child at home (204) (5) -- (6) singles < 65 yrs. (103)	(1) with at least one child ≧ 12 (505) (2) any other (162)	(1) couples ≦ 35, no child at home (58) (2) with children, all < 12 yrs. (458) (3) with at least one child ≧ 12 yrs. (307) (4) couples > 35, no child at home (282) (5) couples or singles ≧ 65 yrs. (397) (6) singles < 65 yrs. (80)
Household income	(1) < 17,000 Hfl/yr. (43) (2) 17-24,000 Hfl/yr. (303) (3) 24-38,000 Hfl/yr. (672) (4) > 38,000 Hfl/yr. (428)	(1) < 17,000 Hfl/yr. (88) (2) 17-24,000 Hfl/yr. (151) (3) 24-38,000 Hfl/yr. (230) (4) > 38,000 Hfl/yr. (179)	(1) < 17,000 Hfl/yr. (27) (2) 17-24,000 Hfl/yr. (550) (3) 24-38,000 Hfl/yr. (494) (4) > 38,000 Hfl/yr. (235)
Sex	(1) male (1069) (2) female (412)	(1) male (375) (2) female (292)	(1) male (423) (2) female (1159)
Age	(1) ≦ 25 yrs. (181) (2) 26-45 yrs. (1038) (3) ≧ 46 yrs. (262)	(1) 12-18 yrs. (469) (2) 19-25 yrs. (163) (3) ≧ 26 yrs. (35)	(1) ≦ 25 yrs. (95) (2) 26-45 yrs. (717) (3) 46-64 yrs. (309) (4) ≧ 65 yrs. (461)
Working hours	(1) part-time (< 25 hrs./wk.) (234) (2) full-time (≧ 25 hrs./wk.) (1247)	(Not included)	(Not included)
Household car ownership	(1) 0 cars (176) (2) 1 car (1036) (3) 2 or more cars (269)	(1) 0 cars (113) (2) 1 car (441) (3) 2 or more cars (113)	(1) 0 cars (454) (2) 1 car (970) (3) 2 or more cars (158)
Residential location	(1) primary urban center (117) (2) secondary urban center (257) (3) tertiary urban center (215) (4) commuter cities (256) (5) small rural community (219) (6) large rural community (417)	(1) primary urban center (32) (2) secondary urban center (135) (3) tertiary urban center (98) (4) commuter cities (89) (5) small rural community (99) (6) large rural community (214)	(1) primary urban center (149) (2) secondary urban center (262) (3) tertiary urban center (233) (4) commuter cities (238) (5) small rural community (219) (6) large rural community (481)

(Column group heading: Category by analysis segment)

TABLE 2: DEFINITIONS OF THE EXPLANATORY VARIABLES (WITH CATEGORY FREQUENCIES IN PARENTHESES)

6.0 RESULTS

6.1 Canonical Correlations

The canonical correlations for one-, two-, and three-dimensional solutions for each of the three analysis segments are shown in Table 3. Also shown for each solution is the sum of squared canonical correlations, which provides an indication of the cumulative fit for the multi-dimensional solutions (the canonical variates being orthogonal). While the solutions of conventional linear canonical correlation analysis are nested, those of non-linear canonical correlation analysis are generally not nested, as revealed in Table 3; the optimal two-dimensional solution does not include the optimal one-dimensional solution as the first canonical variate. This is because the optimal scores to be computed for non-numeric variables provide additional degrees-of-freedom in optimisation.

The trip-chain type distributions of "workers" were most difficult to explain, and a three-dimensional solution was selected. Two-dimensional solutions were selected for the "students" and "others" segments, with the "students" segments being the most readily explained. These selections were subjective, being based on a trade-off between sufficiency and complexity of explanation. For the "workers" segment, the percentage increase in sum of squared canonical correlations was 48.3 going from one to two dimensions, 20.6 going from two to three dimensions, but only 9.8 going from three to four dimensions (not shown). Three dimensions was chosen on the basis of both sufficient correlations (of at least 0.35) and diminishing marginal rate of increased explanation. For the "students" segment, the percentage increase in sum of squared canonical correlations was 62.8 going from one to two

Segment	Sample size	Canonical correlations (sum of squared canonical correlations) 1 dimension	2 dimension	3 dimension
Workers	1,481	0.451 (0.203)	0.420 0.353 (0.301)	0.368 0.356 0.318 (0.363)
Students	667	0.531 (0.282)	0.513 0.443 (0.459)	0.498 0.445 0.320 (0.548)
Others	1,582	0.558 (0.311)	0.533 0.367 (0.419)	0.531 0.355 0.244 (0.468)

TABLE 3: RESULTS OF ONE-, TWO- AND THREE-DIMENSIONAL SOLUTIONS FOR EACH OF THE THREE POPULATION SEGMENTS

dimension but only 19.4 going from two to three dimensions. Finally, for the "others" segment, the percentage increases in the index of explanatory power were 34.8 for one to two dimensions and 11.7 for two to three dimensions. These small increases in the indices of explanatory power for the rejected higher-dimensional solutions reveal that the optimal variable scalings (and thus the correlations among the variables) are probably not very different between the selected and higher-dimensional solutions.

