

The complexities of everyday life: balancing practical and realistic approaches to modelling probable presence in space-time

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ABSTRACT

This paper concerns itself with issues of complexity, simulation, time, and dynamics in the ongoing search for operational models in social science. It considers the role of time and space in 'daily human life', and reports on ongoing research seeking to apply concepts from Hagerstrand's Time Geography to the domain of Tertiary Education. Previous research by the authors has developed a computational framework to describe, query, and aggregate individual Time-Geographies effectively, and has demonstrated the ability to generate unambiguous statements of reach (in the form of potential presence), and access (in terms of effective durations of presence) in an urban context (Huisman and Forer 1998; 1999, Forer and Huisman 2000). The current paper develops further on space-time query aspects of this work, and enlarges on the notion of *probable presence* in space-time as it relates to concepts of access and interaction. It proposes a temporal distance-decay parameter be incorporated within routines that build individual models, in order to move from what might be done with discretionary time to likely outcomes. The paper concludes with a brief discussion of unresolved issues.

Keywords and phrases: Time Geography, accessibility, space-time, query and aggregation, simulation, probable presence.

1.0 INTRODUCTION

There is considerable debate as to how individual actions lead to generalised spatial structures, which, it is argued, our present models just do not address. People are dynamic entities whose behaviour does not conform to many of the concepts which have been used to model and try to understand their aggregate actions. In part, this can be attributed to the inherent complexity of human activities and behaviour, and in part, this is due to the lack of adequate computational power to describe and analyse the same. 'Traditional' modelling approaches are based upon generalised and aggregated descriptions of the individual. Typical inputs to these models include census variables used to describe and model human phenomena in the form of zonal data (Openshaw 1996). As identified above, these are limited in their usefulness, since human activities are a part of broader, dynamic socio-spatial processes unfolding in space and time.

The motivation behind the research stems from an ongoing concern with the dynamics of human processes at the individual, or micro- scale (Dijst and Vidakovic 1997), and with the daily activities which structure our daily lives, such as work, shopping, recreation, and leisure. It views individuals as dynamic entities, engaged in everyday activities including work, shopping, family commitments, and recreational activities which, in the aggregate, create highly complex daily geographies of production and consumption on a variety of scales. Over time, these create material spatial structures and patterns which in turn shape people's opportunities, activities and urban form. However, while aggregate structures emerge from the actions of individuals, it must also be acknowledged that in the course of time, these will in turn influence the options available to individuals or specific social groups.

Hagerstrand's Time Geographic framework (Hagerstrand 1970) provides both simple and powerful ways of conceptualising movement in terms of *paths* through space and time, and potential human movement as prisms, defined by known *constraints* such as activities which are fixed or unmovable in a person's day. These theoretical constructs have been distilled and operationalised to differing degrees in a range of application domains, including accessibility, health and health risk, tourism flow analysis. Previous work by the authors has developed computational routine to generate masks using both raster and vector processing to generate realistic individual-level daily time-geographies of university students. The current paper develops further on space-time query aspects of this work, and enlarges on the notion of *probable presence* in space-time as it relates to concepts of access and interaction. It proposes a temporal distance-decay parameter which can be incorporated within routines that build individual models, in order to move from what might be done with discretionary time to likely outcomes.

2.0 THE COMPLEXITY OF EVERYDAY LIFE

It is argued here that in the aggregate, the basic activities that structure individual lives at the micro-scale constitute processes which shape urban form. This is elegantly summarised by Ellegard (1999: 168), who cites Hagerstrand (1991):

"on a macro-level, human societies are, wherever they are located, formed by the continuous processes of individuals performing activities in their everyday life."

Hägerstrand's seminal work, titled "What about people in regional science," (Hägerstrand 1970), has been credited with returning human actors to the forefront of social processes. His role in identifying the significance of human activities in time as well as space is also widely acknowledged (Parkes and Thrift 1980, Pred 1982, Miller 1991), and the broader ramifications of his views have acquired the title 'Time Geography'. Hägerstrand's geometric model embodies notions of scheduling, constraints, and opportunities in a single framework. Central to this framework is an explicit treatment of time dimension: the view that actions and activities can be observed as having a given duration, and occupying a specific location in space *and* time. According to Parkes and Thrift (1980: 12), the importance of time in social processes cannot be overstated:

"...it is only by inclusion of time that the geometric properties of relations among items (or events) become geographic."

Cities are becoming more complex, due to rapid advances in transport and communication technology, globalisation, widening inequalities and targeted policy decisions. Human activities are becoming increasingly complex in response to these new phenomena and opportunities, and there is an increasing need to describe and understand what people do in time and space, in order to better understand the potential aggregate impacts of their actions (Mey and ter Heide 1997). As noted by Miller (2004), traditional models are no longer tenable in this context. Many are based on static conceptualisations of space, zonal aggregates, and could not deal with (spatial or population) dynamics. Refined models and measures have emerged, based on better concepts of space to model the movement of people, better toolsets for studying urban phenomena, and a deeper understanding of the way that cities and urban systems work.

