Geographical Systems, Vol. 5, pp. 117–137
Reprints available directly from the publisher
Photocopying permitted by license only

THE TEMPORAL ORDERING OF URBAN SPACE AND DAILY ACTIVITY PATTERNS FOR POPULATION ROLE GROUPS

DONALD G. JANELLE[a,*], BRIAN KLINKENBERG[b] and MICHAEL F. GOODCHILD[c]

[a] *Department of Geography, University of Western Ontario, London, Ontario Canada, N6A 5C2;* [b] *University of British Columbia,* [c] *University of California, Santa Barbara, USA*

(Received in final form 14 October 1997)

Space–time activity diaries for respondents in Halifax, Canada provide data for modeling diurnal variations in the ecological structure for the city. Using the PARAFAC three-mode model, underlying factors juxtapose a polarization of work with household obligations and education activity, and solitary individual activity with socializing behavior, along with separate dimensions for shopping and for non-home entertainment. Mappings of standardized scores on each dimension for 29 separate regions and for 8 time periods of the day reveal a dynamic image of an activity-based temporal ordering to urban life. Composite representations of all five factors for separate regions and a mapping of space-time ecological zones for the city as a whole provide grounding for a typology of behavioral settings. Empirical examples and speculations relate ecological structure to individual movement and activity behavior for designated population role groups.

Keywords: Activity patterns; PARAFAC; population role groups; space–time diaries; urban ecology

1. INTRODUCTION

A dynamic view of city life at the daily level requires monitoring the space–time paths and activities of city residents, keeping track of who is where at any given time, and recording what they are doing and with

* Corresponding author. Tel.: (519) 672-5057. E-mail: janelle@sscl.uwo.ca.

whom. Legitimate concerns for individual privacy constrain survey designs of these kinds to voluntary subjects. However, there are pragmatic and scientific reasons for such investigations. In tracking the daily movements of people, it would be possible to generate census-like information for a city at any time of the day. This would enable exploration of diurnal changes in the social ecological character of neighborhoods and better understanding of the daily spatial behavior of different sub-populations. The prospects of an on-line electronic information base of this kind might have important implications for marketing, emergency response, and other public-/private-sector services. It would also facilitate a more informed approach to modeling daily urban activity systems, and would be of particular value in meeting the predictive needs of transportation planners.

The objective of this paper is to illustrate two features of urban systems that have received very little empirical examination. First, it focuses on the diurnal shifts in human activities that occur in different sub-regions of the city, referred to as the temporal ordering of urban ecological structure. An attempt to model the dynamic nature of this unfolding temporal structure of activity space draws on the methodology of urban factorial ecology (see Taylor and Parkes, 1957; Langlois, 1983). Second, it suggests research approaches for illustrating how the spatial behavior of different sub-populations both contribute to and respond to the underlying space–time ecology of the city. Both the methods developed in this research and the results of the Halifax case study have implications for refinements in the modeling of individual transportation behavior.

2. THE HALIFAX SPACE–TIME BUDGET SURVEY AND DATA

The use of individual space–time diaries to describe a dynamic activity-based view of cities was illustrated for Halifax-Dartmouth, Nova Scotia, by Goodchild and Janelle (1984) and by Goodchild, Klinkenberg, and Janelle (1993). They derived a space–time ecology of urban structure from the diurnal travel and activity patterns of residents. This was based on twenty-four hour space–time diary data gathered for the DOMA (Dimensions of Metropolitan Activities) project (Elliott, Harvey, and Procos, 1976; Cosper and Shaw, 1984) in 1971–72. These data, from more than 2,100 respondents between the ages of 18 and 65, were evenly distributed across the seven days of the week.

For this investigation, the underlying data were derived from the space–time diaries of 1,561 weekday respondents. More than 65,000 activity episodes were geo-coded and time-coded to resolutions of 100 meters in space and 1 minute in time. The activity survey included the 99 activity types of the World Time Budget Study (Szalai, 1972), but were collapsed to a set of 19 more general ACTIVITY categories. Linked variables for each activity episode also included descriptions of the social and spatial context of each activity, represented by 10 WHOM and 8 SITE categories. The resulting set of 37 variables is presented in Table I.

Subject to the constraints of spatial and temporal resolution and to the need for appropriate sample sizes, the resulting data set can be analyzed at any level of spatial and temporal aggregation. Individuals can be tracked according to their personal space–time paths, or aggregated into sub-populations based on a wide range of matching social, economic, and demographic attributes.

For convenience of modeling ecological structure, the configurations of individual space–time paths were generalized into eight one-hour time blocks and 29 spatial zones, as described in Goodchild, Klinkenberg, and Janelle, (1993). Together with the activity variables, the space and time attributes of activities yield a data matrix of 37 variables, 8 time periods, and 29 regions. These generalizations reduce the data set to approximately 19,500 activity episodes for the 1,561 respondents.

The data used in the analysis describe the number of respondents engaged in particular activities for each of eight time periods, represented as a percentage of all observed respondents within each of the 29 regions. Values are weighted to account for respondents who engage in more than one activity and who occupy more than one of the regions within a period. The designation of time periods and regions (shown in Figures 2 and 3), a review of data management issues, the selection of an appropriate model of ecological structure, and a range of GIS techniques are discussed in Goodchild, Klinkenberg, and Janelle (1993).