Interpretations of CANALS solutions are most effectively guided by two sets of information provided in the output. First, there are the resultant correlations between the optimally scaled variables and the canonical variates. These correlations are more useful than the variable coefficients because they are more stable with regard to the elimination of variables or individual observations (Thorndike and Weiss, 1973; Barcikowski and Stevens, 1975). And, second, there are the category scores defining the optimal scales for each non-numeric variable. The category scores are standardised to a frequency-weighted zero mean and weighted sum of squares equal to the sample size. In the present analyses, all explanatory variables are treated as nominal (the most general treatment), while all dependent chain-type variables are dichotomous (and are thus equivalent to numerical variables).

6.2 The "Workers" Segment

The variable-canonical variate correlations for the three-dimensional solution for the "workers" segment are listed in Table 4. Only correlations with absolute value greater than 0.20 are shown. The optimal category scores for the seven explanatory variables are shown in Figure 1. For each variable in Figure 1, the vertical scale displays the optimal scores for the variable categories. These categories are indexed on the horizontal scale, the indices being those listed in Table 2. For convenience, abbreviated category names are also given on the graphs. The relative scale values for the variable categories, together with the correlations listed in Table 4, allow interpretations of the canonical variates to be made. The complete sets of variable coefficients are listed in Table A.1 of the Appendix to this paper. These coefficients, together with the category scores for the multi-category variables (Figure 7), provide a means of replicating the analysis results.

Variable	Correlation Variate 1	Variate 2	Variate 3
Dependent (chain-type) variable set			
1. H-Work-H	0.31		- .24
2. H-Work-Work-	0.52		0.30
3. H-Work-Shop-	- .22	- .23	0.44
4. H-Work-Other than Work or Shop-		- .41	
5. H-School-H			- .20
6. H-School-Other than Home-	- .21		
7. H-P. Bus.-H		0.35	
8. H-Serve P.-H		0.61	
9. H-P. Bus/Serve P.-Other than Shop or S. Rec.-		0.40	
10. H-P. Bus/Serve P.-Shop-	- .20		0.45
11. H-P. Bus/Serve P.-S. Rec.-			- .27
12. H-Shop-H	- .37	0.35	
13. H-Shop-Shop-			
14. H- Shop-S. Rec.-	- .44	- .21	
15. H-S. Rec.-H			- .39
16. H-S. Rec.-S. Rec.-			- .32
17. H-S. Rec.-Shop-	- .33	- .23	
18. H-Other-H		0.25	
19. H-Other-Other-			
20. Anything else			
Canonical correlations between variable sets	0.37	0.36	0.32
Explanatory (traveller characteristics) variable set			
1. Household life cycle	0.37	0.79	
2. Household income			0.67
3. Sex	0.93		
4. Age	0.23	0.29	0.55
5. Working hours	0.71	- .50	
6. Household car ownership	0.21	0.28	- .24
7. Residential location			0.42