Hägerstrand's early work (1970) illustrated that individuals construct a range of unique life paths in time and space, however, we still know relatively little about individual life-lines or *paths* (Lenntorp 1976, Laube et al 2004), or the specific impacts that particular life styles and mobility factors have upon accessibility and activity patterns (Mey and ter Heide 1997). We know even less about how individual life patterns shape, and in turn are shaped by, the spatial and social structure of facilities (Couclelis and Getis 2000); the role of transport networks and communication technologies (Janelle 1986), and the impact of potential changes in these structures (Forer and Huisman 2000). In their significant extension of Hägerstrand's pioneering work, Parkes and Thrift (1980)

develop the concept of *pacemakers*. These refer to structures which influence the timing of space: in an urban context, the spatial distribution of facilities, their temporal availability (in terms of opening hours) and societal institutions such as the working week conspire to create dynamic daily geographies of availability – or, more accurately, presence and absence of opportunities. Institutions such as Universities impose what Hägerstrand has termed *coupling constraints* upon students in the form of lecture attendance and timetables, in turn shaping the availability of student work time. If we take this geometric view to the extreme, daily life might be viewed as a path which conditions the immediate 'short-term' futures, but also long-term ones by virtue of the 'life-experience' and value associated with experiences on that path. While the inherent complexity of urban microprocesses render such a 'rich' description of daily life untenable, previous work has demonstrated Pred's assessment that Time Geography can describe the *necessary* conditions for virtually all space-time interaction (Pred, 1983). It should be noted that in seeking to describe daily human life, a key problem lies in the lack of data available at sufficient temporal resolution for representing and modelling the range of activities and constraints which shape people's daily routines. Ongoing progress in urban simulation and Geocomputation continues to bring new technologies and methods to implement and extend key Time-Geographic concepts and investigate their usefulness in a real-world context.

3.0 TOWARDS A COMPUTATIONAL TIME-GEOGRAPHY

During the 1970's and early 1980's, Time-geographic research showed much promise (Carlstein et al. 1982; Pred 1983), but it lost favour due in part to the lack of detailed data on (increasingly dynamic) human geographies, and also to the lack of adequate computational tools to implement concepts. The field has enjoyed a resurgence in popularity since the 1990's, as illustrated by a growing body of research which has sought to apply Time-Geographic concepts to specific research problems (Miller 1991, Forer 1998, Huisman and Forer 1998, Dijst 1995, O'Sullivan et al. 2000, Forer and Huisman 2000, Theriault et al. 2002, Weber and Kwan 2002, Church and Marston 2004). In part, this is due to advances in software and computational power and the increasing availability of space-time activity data (STA). Specifically, computational developments in the domain of urban modelling and individual microsimulation have much to contribute to key modelling issues (Dibble 1996, Batty et al. 2003, Torrens and Benenson 2005). More generally, it is due to the growing recognition that the adequate functioning of urban areas depends to a large extent upon the scheduling of many events in time and space (Mey and ter Heide 1997). However, many practical applications have noted the difficulty in coping with highly complex agents and substantial sample sizes to allow this to emerge (see for example Dibble 1996, Schweitzer 1997, Janssens et al. 2004). Toolsets for analysis of individual lives in space and time remain rare, and the data often unavailable at the level required, as it is both costly and time-consuming to collect. Moreover, despite two decades of research and academic discourse, the current generation of GIS are still significantly limited in their ability to model such human phenomena due to their inability to incorporate time into their data models (Forer 1998, Shaw and Xin 2003).

While increasingly powerful data-mining algorithms enable the extraction of meaningful patterns of behaviour and activities from very large databases, as illustrated in some recent work (Laube et al. 2004), it should be noted that these patterns are in fact the result of individuals acting within their given environment in response to particular stimuli, and based upon preferences and knowledge. In the current context, human activities can be loosely described as social, economic, and recreational events that have an immediate spatial and temporal setting. However, to tie activities down beyond that point becomes difficult due to the range and complexities of behaviours involved. An argument which derives from a slightly more 'puritanical' time-geographic view of process sees the core issue associated with human activities, access and behaviour, as one grounded firmly in identifying the constraints which shape the daily routines of individuals rather than attempting to calibrate models with behavioural data.

3.1 Prisms and action-spaces

One of the core concepts of the time geographic framework is the space-time prism (STP). Essentially, the space time prism is created by the existence of fixed activities (which includes such inflexible options as undertaking paid work or attending an important appointment). Essentially, these fixed activities impose constraints upon an individual's activity pattern. Rather than focussing on observed behaviour, Time-Geography has sought to define the physical (spatial and temporal) constraints which restrict the choice of alternatives open to the individual. This describes what is physically possible or accessible within certain time constraints. Actual behaviour in the form of travel patterns can only occur within action spaces, through the mechanisms of individual perceptions and cognitive filters (Golledge and Stimson 1987).