TABLE I Activity variables: time-geography of a Canadian City project

ACTIVITY	1. Work, income-producing
	2. Work, non-income-producing
	3. Travel to and from work
	4. Household work
	5. Household maintenance
	6. Child care
	7. Marketing and shopping for household
	8. Other household work
	9. Travel related to household
	10. Sleep and personal care
	11. Meal times
	12. Educational time
	13. Recreation outdoors and sports
	14. Entertainment away from household
	15. Leisure: Socializing
	16. Leisure: radio and television
	17. Reading, non-educational
	18. Other leisure time
	19. Travel for leisure only
WHOM	20. Alone
	21. With spouse or fiancé
	22. With child of household
	23. With adult of household
	24. With relative
	25. With colleagues
	26. With organization and club associates
	27. With neighbors
	28. With non-business associates
	29. With others, and unknown
SITE	30. At home
	31. At workplace
	32. Someone else's building
	33. Outdoors travel by public transit
	34. At public or private building
	35. Leisure indoors
	36. Restaurants and bars
	37. All other places

In that study, methods were developed to aggregate records into temporal and spatial units to satisfy a number of specific criteria, including compactness, socio-economic homogeneity, and abundance of data. The numerical results depended to some degree on the choice of aggregate units (the Modifiable Areal Unit Problem or MAUP (Openshaw, 1983)), but these effects were not evaluated in this research. Rather, and following the results obtained in many studies of the MAUP, the analysis was performed at the lowest level of aggregation possible given the size of the sample available. This paper builds on the discussion in Goodchild, Klinkenberg, and Janelle (1993), providing a graphical interpretation of the model, concentrating on the linkages between space–time ecological structure and the activity behavior of selected sub-populations, and on their possible importance to modeling individual travel behavior.

3. MODELING THE SPACE–TIME ECOLOGY OF HALIFAX

Traditional attempts to describe urban human ecology (e.g., Berry, 1971; Davies, 1984) use census data on the social and demographic traits of households. Usually, these relate to fixed residential addresses, with aggregations by enumeration areas and census tracts. In sharp contrast, this study adds the temporal component of daily movements through space, and bases the ecological interpretation of the city on behavior (activities).

The complexity inherent in the space–time activity sequence of more than 1,500 individuals is generalized by means of PARAFAC, a three-mode factor model (Harshman, 1976; Harshman, Ladefoged and Goldstein, 1977). This model allows for a single set of unique factors that apply simultaneously to the space, time, and variable modes. PARAFAC assumes the presence of common factors that appear to varying degrees in each time period. As a model of urban structure, it allows one to ask whether the standard structure observed for night-time populations (typical of census tabulations by place of residence) is also the fundamental structure for all time periods. And, to what extent do alternative dimensions of urban variation appear and disappear during the diurnal cycle? This feature allows generalizations beyond the findings of traditional urban ecological analyses, and it allows for both descriptive and explanatory insights about human activity and movement behavior.

PARAFAC is an "explanatory" multi-modal factor analysis for use with ratio-scale measurements. In contrast to traditional two-mode factor analytic models, it is not confronted with the indeterminacy of axial rotations. It yields a unique solution and provides measures of factor significance by spatial units, through time, for individual variables, and for combinations thereof. Adjustments in the model to enhance interpretation in the Halifax study included normalization (mean square = 1.0) of the 37 variables across time periods and regions, and the centering of results on regions. Thus, regions that differ from the mean value for all regions will stand out in the interpretation of a given factor for any time period. In the solution described in this paper, regions were constrained to be orthogonal so that the loadings (factor weights) could be interpreted as in normal two-mode factor analysis. However, correlations between factors were allowed across the time dimension.

Through a least-squares procedure, PARAFAC converges iteratively on a solution to minimize the deviations between the input data and the predictions from the common factors. The number of factors in the output solution is prescribed by the researchers. Following experimentation, five factors were found to provide a good balance between ease of interpretation and goodness-of-fit.

4. INTERPRETING THE CITY'S SPACE–TIME ECOLOGICAL DIMENSIONS

Table II identifies the five common underlying factors and the percentage of the explained variance accounted for by each. Collectively they account for 31 percent of the variance in the original data set. However, unlike two-mode factor models, PARAFAC goes beyond this level of explanation, providing goodness-of-fit measures for specific variables, spatial units, and time periods. Levels of explanation were strongest for obligatory activities (for example, work for income, household shopping, and educational time), for work with colleagues, and presence at home, work places, and in public buildings. More structured times of the day, mid-morning to mid-afternoon, were more readily explained by the model than were more transitory periods (0800–0900 and 1800–1900).

TABLE II 5-Factor PARAFAC solution: percent of explained variance

	Percent of explained variance
Paid work (+) household obligations (–)	51.7
Non-home entertainment	15.1
Shopping	11.9
Paid work (+) education (–)	11.0
Sleep/alone (+) socializing (–)	10.4

In addition, the model's ability to explain activity variations by region was greatest for areas dominated by clusters of commercial, governmental, and institutional landuses (for example, the CBD, hospital areas, and locations of universities). More specific details on the levels of explanation are presented in Goodchild, Klinkenberg and Janelle (1993), along with a complete listing of PARAFAC factor weights (loadings) for each mode of analysis (variables, regions, and times). By way of illustration, however, the complete listing of loadings for Factor 2 is presented in Figure 1, and the dominant variable loadings for all five factors are noted in Figures 2 and 3.

Figure 1 combines the PARAFAC output on Factor 2 for the three modes on a single graphic scale of factor weightings. High weightings for variables "leisure indoors," "entertainment away for home," "at restaurant or bar," and "leisure travel" combine with time period 2200–2300 hours, and with regions 4 and 9 to yield a distinct non-home entertainment factor. Regions 4 and 9, comprising the city's central business district and surrounding areas, have high concentrations of eating and entertainment establishments. Whereas the loadings for mode A (variables) range from −1.00 to 1.00, the weightings for modes B and C are presented as standardized scores.

Figures 2 and 3 illustrate the space–time pattern of each factor by means of standardized scores, plotted as bar graphs for each region, with a bar for each of the eight time periods. Regions and individual bars (times) with little vertical dimension have presence of a given factor that is close to the average for the city's regions.