TABLE 4: CORRELATIONS BETWEEN VARIABLES AND CANONICAL VARIATES, AND CANONICAL CORRELATIONS - "WORKERS" SEGMENT

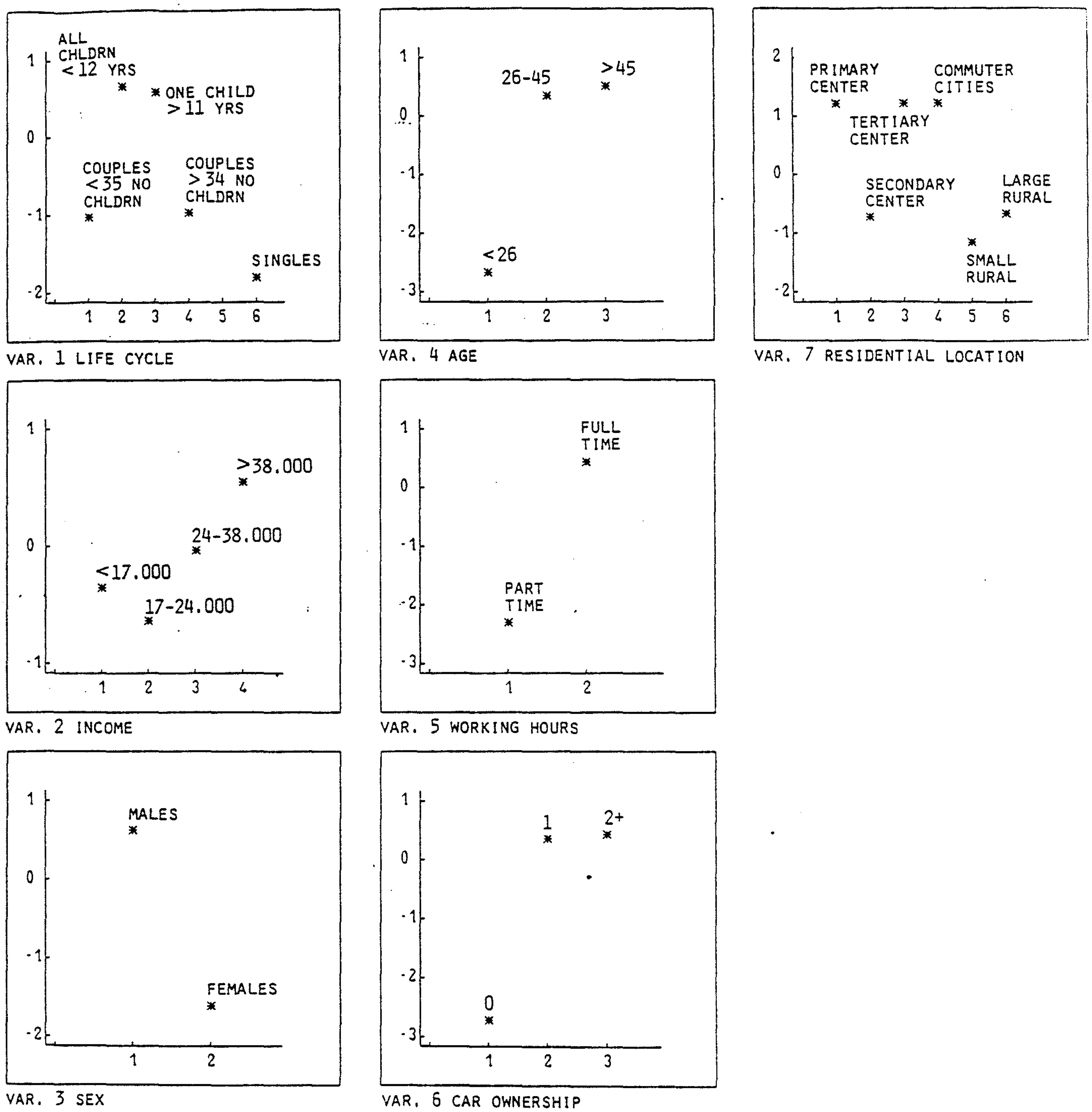

FIGURE 1: OPTIMAL CATEGORY SCORES FOR THE "WORKERS" SEGMENT

Variate one, on the dependent-variable side, contrasts the simple two-link work chain and the multiple-work destination chain with six other chains which involve shopping or child-care activities. On the explanatory-variable side, this variate is very highly correlated with sex (correlation = 0.93). Female workers make more chains involving shopping after work, shopping before or after social or recreational activities, simple shopping trips, and shopping or personal business associated with serve-passenger or school activities. Male workers make more simple work trips and chains with multiple-work destinations. Such chains are also made more by full-time (vs. part-time) workers, and by workers from households with children living at home. Household income and residential location have the weakest relationship with the first canonical variate.

Variate two primarily contrasts chains involving personal business and serve-passenger activities with chains involving non-work activities after work and shopping activities in conjunction with social or recreational activities. The principal explanatory variable is life cycle: the personal business and serve-passenger chains are made more by workers from households with children. Also, the negative correlation with working hours indicates that the personal business and serve-passenger chains are made more by part-time workers. Household income, residential location, and sex of the worker are explanatory variables which are not strongly related to this dimension.