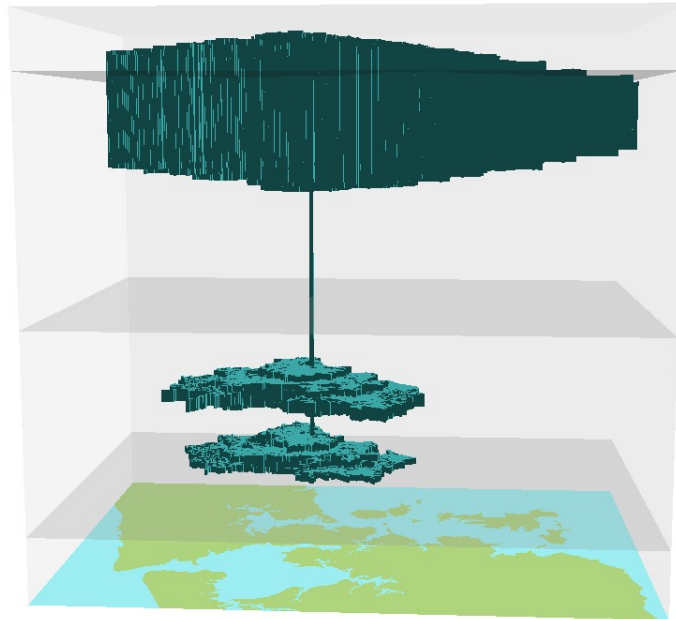


Figure 1: An individual space-time mask.

Horizontal shaded layers represent 7am, 12 noon and 7pm respectively.

Free periods of time between fixed activities are known as time budgets, and determine the spatial extent of the individual's action space (or 'reach') by a given mode of transport. This in turn can be translated into a set of locations at which activities or combinations of activities can be carried out. Time budgets translate into a prism shape based on the fact that travelling 'out' in a certain direction is limited by the ability to get back to the location of the next marker or activity on time. The size and shape of the prism is highly dependent upon the transport options available to the individual. Moreover, a prism can be symmetrical or non-symmetrical about its x-axis, depending on whether or not the location of the next activity is different to the current location of the individual, and whether individual mobility and the state of the transport system is constant or not. *Action spaces* are the planimetric expression of prisms, and are also referred to as Potential Path Areas or PPAs (Miller 1991), and, when translated to activity settings, are known as Feasible Opportunity Sets (Kwan, 1999). The action space concept has been adopted relatively widely in the literature (Dijkstra 1995; Mey and ter Heide 1997; Forer and Huisman 2000, Lee and McNally 2003, Church and Marston 2003), and provides a more widely accepted measure of 'real' accessibility than purely spatial measures of separation (Pooler 1995).

3.2 Querying individual Time Geographies in GIS

Previous work has developed computational routines to generate masks using both raster and vector processing to generate realistic individual-level daily time-geographies of university students. These models are termed *masks*, for management, analysis and visualisation. Masks are made up of a volume of cells referred to as *taxels* (Huisman and Forer 1998). In order to turn this model into a useful tool, five key functions have been developed for the analysis of masks. These functions are programmed within the ArcGIS workstation platform and are described below.

- TimeSlice
- Intersect
- PeopleSum
- DurationSum
- DurationQuery

Basic individual queries might focus on concepts relating to the concepts of reach and accessibility. For example *For how long can X be at location Y? Where are all the activities that X can get to for a certain minimum duration? How likely is X to be here at time T to undertake activity A?* Queries concerning aggregate processes relating to access and interaction require the analysis of multiple masks and include core questions such as *How many people can possibly be here at time T? For how long is a meeting possible at location Y or How many*

people are likely to be here or undertake activity x at time T ? All of these queries can be answered using various (geometric) combinations of drilling and slicing masks.

TimeSlice (Figure 2) can be used to determine the spatial extent of the potential presence of an individual by ‘slicing’ a mask along the time axis. This yields a planimetric statement of an agent’s potential presence within their day, and translates directly into the concept of action space (Dijst 1995) and the notion of reach (Pirie, 1979). *TimeSlice* can also be utilised to display or visualise query results for aggregations of masks for a specific time interval.

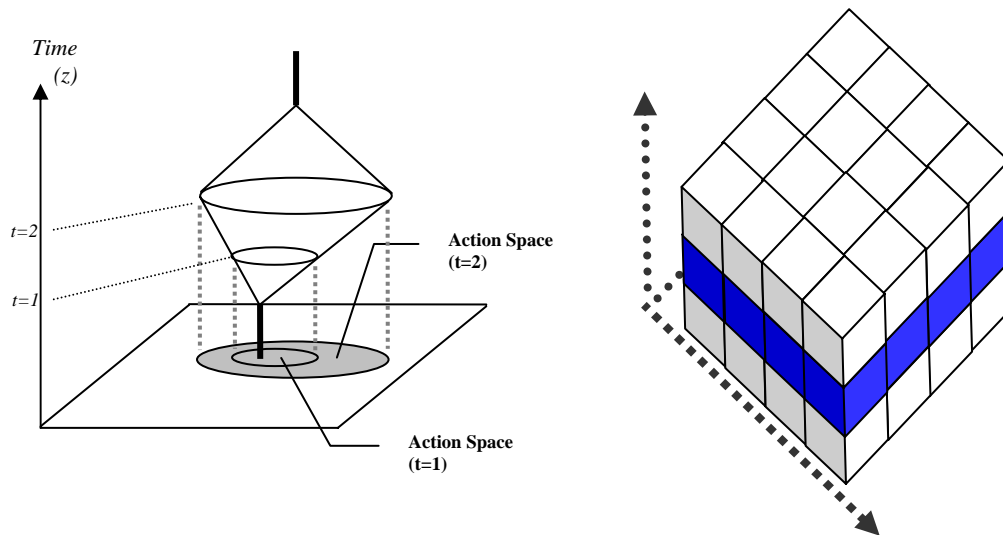


Figure 2: The *TimeSlice* function

Intersect represents a Boolean query which returns a ‘1’ where ALL of the masks in the sample contain filled cells (presence), and a ‘0’ where the condition is not satisfied (absence). The more masks in the sample, the more sparse the returned mask is likely to be, due to the conditional nature of the query. In the figure below, a ‘yellow’ mask and a ‘blue’ mask are combined using the intersect function, returning a mask of sparsely filled cells (those which would be ‘green’ in this example). The output from hundreds of individual masks would yield substantially less cells which might be accessed by all individuals.