For Factor 1 (Figure 2), positive and negative scores distinguish regions and times associated with income-producing work (for example, at the work place, with colleagues) and household obligations (for example, caring for children and housework). Factor 1 draws a sharp distinction for all times of the day. Positive values distinguish the work dimension for the central peninsula of Halifax. This area is dominated by commercial and government activities in region 9, Dalhousie and St. Mary's universities in 5 and 3, a concentration of hospitals in 8, container port activities and railway marshalling yards in 3, 4 and 16, military establishments in 6 and 10, and retailing activities in region 12. In contrast, the outlying areas demonstrate a more pronounced domestic character throughout the day. Factor 1 captures more than half of the variance in

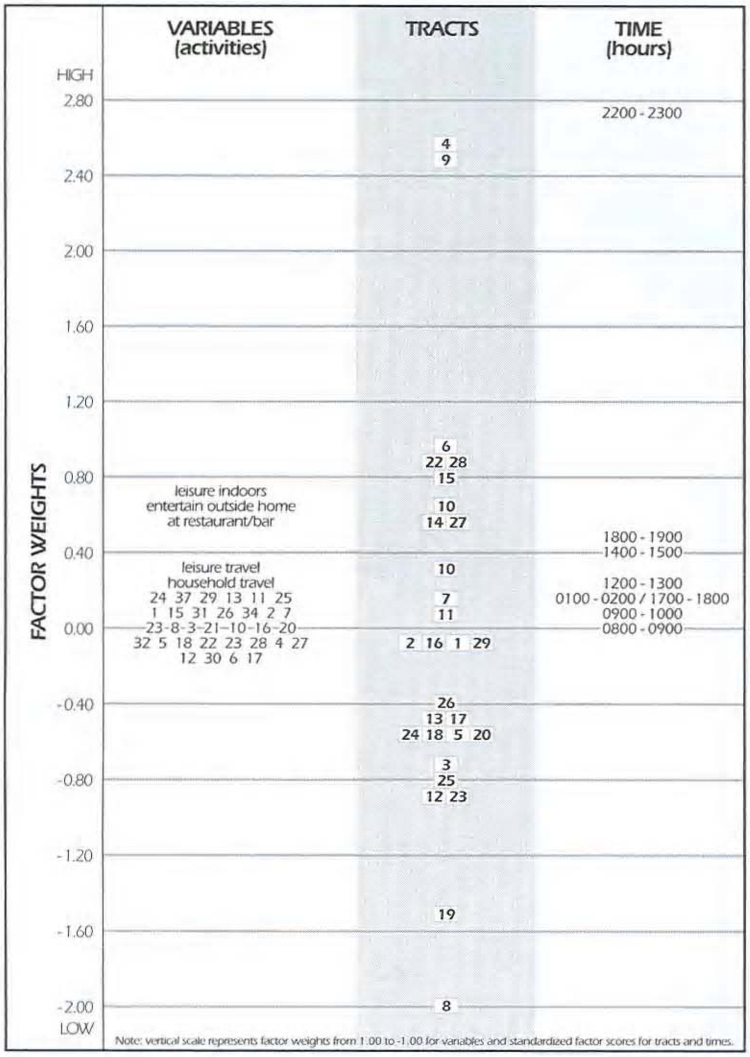


FIGURE 1 PARAFAC solution for Factor 2. For complete solutions for Factor 1 and for Factors 3–5, see Goodchild, Klinkenberg, and Janelle (1993).

the original data and is the most distinct feature in the city's space–time structure.

Factor 2, described with reference to Figure 1 as the non-home entertainment dimension, reveals itself with exceptionally pronounced

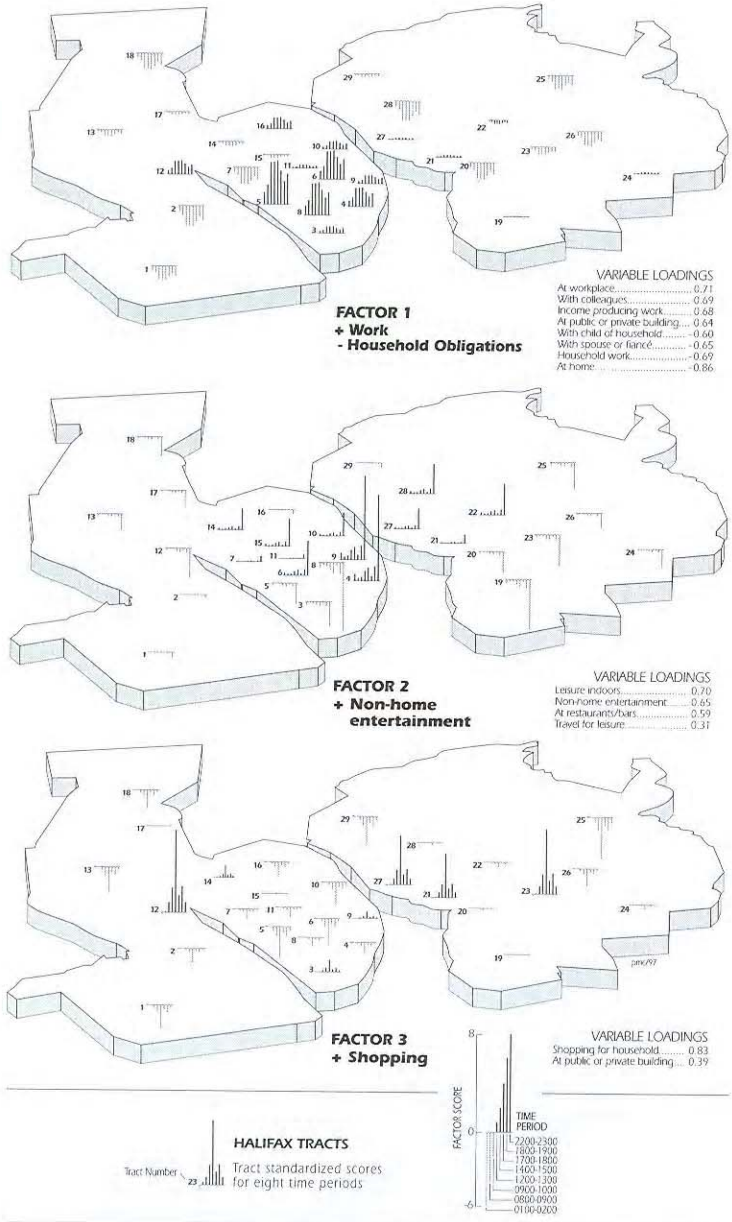


FIGURE 2 Standardized space–time scores for PARAFAC Factors 1–3, by region and time of day, Halifax, Canada.