Variate three contrasts chains involving shopping after work or personal business or serve-passenger activities with chains involving social or recreational activities and the simple work trip. The principal explanatory variables are household income, age of the worker, and residential location. Second-sojourn shopping activities are associated with the highest two household income classes, workers over twenty-six years of age, and workers residing in primary urban centers

(Amsterdam and Rotterdam), tertiary centers (Delft, Sittard, and Drachten) and commuter cities (Bussum, Dieren, Geldrop, H.I. Ambacht, Purmerend, and Westervoort). In contrast, social or recreational activities are associated with the lower-middle and low income classes, workers under twenty-six years of age, and those residing in rural communities and secondary urban centers (Groningen, Nijmegen, and 's-Hertogenbosch).

Considering all three canonical variates together, the optimal scores graphed in Figure 1 provide information about which categories of the population exhibit similar trip-chaining behaviour. With respect to life cycle, households with children at home are distinguished from those without children; and single-person households are unique but are more similar to households without children than to households with children. With respect to income, there is a linear relationship among three of the categories, but the lowest category is unique. Regarding age, workers under twenty-six years of age are distinguished from those over twenty-six, but there is no difference between the two older categories of workers. With respect to car ownership, zero-car households are different from car-owning households. Finally, households located in primary urban centers, tertiary centers and commuter cities tend to behave homogeneously, while those in secondary urban centers are more like rural households in the trip-chaining behaviour of workers.

6.3 The "Students" Segment

The correlations for the "students" segment are given in Table 5, and the optimal scores are plotted in Figure 2. The variable coefficients are listed in Table A.2 of the Appendix. The first of the two canonical variates contrasts the simple school trip with a number of other chain types, most of which are complex three-or-more link types. Of the ten chain types exhibiting correlations with the first variate of less than - 0.20, eight are three-or-more link types, and the only two-link types are the simple work trip and the simple serve-passenger trip. On the explanatory variable side, age and household life cycle are strongly correlated with this canonical variate, and residential location is moderately correlated with it. Simple school trips are associated with younger students who are from households with children twelve years of age or older and who tend to reside in more rural communities. The complex chains involving work and serve-passenger activities are associated with older students from households in other life cycle categories who tend to reside in more urban communities.

Students who score high on the second canonical variate tend to engage in a relatively large number of shopping activities, often in conjunction with work or social or recreational activities, and they make a relatively lower number of simple work trips. On the explanatory-variable side, they are from lower-income households and tend to be younger females who live in more urban communities.

Focusing on the overall optimal category scores (Figure 2) for each variable with more than two categories, the only income group that is distinguished is the lowest one. There is a linear relationship among the category scores for both car ownership and age, and, with the exception of the two categories of rural communities, the residential location categories are linearly ranked approximately on the basis on population size.

Variable	Correlation Variate 1	Correlation Variate 2
Dependent (chain-type) variable set		
1. H-Work-H	- .37	- .31
2. H-Work-Work-		
3. H-Work-Shop-		0.53
4. H-Work-Other than Work or Shop-	- .31	
5. H-School-H	0.51	
6. H-School-Other than Home-	- .22	
7. H-P. Bus.-H		0.29
8. H-Serve P.-H	- .35	
9. H-P. Bus/Serve P.-Other than Shop or S. Rec.-	- .28	
10. H-P. Bus/Serve P.-Shop-		
11. H-P. Bus/Serve P.-S. Rec.-	- .36	
12. H-Shop-H		0.38
13. H-Shop-Shop-	- .33	
14. H- Shop-S. Rec.-		
15. H-S. Rec.-H		
16. H-S. Rec.-S. Rec.-	- .22	
17. H-S. Rec.-Shop-	- .33	0.37
18. H-Other-H		
19. H-Other-Other-		- .23
20. Anything else	- .42	
Canonical correlations between variable sets	0.51	0.44
Explanatory (traveller characteristics) variable set		
1. Household life cycle	0.83	
2. Household income		0.92
3. Sex		0.34
4. Age	0.91	
5. Household car ownership		0.31
6. Residential location	- .37	0.34