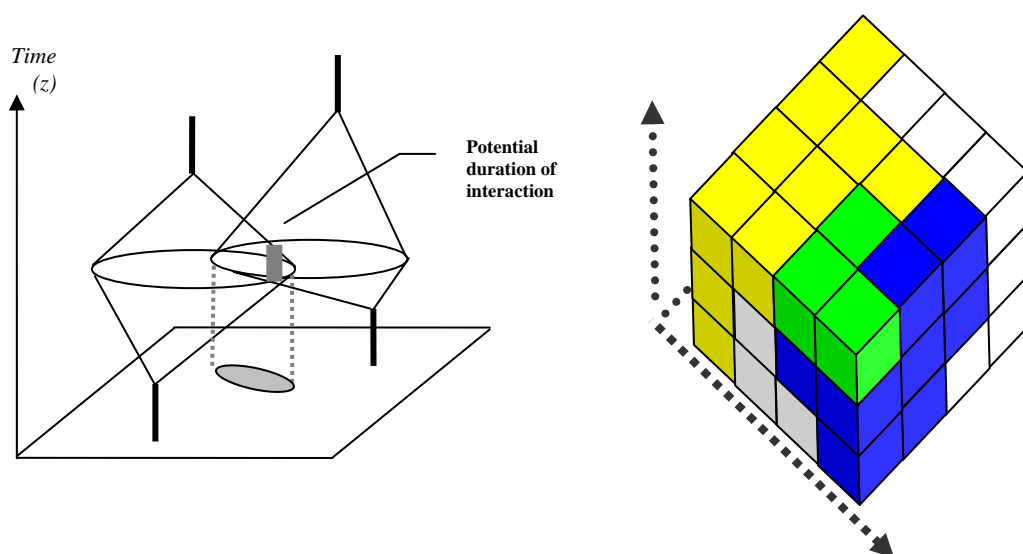


Figure 3: The *Intersect* function

PeopleSum is a recursive summation which calculates the number of individuals which satisfy a given condition, usually a presence/absence condition. It works by intersecting a set of sample masks using an additive function which sums all instances of potential presence in the input masks. Each cell in the output mask denotes aggregate potential presence, or aggregate reach in space-time.

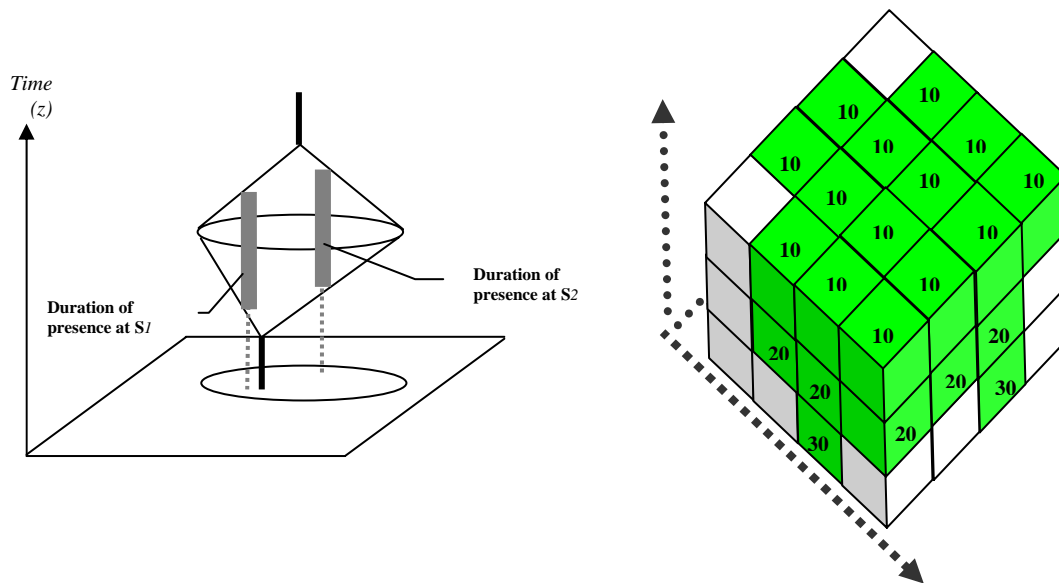


Figure 4: The DurationSum function.

DurationSum calculates the duration for which an individual can occupy a specific location (Figure 4). As noted, the ability to be present in a specific cell is an indication of an individual's ability to reach the location, but an effective measure of physical accessibility should incorporate the time required to perform an activity. These durations can be translated directly into notions of densities, and can be used to derive a range of choices open to individual. The algorithm parallels the notion of 'drilling down' through the time axis: durations of presence are calculated through additive summation of contiguous filled cells along the Z-axis, for any mask. Upon finding a taxel which is empty, the counter for that specific taxel is (re)set to zero. Each taxel in the output grid is assigned the duration which the individual can occupy the location at that specific time. If the taxel resolution in the figure below is 10 minute / 200 metres, then a DurationSum function would calculate the values for the cells as indicated.