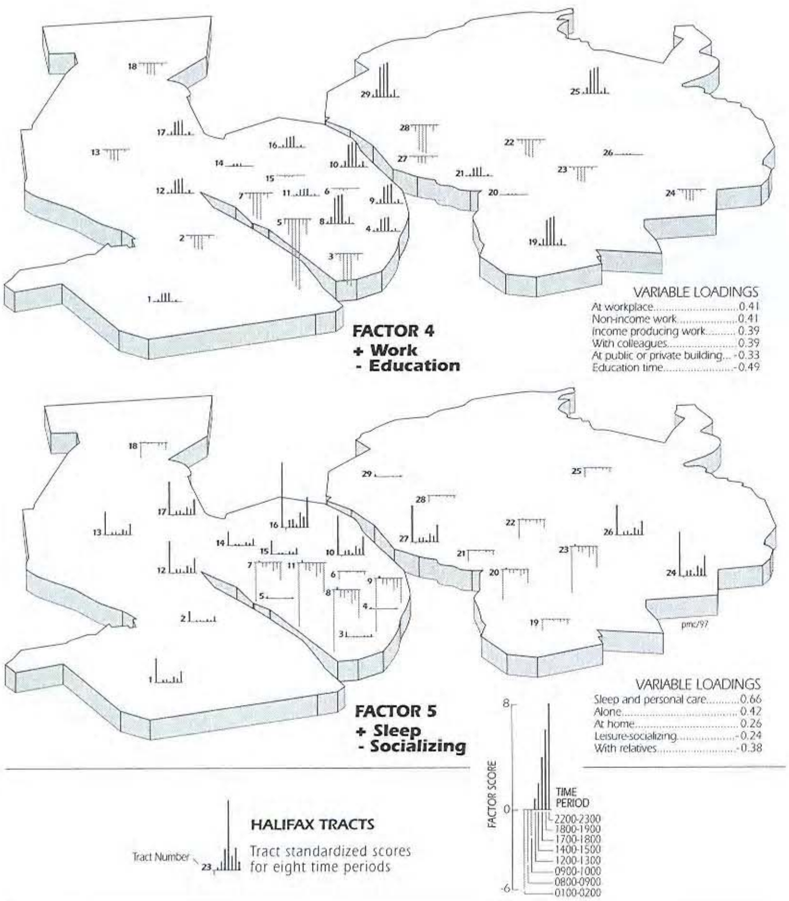


FIGURE 3 Standardized space–time scores for PARAFAC Factors 4–5, by region and time of day, Halifax, Canada.

diurnal variations of regional dominance in Figure 2. High positive late evening (2200–2300) scores reflect the entertainment and hospitality role of the central business area and vicinity, with equally pronounced non-entertainment profiles in the presence of hospitals, residential suburbs and industrial areas (for example, 19, site of oil refining operations and industrial parks, across the harbor in Dartmouth).

Factor 3 captures the shopping dimension, with high loadings on the variables "shopping for household" and "at public or private building." The peak of shopping activity occurs, not unexpectedly, in mid afternoon and is most prominent in outlying shopping centers (12, 14, and 23) and in the vicinity of Dartmouth's central business area (21 and 27). Equally sharp, but negative in the shopping domain, are the university and residential regions.

Factor 4 combines a work dimension (positive values for both income and non-income work) with education (based on negative loadings for variables "education time" and "at public or private building").

The mapping of these scores in Figure 3 reveals with exceptional clarity the presence of universities (regions 3, 5, and 13—Mount St. Vincent University) and large public secondary schools, scattered about residential areas and in region 7 on the central peninsula. Areas associated strongly with work combine those regions noted for Factor 1. They also include prominent industries in 19, Department of National Defense facilities in 25 and 29, and the Bedford Institute of Oceanography, and rail and port facilities, in region 29.

Sleep and other personal solitary activities versus socializing activities characterize the bi-polar nature of Factor 5. Its space–time rendering in Figure 3 illustrates the peaked night-time role of socializing activity in central Halifax and Dartmouth, in region 23 (site of a large shopping complex), and in medium- to high-density residential areas, 7 and 11. The importance of hospitals in generating family gatherings shows up in region 8. In contrast, sleep and solitary activities dominate the primary residential areas.

5. A SPACE–TIME TYPOLOGY OF URBAN ECOLOGICAL STRUCTURE

The separate mappings of intensity measures for each factor (Figures 2 and 3) mask an important feature of urban regions—the fact that all of the underlying dimensions operate simultaneously and interactively over space and time. This is illustrated for tracts 8 and 23 in Figure 4, showing standardized scores for each factor by time of