TABLE 5: CORRELATIONS BETWEEN VARIABLES AND CANONICAL VARIATES, AND CANONICAL CORRELATIONS - "STUDENT" SEGMENT

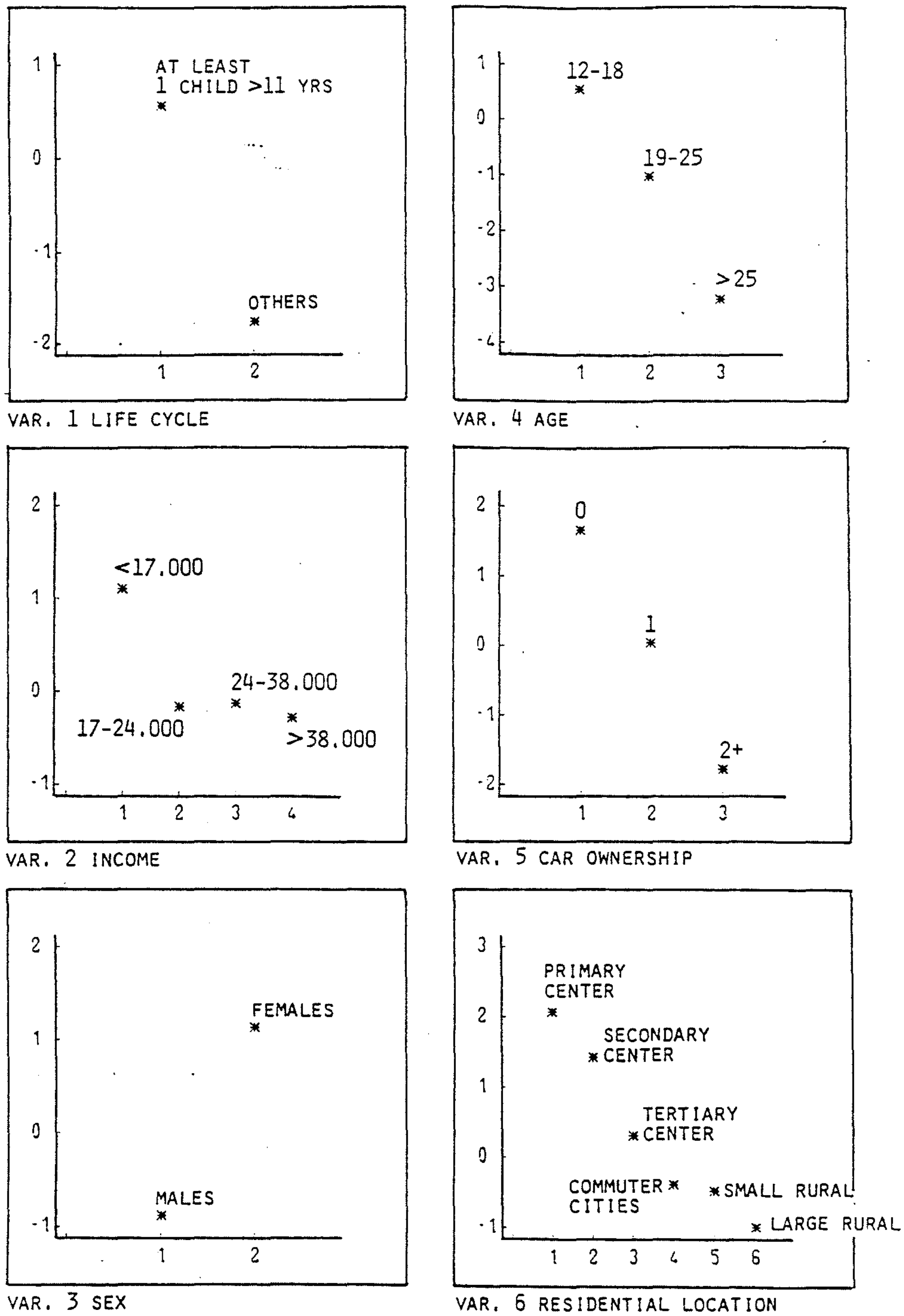

FIGURE 2: OPTIMAL CATEGORY SCORES FOR THE "STUDENTS" SEGMENTS

6.4 The "Others" Segment

The results for the individuals who are neither workers nor students are given in Table 6 and Figure 3. The variable coefficients are listed in Table A.3 of the Appendix. The first canonical variate principally identifies individuals who are engaged in patterns involving serve-passenger activities. The major explanatory

Variable	Correlation	
	Variate 1	Variate 2
Dependent (chain-type) variable set		
1. H-Work-H		0.40
2. H-Work-Work-		
3. H-Work-Shop-		0.24
4. H-Work-Other than Work or Shop-		0.49
5. H-School-H		0.56
6. H-School-Othr than Home-		0.30
7. H-P. Bus.-H		
8. H-Serve P.-H	0.87	
9. H-P. Bus/Serve P.-Other than Shop or S. Rec.-	0.42	
10. H-P. Bus/Serve P.-Shop-	0.50	
11. H-P. Bus/Serve P.-S. Rec.-	0.22	
12. H-Shop-H	0.26	
13. H-Shop-Shop-		
14. H- Shop-S. Rec.-		0.24
15. H-S. Rec.-H	0.22	
16. H-S. Rec.-S. Rec.-		0.38
17. H-S. Rec.-Shop-		0.22
18. H-Other-H		
19. H-Other-Other-		0.20
20. Anything else	0.28	0.22
Canonical correlations between variable sets	0.53	0.37
Explanatory (traveller characteristics) variable set		
1. Household life cycle	0.86	- .41
2. Household income	0.54	0.30
3. Sex	0.28	- .31
4. Age	0.68	0.41
5. Household car ownership	0.41	
6. Residential location		0.31