DurationQuery is effectively a conditional function which filters all taxels in an input mask. The operators $>$, $<$ and $=$ can be employed to test if the taxel value satisfies a condition ($d > x$, or $d < x$), where x is a threshold duration expressed in minutes. This function is often employed in tandem with DurationSum to filter out all durations less than a certain threshold value.

3.3 Examples of domain-specific space-time Queries

Space-Time masks are statements about potential and actual physical presence derived from modelling using non-Euclidean models of space (network analysis). A range of combinatorial functions can be applied to single or multiple masks to yield substantive insights into accessibility, presence and interaction in urban space. In real world contexts these insights could extend current research into daily routines (Takahashi et al. 2001), the spread of disease (Schærström 1996), and risk analysis (Forer 2002).

Extending previous work in the context of Student Time Geographies in Auckland New Zealand, Figure 5 illustrates the action spaces of two individual students overlaid on the same map. This shows differential reach due to differential mode access: the 'red' student here has access to a car whereas the 'blue' student travels by means of public transport. Figure 6 extends on this, deriving possible duration of presence from the mask of the 'blue' student in Figure 5, illustrating the complex nature of accessibility by scheduled public transport. Figure 7 is an aggregate representation derived from the masks of some 2100 student masks. It illustrates where these students *could* be, based upon given transportation options and lecture timetables generated from real-world

data. Extending on this, Figure 8 shows the possible time density available to the same sample of students, and is generated by calculating the sum of all durations of presence for individual masks at each time interval.

While these figures illustrate the (highly) dynamic nature of access in urban space they tell us little about likely patterns of access and occupance and activities which might be carried out. The remainder of this paper will focus on extending masks to enable greater insight into the aggregate patterns which might emerge from collective student Time Geographies.

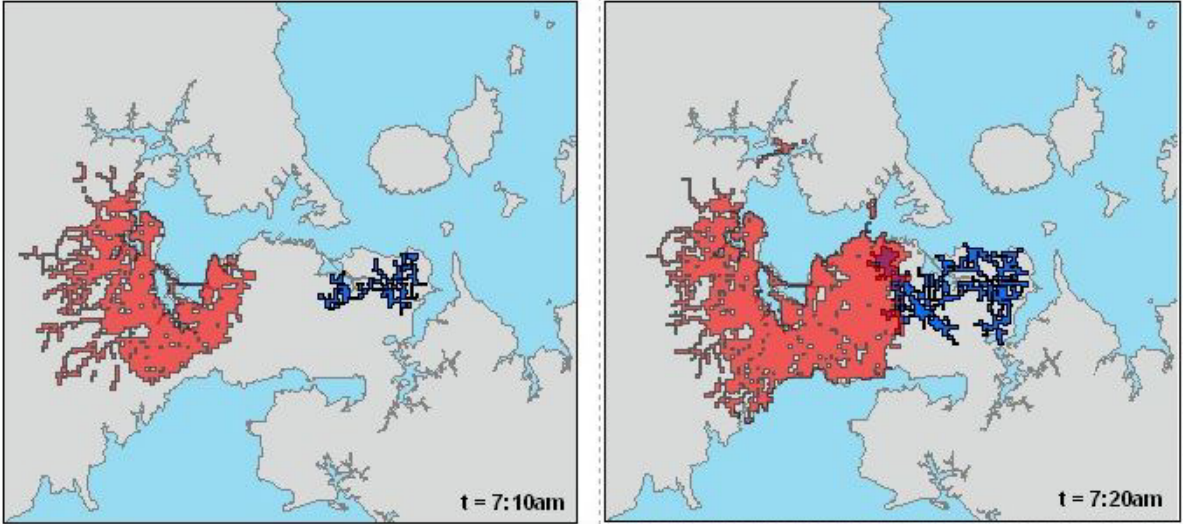


Figure 5: Potential presence for two students at two time intervals. These are based on known home locations and modelled transport options.