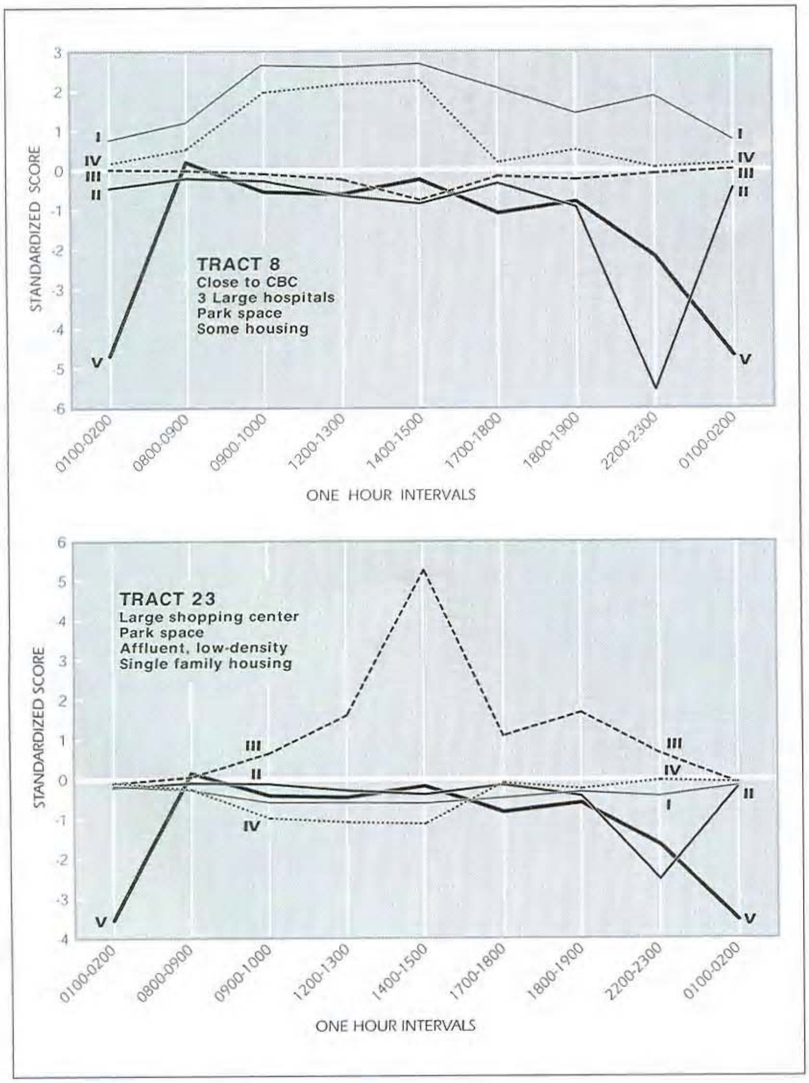


FIGURE 4 Regional composites of standardized scores for PARAFAC Factors 1–5 for Halifax Regions 8 and 23. See Figures 2 and 3 to locate regions.

day. This simultaneous representation of all factors provides a more holistic view of each region's unique character, and allows for a clearer assessment of its role as a behavioral setting for individuals.

Region 8 contains three significant Halifax hospitals, institutions that play a dominating role over its temporal ordering of activities.

Thus, Factors 1 and 4, the work factors, are forever present and well above the city average at all times of day. With the exception of late evening and early morning, the remaining three factors are close to the city-wide average. However, Factor 5, socializing activities (visits with relatives), exceeds the city norm by five standard deviation units in the 0100–0200 period. And, when non-home entertainment (Factor 2) is at its peak in neighboring regions, at 2200–2300, region 8's entertainment function is the lowest among the city's 29 regions.

Region 23 provides another example of a distinctive behavioral setting, as defined by the composite presence of all five factors. Shopping (Factor 3) is the pre-eminent activity, mostly associated with the large Mic Mac Mall, which serves the residential communities of Dartmouth and surrounding areas. The peak of shopping activity, 1400–1500, is in excess of 5 standard deviation units above the city norm. In contrast, all of the remaining 4 factors vary only slightly from city averages. Exceptions include the significance of socializing activity in late evening and early morning, and the drop in non-home entertainment in the 2200–2300 hour.

The rationale for viewing the influence of all factors simultaneously is extended in Figure 5. Using the first four factors, the standardized scores for each factor are divided into high (≥ 1.75 sd) normal (< 1.75, > -1.75 sd) and low (≤ -1.75 sd) categories. Combinatorial groupings of the high (+), normal, and low (−) categories for each factor are then mapped for 232 space–time units (29 regions $\times$ 8 time periods). Empirically, 23 distinct ecological types result from this procedure, but this was reduced to 20 types by joining Factor 1+ (work) and Factor 4+ (work) as a single category. The unique combinations of factors that define each of these 20 types of ecological zones are itemized and mapped in Figure 5.

The mapping of activity-based ecological zones calls attention to the diversity of the city's sub-regions. By time of day, the city's activity profile shows remarkable homogeneity at 0100–0200, when most people are at home, sleeping. Only regions 8 and 5 stand out, with persistent work and education roles associated with hospitals and Dalhousie University. Gradually, complexity in the mix of activities within regions, and differences in the activities among regions, increases, reaching a peak in diversity by mid-day, in time periods 1200–1300 and 1400–1500.