TABLE 6: CORRELATIONS BETWEEN VARIABLES AND CANONICAL VARIATES, AND CANONICAL CORRELATIONS - OTHERS SEGMENT

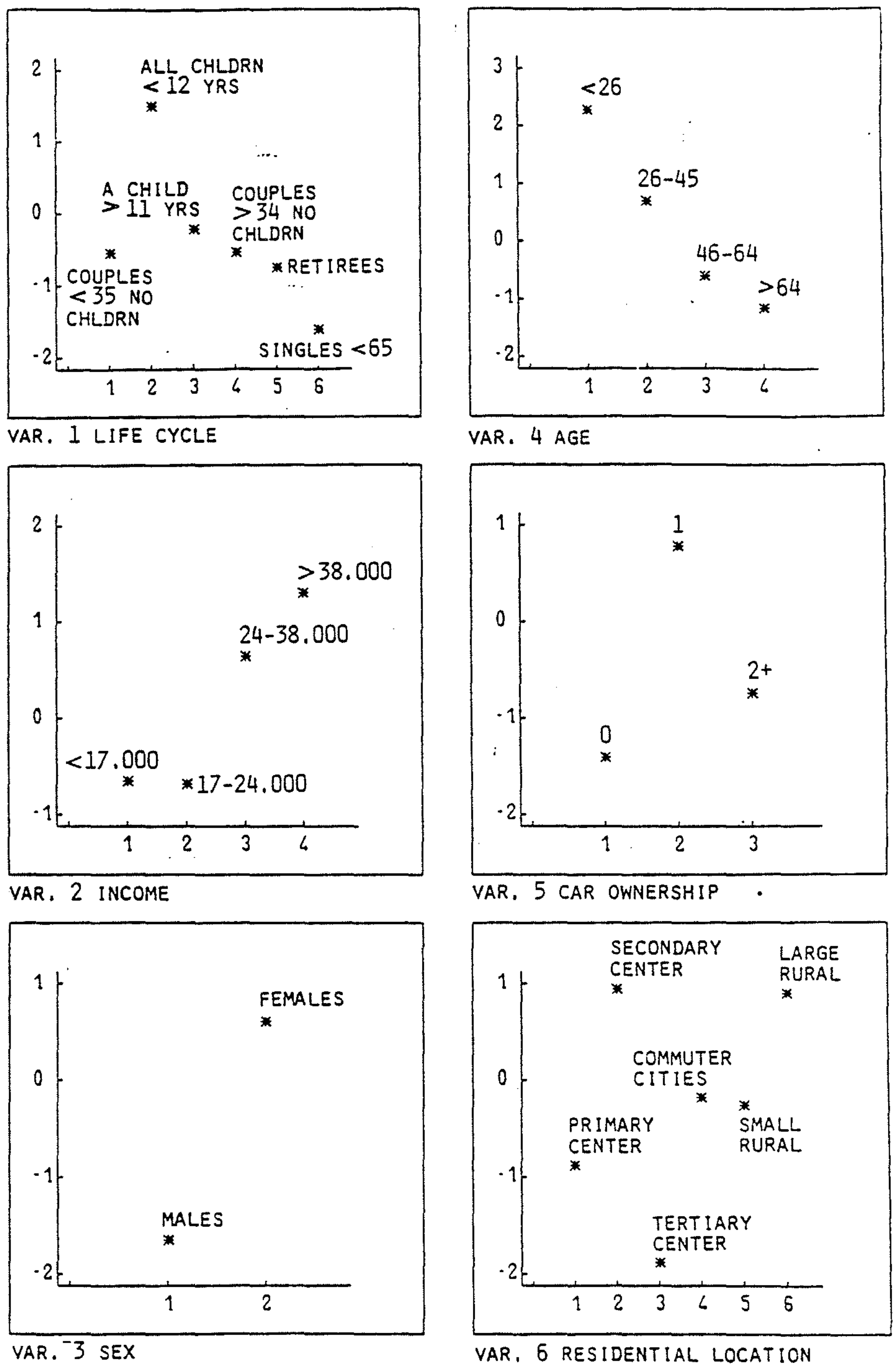

FIGURE 3: OPTIMAL CATEGORY SCORES FOR THE "OTHERS" SEGMENT

variable for this variate is life cycle. These individuals tend to be the non-workers, non-students from households with young children; they are least likely to be single persons. The individuals scoring high on this variate also tend to be younger, from higher income households with one car, and female.