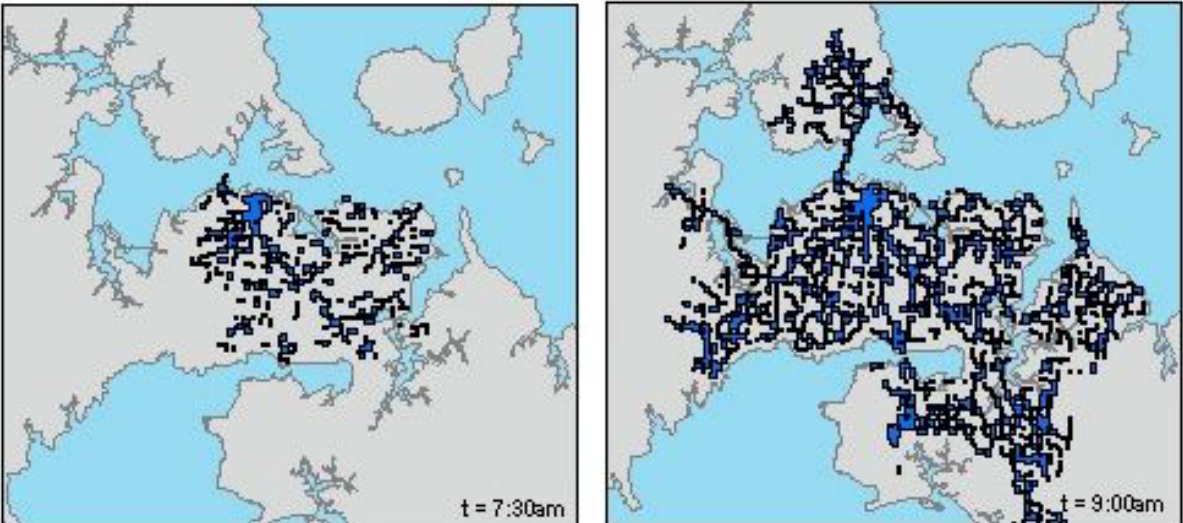


Figure 6: Available durations of presence for a student travelling by bus at two different times of the day. This illustrates the highly complex patterns of access using scheduled bus services.

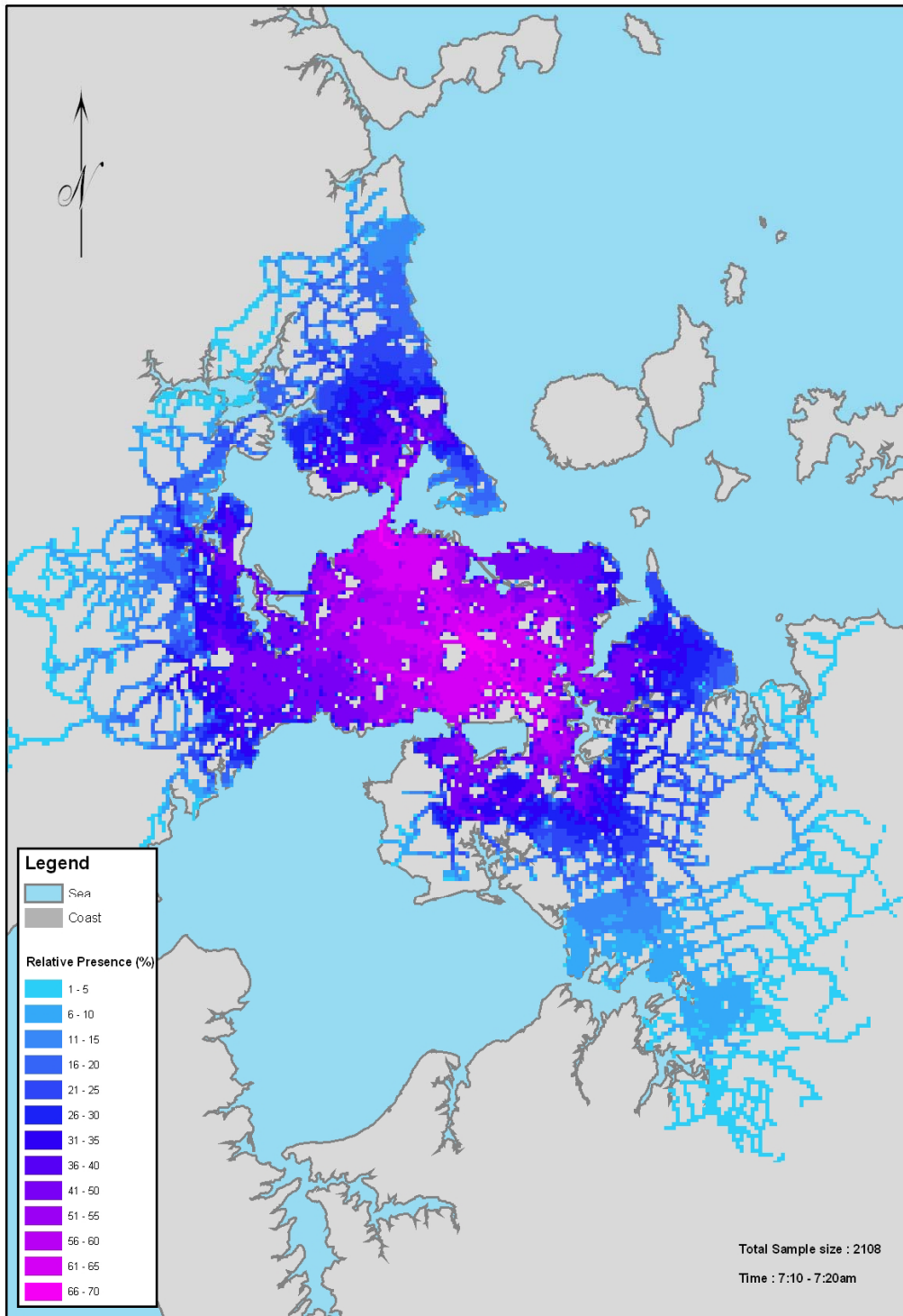


Figure 7: Potential presence (reach) for students between 7:10 and 7:20am. Shading represents percentage of the sample that can be present at that location.