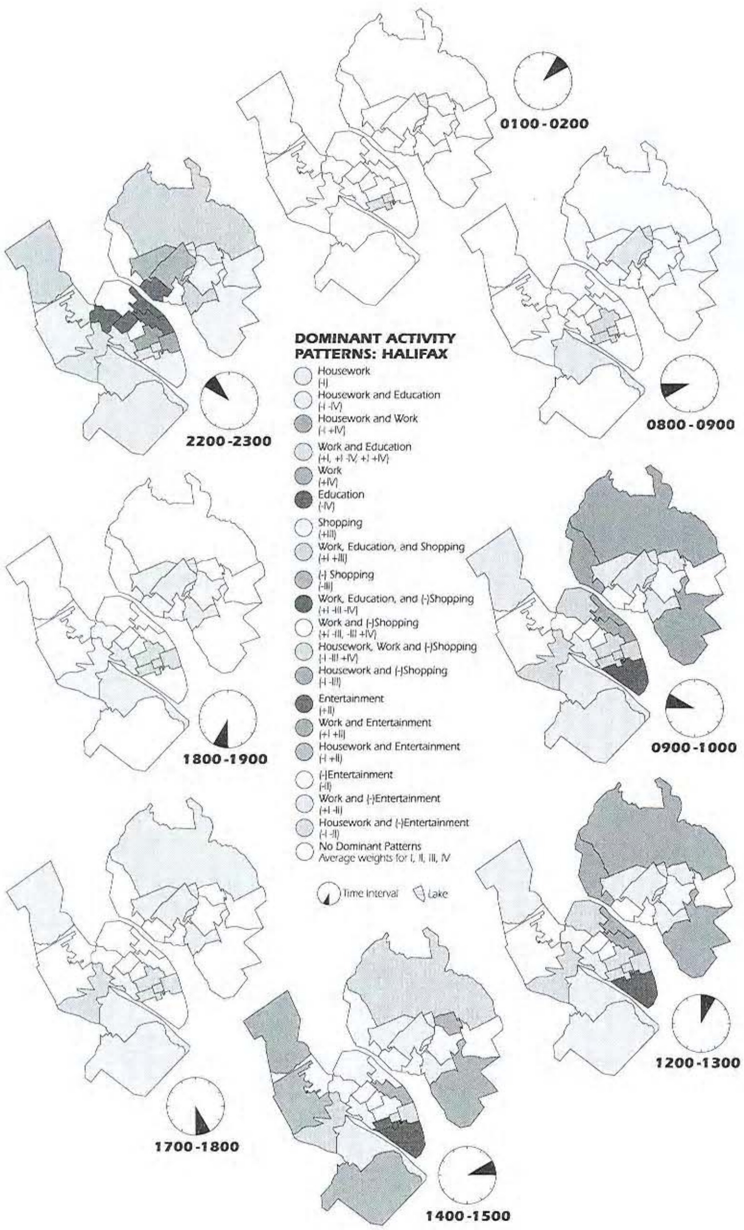
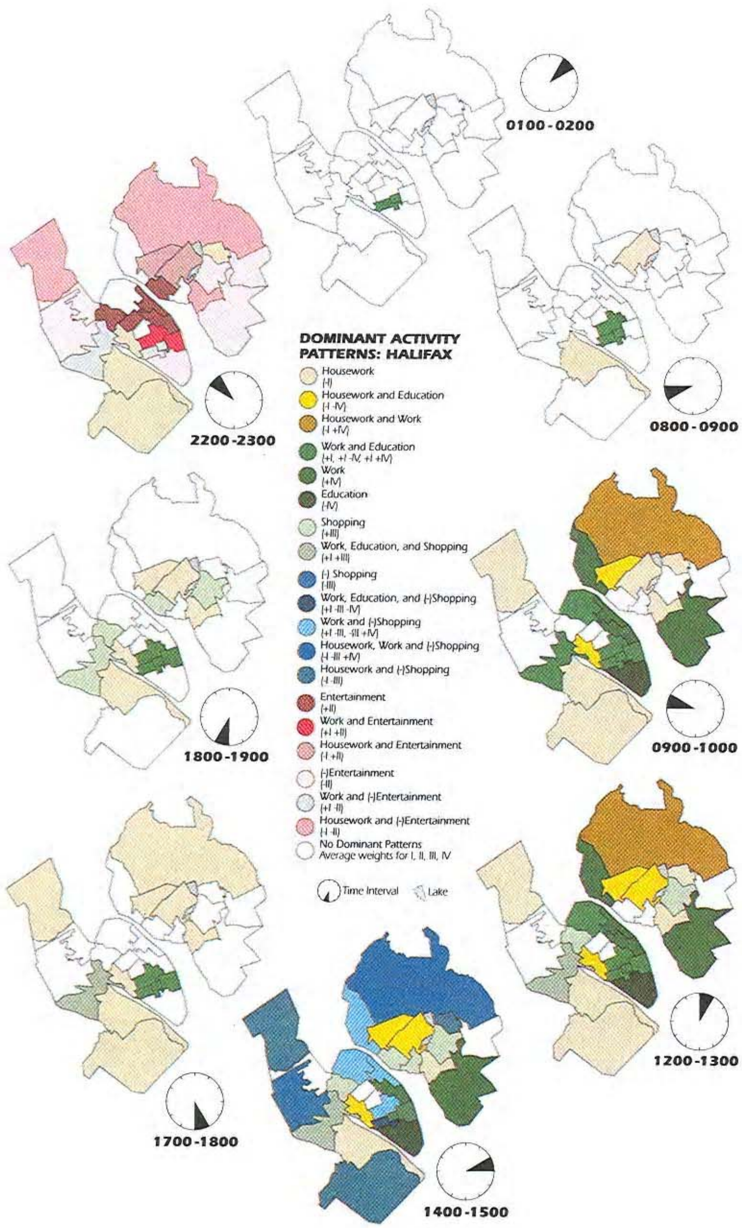


FIGURE 5 Space–time ecology of dominant activity patterns. Regionalization is based on a combinatorial mapping of High (≥ 1.75 sd), normal (< 1.75 sd, > -1.75 sd) and low (≤ -1.75 sd) scores for PARAFAC Factors 1–4, by region and time of day for Halifax, Canada. (See color plate I.)



Geographical Systems, Vol. 5, Nos. 1–2, Color Plate I.
See D.G. Janelle *et al.*, Figure 5.

In period 1400–1500, eleven distinct ecological zones provide a range of behavioral settings essential to daily social and economic life. At this time, only four regions are classed as normal for all four factors (having no dominant patterns) and only two regions show sole dominance in housework activities (−I). As a weekday activity, housework is most prominent in the 1700–1800 period, when it is dominant in eight regions. The early evening hours display general homogeneity in activity patterns, with distinct clusters of work and shopping zones, breaking the predominance of regions with either no dominant activities or dominance in housework activities. However, diversity is restored briefly in the 2200–2300 period, with pronounced polarization between regions of high (+II) and low (−II) entertainment levels, mixed with combinations of housework and work activities.

6. INDIVIDUAL ACTIVITY BEHAVIOR AND URBAN ECOLOGICAL SETTINGS

The temporal patterns of ecological structure, as defined in this research, are based on the actual activity and movement behavior of sampled respondents. As individuals travel through the city, their attributes and activities contribute to the character of the spaces they occupy. Correspondingly, the ecological character of regions is one of many factors that might, also, influence decisions on individual activity and travel behavior.

The remainder of this paper speculates on the link between the ecological structure of the city and the behavior of individuals. However, to avoid the complexities of focus on specific persons, fourteen population role groups were defined, each consisting of people with similar traits. Role groups are disaggregated from the total data set, based on combined attributes of gender (male or female), marital status (married or single), job (employed or unemployed), child care (yes or no), residence tenure (own or rent), and mobility (auto or no auto). The concatenation of these six dichotomous attributes results in 36 possible role groups. However, this analysis is limited to groups with sample populations of at least 22 individuals (Table III). The use of role groups is a convenience, in part, to avoid wide variance at the individual level. Role groups draw attention to dominant combinations of individual traits that are seen as diagnostic of behavioral patterns.