The second dimension groups together work and school activities, usually in complex three-or-more link chains, and social or recreational activities, always in complex chains. Individuals scoring high on this variate are part-time students and workers with irregular hours of work. They tend to be younger singles, who are more likely males with higher incomes residing in secondary urban centers or large rural communities.

Overall, the optimal scores for the life-cycle categories (Figure 3) reveal that non-workers/non-students from households with all children under twelve years of age are different from their counterparts in other categories of household. With respect to household income, the two lowest income categories are not distinguishable. There is a smooth scale for age with decreasing marginal effects. Finally, both car ownership and residential location exhibit orderings among category scores which suggest further analyses. These results highlight the exploratory nature of the analysis technique.

6.5 Relative Contributions of the Explanatory Variables

Comparisons can be made of the relative powers of the explanatory variables in each of the three analyses. An appropriate index of explanatory power is the square root of sum of squares of the correlations between each variable and the canonical variates of the dependent (trip chains) variable set. These correlations can be computed from the correlations in Tables 4 through 6 by multiplying the correlations listed under the "explanatory variable set" headings by the canonical correlations for each canonical variate. The indices are listed in Table 7.

	Communalities		
Explanatory variable	Worker segment (3 dimensions)	Student segment (2 dimensions)	Others segment (2 dimensions)
Household life cycle	0.31	0.43	0.48
Household income	0.21	0.41	0.31
Sex	0.35	0.16	0.19
Age	0.22	0.47	0.39
Working hours	0.32	(not included)	(not included)
Household car ownership	0.15	0.15	0.22
Residential location	0.15	0.24	0.13

TABLE 7: SQUARE ROOTS OF SUMS OF SQUARED CORRELATIONS BETWEEN THE EXPLANATORY VARIABLES AND THE CANONICAL VARIATES OF THE DEPENDENT (TRIP CHAINS) VARIABLE SET

For the "workers" segment, the three most effective variables are sex, working hours and life cycle; the least effective variables are car ownership and residential location. For the "students" segment, age is the most effective variable, followed by life cycle and income, with car ownership and sex being the least effective. Finally, for the segment of non-workers, non- full-time students, life cycle is most effective, followed by age and income; residential location and sex are the least effective variables.

Considering all three analyses together, life cycle is uniformly the most effective explanatory variable, followed by age and income. Sex is effective only in the case of "workers". Car ownership and residential location are uniformly the least effective variables; each is marginally effective in only one of the three analyses cases. It appears that the influences of car ownership levels on trip chaining behaviour can be accounted for by the more fundamental influences of income and household structure. This might be due to the high level of service of public transport and the extensive use of the bicycle mode in the Netherlands.

7.0 CONCLUSIONS

The primary objective of the reported research was to identify relationships between the patterns of activities pursued in home-based trip chains and the socioeconomic and sociodemographic characteristics of the persons who generate the chains. This objective appears to have been accomplished through the application of non-linear canonical correlation analysis to three mutually exclusive segments of travelers: "workers", "students", and "others". Results of the analysis were clearly interpretable. Thus, the secondary objective, the demonstration of the effectiveness of non-linear canonical correlation analysis as a general analysis tool, was also accomplished.

The results are useful in improving understanding of how different segments of the population satisfy their demands for away-from-home activities in different ways. These insights can then be used to forecast the effects of changing population characteristics such as the probable effects of the evolving role of females in the work force. They could also be used to identify the relative impacts on various population groups of changes in physical and temporal structures which affect activity availability, such as the provision of shopping in the vicinity of work locations, or longer opening hours of shops.

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APPENDIX

CANONICAL COEFFICIENTS (VARIABLE WEIGHTS)