4.0 EXTENDING MASKS: FROM POTENTIAL TO PROBABLE PRESENCE

Original time-geographic studies were often criticised for their inability to translate the possibility of a presence into the likely occurrence of an event or activity (presence) (Forer 1997; Huisman and Forer 1998). Previous work has speculated on populating the cells of individual masks with values other than a binary presence/absence key. It should be noted that there are both theoretical as well as computational challenges in

moving from the opportunities available to an individual to predicting the activities that a particular individual might carry out. This is due to a host of subjective and contextual factors, which together determine behaviour. While durations of possible presence can be quite easily derived from individual masks, modelling where people are likely to be within their prisms, for example in terms of site preference or distance decay, represents a complex endeavour: there is a very steep research gradient in moving from the possible to the probable or likely : once people are not limited solely by factors of proximity the modelling of probable presence becomes much more complex as it tries to cope with behavioural factors (Hensher and Stopher 1979; Jones et al 1985; Golledge and Stimson 1997).

There are essentially two ways forward. The first is to adjust or calibrate the decision rules used in the generation of masks. The second, and more attractive way forward is to populate masks with probabilities of occupancy, as some function of the remaining available time in a cell. This would allow the derivation of various spatial or volumetric outcomes from combinations of masks that could provide a direct statement about likelihood of presence and interaction. This represents a workable attempt to incorporate a more realistic degree of 'agency' into the building of individual masks. The net result provides an assessment of where, over a day, individuals are likely to be, given a range of constraints and activities which they routinely carry out.

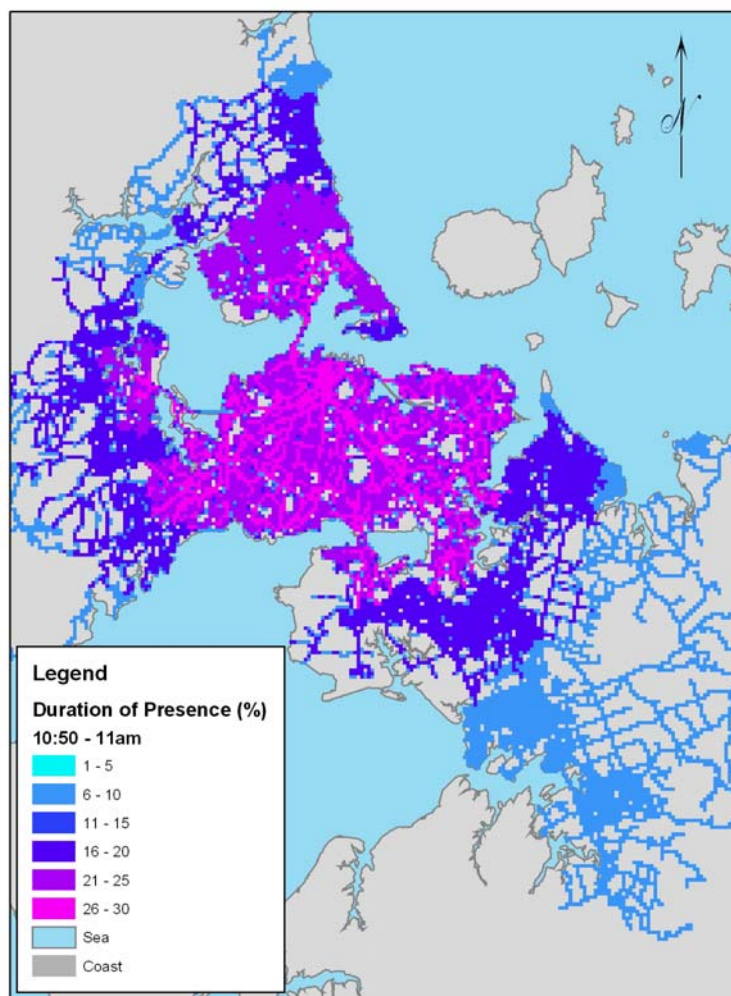


Figure 8: Duration of presence for a sample of 2100 students. Shading illustrates the distribution of free time (in this case 60 minutes) for all students in the sample.

Huisman and Forer (1998) incorporated a simple 'distance decay'-type function across an aggregate mask of student potential presence, to speculate on the potential density of the student population, and illustrate the emergent characteristics of aggregate time geographies. This approach does have some merit, as most of the periods of free time in student days are still conditioned by campus locations, and thus most of the prisms which form are (theoretically) symmetrical in that the previous activity (lecture or lab attendance) is generally located

at the same (campus) location as the following scheduled activity. However what is required is a function which can be implemented within computational routines that generate masks at the individual-level.

4.1 The Travel Time Ratio

The *travel-time ratio* (Dijst 1995) is a distance-decay type function which takes into account (potential) activity duration and travel time. This function has been used successfully in related work on action spaces and activity-based modelling to determine likely activity outcomes for both actual and hypothetical individuals and is a key input into the simulation model MASTIC (Dijst and Vidakovic 1997). The ratio r is given by:

$$r = \frac{T_t}{T_b + T_t}$$

Where: T_t = travel time to destination
 T_b = time budget

This function can be modified to work across action spaces, using travel time to get to the current cell as a function of its probability of occupancy rather than the destination. In this way masks can be populated with meaningful probability measures by applying a standardised probability across action spaces, and we could estimate likelihood of travel/activity combinations actually occurring (Figure 9).