Individual movement behavior serves to integrate and segregate role groups over the course of a day. Table IV presents simple Spearman correlation values for some of these groups, illustrating three distinct patterns. Unmarried role groups (FSNERa and MSNERA) show positive spatial correlation at all times of the day, but more so in the late evening hours. This is in sharp contrast to the negative correlation patterns between unmarried single women with no automobiles

TABLE III Population role groups

	Number
FWNEOA	23
FWNERA	40
FWNUOA	28
FWCEOA	55
FWCERA	28
FWCUOA	133
FWCURA	63
FSNERA	31
FSNERa	48
MWNEOA	40
MWNERA	41
MWCEOA	134
MWCERA	95
MSNERA	22
	781

F = Female, M = Male
W = Married, S = Single
C = Children, N = No children
E = Job, U = Unemployed
O = Own home, R = Rent
A = Auto, a = No auto

TABLE IV Space-time correlations (Spearman) for role groups

Time	*FSNERa/MSNERA*	*FWCUOA/MWCEOA*	*FSNERa/FWCUOA*
0100–0200	0.50	0.73	−0.54
0800–0900	0.33	0.20	−0.59
0900–1000	0.17	−0.14	−0.68
1200–1300	0.30	−0.17	−0.74
1400–1500	0.44	−0.22	−0.63
1700–1800	0.37	0.27	−0.65
1800–1900	0.71	0.44	−0.60
2200–2300	0.55	0.66	−0.75

Correlations are based on the number of activity episodes by role group in each of 29 regions.

(FWCUOA). These two role groups are the most highly segregated cohorts of all 36 groups investigated in this research.

The temporal ordering of family life is revealed in a comparison of the regional associations for the most common Halifax household composition—FWCUOA and MWCEOA, home-owning married respondents with child-care obligations. The gender division of household labor corresponds with negative correlations in the mid-day work period, and high positive spatial relationships in the late evening and early morning. These observations are reinforced with strong associations to the ecological dimensions identified by PARAFAC.

Figure 6 displays average standardized factor scores on the first three PARAFAC dimensions for individuals who comprise six different role groups. The temporal pattern of these scores draws clear linkages between the movement and activity behavior of specific groups and the behavioral settings identified in the factor structure. On Factor 1, it is evident that employed, unmarried respondents (FSNERa, FSNERA, and MSNERA) are above the norm on the work dimension at all times of day. These groups hold little in the way of household responsibilities. Married men (MSNERA) move from the work role during the day to the household role in late afternoon and evening hours. In contrast, the homemaker (FWCUOA) shoulders above average household obligations throughout the day.

A similar discrepancy between single and married respondents dominates the interpretation of the non-home entertainment factor. The late evening period (2200–2300) sees pronounced divergence of populations based on marital status. The singles (FSNERa, FSNERA, and MSNERA) are between 2 and 4 standard deviations above the norm for entertainment activity, while all of the married cohorts (MSNERA, FWCUOA and FWNERA) show negative values on the entertainment dimension. Apparently, the absence of an automobile for the FSNERa grouping is not a deterrent to evening non-home entertainment. This particular population cohort is the most spatially concentrated of all 36 role groups, living primarily in rental accommodations within or near the center of Halifax, in close proximity to jobs and entertainment establishments.

The shopping dimension shows the sharpest levels of role-group divergence in mid-afternoon, with homemakers dominating marketing behavior. Married, employed men show consistent above-average

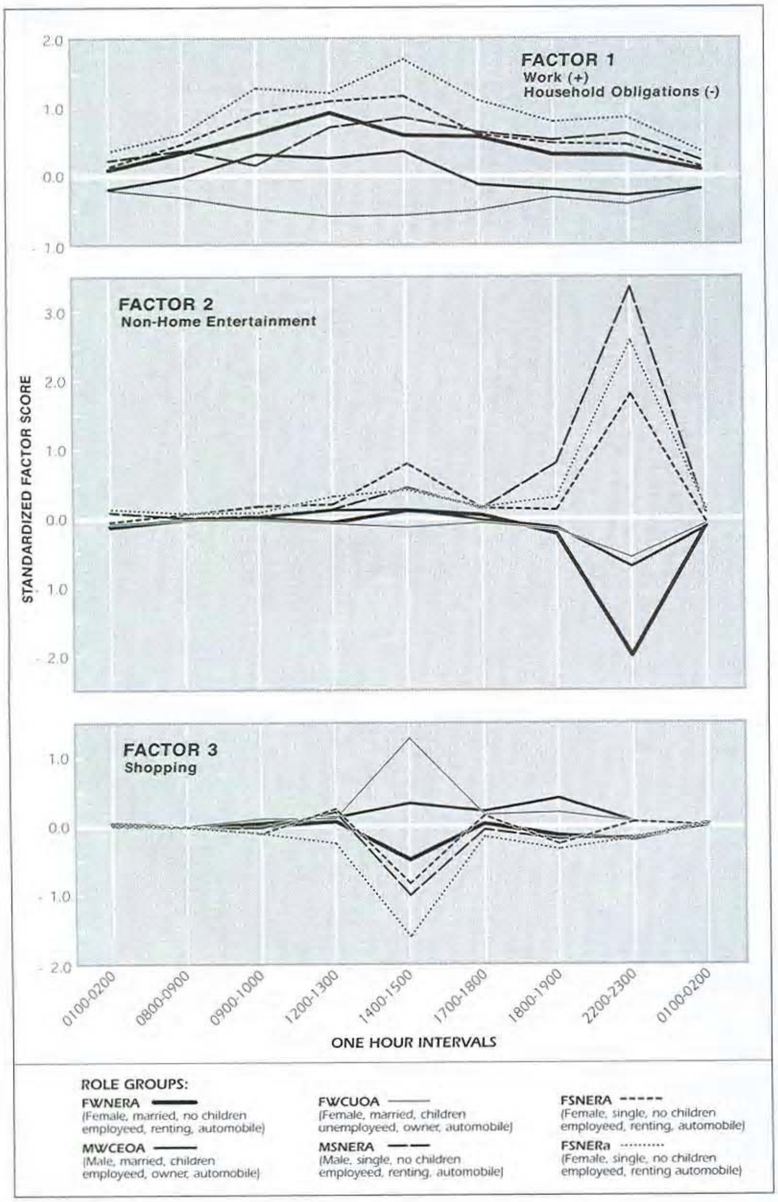


FIGURE 6 Standardized scores on factors 1, 2, and 3, by time of day for representative role groups. M/F Male/Female; W/S Married/Single; C/N children/No children; E/U Employed/Unemployed; O/R Own Home/Rent; A/a Auto/No auto.

shopping from the noon hour through early evening hours, peaking in the 1800–1900 period. In contrast, the three role groups based on unmarried respondents, and married, employed women (FWNERA), show comparatively low weekday marketing activity.