variable	variate 1	variate 2	variate 3
dependent (chain-type) variable set			
1. H-Work-H	0.363	-0.168	-0.176
2. H-Work-Work-	0.518	-0.081	0.282
3. H-Work-Shop-	-0.239	-0.159	0.443
4. H-Work-Other than Work or Shop-	0.080	-0.358	0.106
5. H-School-H	-0.153	-0.158	-0.097
6. H-School-Other than Home-	-0.164	0.054	-0.012
7. H-P. Bus.-H	-0.004	0.251	-0.052
8. H-Serve P.-H	0.201	0.486	0.135
9. H-P. Bus/Serve P.-Other than Shop or S. Rec.-	-0.010	0.296	-0.028
10. H-P. Bus/Serve P.-Shop-	-0.141	0.027	0.495
11. H-P. Bus/Serve P.-S. Rec.-	-0.134	0.028	-0.334
12. H-Shop-H	-0.389	0.240	0.025
13. H-Shop-Shop-	-0.109	0.069	-0.002
14. H- Shop-S. Rec.-	-0.401	-0.166	0.176
15. H-S. Rec.-H	-0.043	0.081	-0.336
16. H-S. Rec.-S. Rec.-	0.013	-0.081	-0.346
17. H-S. Rec.-Shop-	-0.218	-0.245	-0.214
18. H-Other-H	0.063	0.197	0.009
19. H-Other-Other-	0.036	0.039	-0.036
20. Anything else	-0.099	0.030	0.046
Explanatory (traveller characteristics) variable set			
1. Household life cycle	-0.211	-0.749	-0.063
2. Household income	0.043	-0.021	0.665
3. Sex	-0.716	0.022	0.184
4. Age	0.069	0.193	0.575
5. Working hours	0.282	-0.520	0.148
6. Household car ownership	0.110	0.246	-0.261
7. Residential location	0.047	0.139	-0.374

TABLE A.1: VARIABLE WEIGHTS - "WORKERS" SEGMENT

variable	variate 1	variate 2
dependent (chain-type) variable set		
1. H-Work-H	-0.328	-0.483
2. H-Work-Work-	0.098	0.039
3. H-Work-Shop-	0.018	0.600
4. H-Work-Other than Work or Shop-	-0.155	0.133
5. H-School-H	0,337	0.016
6. H-School-Other than Home-	-0.109	0.123
7. H-P. Bus.-H	-0.094	0.281
8. H-Serve P.-H	-0.282	-0.137
9. H-P. Bus/Serve P.-Other than Shop or S. Rec.-	-0.254	-0.041
10. H-P. Bus/Serve P.-Shop-	-0.103	0.067
11. H-P. Bus/Serve P.-S. Rec.-	-0.288	0.007
12. H-Shop-H	-0.070	0.317
13. H-Shop-Shop-	-0.267	-0.087
14. H- Shop-S. Rec.-	-0.083	0.175
15. H-S. Rec.-H	0.133	0.156
16. H-S. Rec.-S. Rec.-	-0.114	-0.095
17. H-S. Rec.-Shop-	-0.234	0.394
18. H-Other-H	-0.035	-0.126
19. H-Other-Other-	-0.025	-0.199
20. Anything else	-0.247	-0.149
explanatory (traveller characteristics) variable set		
1. Household life cycle	-0.424	0.238
2. Household income	-0.229	0.884
3. Sex	-0.120	0.298
4. Age	-0.644	-0.192
5. Household car ownership	-0.115	0.049
6. Residential location	0.107	0.194

TABLE A.2: VARIABLE WEIGHTS - "STUDENTS" SEGMENT

variable	variate 1	variate 2
Dependent (chain-type) variable set		
1. H-Work-H	-0.030	0.294
2. H-Work-Work-	-0.021	-0.019
3. H-Work-Shop-	0.047	0.104
4. H-Work-Other than Work or Shop-	0.016	0.358
5. H-School-H	0.106	0.496
6. H-School-Other than Home-	0.001	0.193
7. H-P. Bus.-H	-0.123	-0.051
8. H-Serve P.-H	0.711	-0.207
9. H-P. Bus/Serve P.-Other than Shop or S. Rec.-	0.199	-0.152
10. H-P. Bus/Serve P.-Shop-	0.250	-0.066
11. H-P. Bus/Serve P.-S. Rec.-	0.049	0.127
12. H-Shop-H	0.158	0.013
13. H-Shop-Shop-	0.095	0.070
14. H- Shop-S. Rec.-	0.056	0.161
15. H-S. Rec.-H	0.097	0.058
16. H-S. Rec.-S. Rec.-	0.125	0.250
17. H-S. Rec.-Shop-	0.035	0.118
18. H-Other-H	0.051	-0.127
19. H-Other-Other-	0.026	0.214
20. Anything else	0.092	0.121
explanatory (traveller characteristics) variable set		
1. Household life cycle	0.623	0.877
2. Household income	0.388	0.375
3. Sex	-0.001	-0.236
4. Age	0.271	-0.900
5. Household car ownership	0.149	-0.065
6. Residential location	0.077	0.285

TABLE A.3: VARIABLE WEIGHTS - "OTHERS" SEGMENT