This simple analysis reveals an association between the ecological character of space–time units and socio-demographic traits of subpopulations. It is based on the requirements and responsibilities that accompany role-group status. Shifting from one location to another throughout the day allows one to take advantage of the unfolding cyclical transitions in the ecological character of urban space.

7. DISCUSSION AND CONCLUSIONS

This paper has illustrated the use of information from space–time activity diaries to describe how a city's ecological structure changes in response to the daily activity and movement behavior of its residents. A three-mode factor analysis (PARAFAC) modeled the complexity of daily activities for more than 1,500 Halifax respondents into five underlying dimensions. This provided a basis for generalizing the space–time ecological structure of the city and for relating this structure to the activity profiles of population role groups.

While the ecological approach to the analysis of activity diaries does not address issues regarding the behavior of specific individuals, this study has attempted to illustrate variations in the underlying behavior of population role-groups in contributing to the ecological structuring of urban activity patterns. This is in contrast to the presumption of equivalence between the characteristics of individuals within an urban sub-region and the average population or activity characteristics of that region.

While offering insights into the temporal ordering of urban space, the ecological approach does not permit direct assessment of whether or not individuals structure their activity patterns and travel behavior in response to their own conceptions of the ecological character of spaces within cities. It is suspected, in part, that this is the case. However, it is acknowledged that important questions regarding the motivations and intentions of people were beyond the capabilities of the data and methodology.

The methods developed in this study hold promise for useful inputs into decisions about urban transport systems and about individual transportation behavior. The three-dimensional matrices modeled here by three-mode factor analysis allow predictions to be made about the demands placed on the transport system by area, and by time of day. Moreover, as illustrated in the analysis by role groups, they allow the impacts of changes in demographics, socio-economic structure, and activity patterns to be modeled and evaluated. Because of the relatively small sample size, it was necessary to aggregate data into relatively coarse areas and time periods. With more data, it would be possible to make more precise predictions for smaller areas and intervals, and for more narrowly defined role groups.

The results of this research accord closely with general understandings about the urban social and temporal geographies of cities (see Chapin, 1974) and with what is known intuitively to be important patterns of diurnal change in the life of a mid-sized Canadian city in the early 1970s. As such, the methodology lends itself for replication in a time-series of periodic studies, possibly every ten years in conjunction with national census practice.

Even though space–time activity analysis can facilitate understanding of fundamental societal changes, the lack of a comparable time-series of geo-coded activity diaries for a single city make such analysis difficult. Consider, for example, the benefits that such an information base would hold for interpreting changes in the conditions of employment—the growth of flexible and staggered work hours, compressed weeks, 24-hour cities, job sharing, and early retirement. Other processes that would be more clearly understood through access to space–time contextual information include the increasing presence of women in the labor force, the growth of multi-income households, and expanded household reliance on child day-care services. In addition, space–time diary data could aid our understanding of how growth in automobile dependence, improved mobility systems for handicapped populations, and diffusion of new communication technologies and practices alter society's daily activity patterns. Examples of the later include electronic pagers, facsimile transmission, cellular phones, computer networks, mobile offices, and telecommuting. Spatially and temporally coded activity diaries hold significant promise in assessing the implications of these developments on the temporal ordering of urban space and on the daily routines of specific population role groups. They would be of special significance to transportation planners, allowing for more finely tuned predictive models on the space–time movement behavior of different populations.

Acknowledgements

The authors acknowledge financial support from the University of Western Ontario and the Social Sciences and Humanities Research Council of Canada. They thank Patricia Chalk, for contributing to the design and execution of graphics; Richard Harshman, for access to PARAFAC; the organizers of the Dimensions of Metropolitan Activity (DOMA) project, particularly Andrew Harvey, for access to the data; and Harvey Miller, for comments on an earlier draft.

References

Berry, B.J.L. (1971) Comparative Factorial Ecology. *Economic Geography*, **47**, 209–19.

Chapin, F.S. Jr. (1974) *Human Activity Patterns in the City: What People Do in Time and Space*. John Wiley, New York.

Cosper, R.L. and Shaw, S.M. (1984) The Validity of Time-Budget Studies: A Comparison of Frequency and Diary Data in Halifax, Canada. *Leisure Science*, **7**, 205–25.

Davies, W.K.D. (1984) *Factorial Ecology*. Gower, Aldershot.

Elliott, D., Harvey, A.S. and Procos, D. (1976) An Overview of the Halifax Time-Budget Study. *Society and Leisure*, **3**, 145–59.

Goodchild, M.F. and Janelle, D.G. (1984) The City around the Clock: Space–time Patterns of Urban Ecological Structure. *Environment and Planning A*, **16**, 807–20.

Goodchild, M.F., Klinkenberg, B. and Janelle, D.G. (1993) A Factorial Model of Aggregate Spatio-Temporal Behavior: Application to the Diurnal Cycle. *Geographical Analysis*, **25**, 277–94.

Harshman, R. (1976) PARAFAC: Methods of Three-Way Factor Analysis and Multidimensional Scaling According to the Principle of Proportional Profiles. Ph.D. dissertation, Department of Educational Psychology, University of California, Los Angeles.

Harshman, R., Ladefoged, P. and Goldstein, L. (1977) Factor Analysis of Tongue Shapes. *Journal of the Acoustical Society of America*, **62**, 693–707.

Langlois, A. (1983) Les transformations de l'espace social de la ville: une application de l'analyse factorielle à trois entrées. *The Canadian Geographer*, **27**, 67–73.

Openshaw, S. (1983) The Modifiable Areal Unit Problem. *Concepts and Techniques in Modern Geography* (*CATMOG*), **38**. Geobooks, Norwich.

Szalai, A. (ed) (1972) *The Use of Time, Proceedings of the World Time Budget Study*. Mouton Publishers, The Hague.

Taylor, P.J. and Parkes, D.N. (1975) A Kantian View of the City: A Factorial-Ecology Experiment in Space and Time. *Environment and Planning A*, **7**, 671–88.