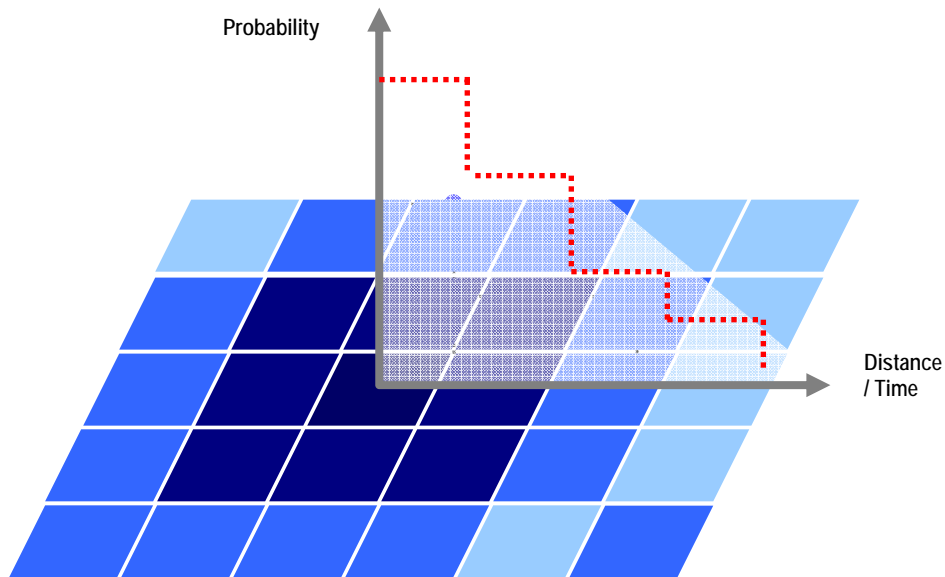


Figure 9: decreasing probability of occupancy over space.

For example, if the available time budget is 50 minutes, and the temporal resolution is 10 minute / 100 metre taxel, then the maximum set of transitional zones is (50 / 10) or 5, as illustrated by the blue shading in the figure above. The probability of an individual occupying each zone is determined by the travel time to any cell within the zone, as a function of duration of presence or *how long it is possible to occupy that cell*. It is proposed that this function be standardised over all duration of presence categories so that all probabilities sum to 1 for n zones:

$$P_{pres} = \frac{1 - [T_t / (T_b + T_t)]}{\sum_n [1 - (T_b / (T_b + T_t))]}$$

Where: T_t = travel time to destination
 T_b = time budget
 n = number of zones in action space (defined by time interval and time budget).

The result shares some similarities with related work on *travel probability fields* (Beckmann et al. 1983), except that the probabilities are derived from non-isomorphic time-spaces, which are mapped into discrete space-time to make analysis computationally manageable and more straightforward. It should also be noted that when building floating-point masks, there is a significant explosion in storage requirements. The issues and implications arising from this significant extension of binary masks are currently unresolved, and will be reported in future work.

5.0 CONCLUSIONS

This paper has sought to elaborate and extend previous research by the authors. It has attempted to demonstrate possible outputs from a range of space-time queries involving single and multiple individual Time-Geographies. It is proposed that a distance-decay parameter be incorporated within the routines which generate masks to enable more realistic assessment of likely patterns of presence, accessibility, and interaction in urban space. Future work will report on the issues for modelling and associated implications for research into daily human life.

It is worth noting the potential for calibrating parameters for specific services or specific social groups to more accurately represent real-world needs and activities. This data could be sourced through survey methods (Forer et al 1999). Related work in progress seeks to deal with choice and uncertainty in terms of individual constraints and activities and to develop methods for representing and visualising uncertainty of constraint timing and/or location. These developments are likely to contribute significantly to the evaluation and refinement of individual and aggregate masks as well as space-time queries.

REFERENCES

- Batty, M., J. Desyllas and E. Duxbury (2003). The discrete dynamics of small-scale spatial events: agent-based models of mobility in carnivals and street parades. *International Journal of Geographic Information Science* 17(7): 673-697.
- Beckmann, M.J., T.F. Golob and Y. Zahavi (1983). Travel probability fields and urban spatial structure: Theory. *Environment and Planning A*, 15: 593-606.
- Church, R. L. and J. R. Marston (2003). Measuring accessibility for people with a disability. *Geographical Analysis* 35(1): 83-96.
- Conte, R. and N. Gilbert (1995). Computer simulation for social theory, IN N. Gilbert and R. Conte (eds.) *Artificial Societies*. London: UCL Press.
- Couclelis, H. and A. Getis (2000). Conceptualizing and measuring accessibility within physical and virtual spaces, IN *Information, Place and Cyberspace: Issues in Accessibility*. Editors D.G. Janelle and D.C. Hodge. Berlin, Springer-Verlag: 15-20.
- Dibble, C. (1996). Theory in a complex world: agent-based simulations of geographic systems. *Proceedings Geocomputation'96 Conference*, University of Leeds, September 1996, UK.
- Dijst, M. (1995). Het elliptisch leven: Actieruimte ans integrale maat voor bereik en mobiliteit. Netherlands Graduate School of Housing and Urban Research. Utrecht. *Netherlands Geographical Studies* 196.
- Dijst, M. and V. Vidakovic (1997). Individual Action Space in the City. *Activity Based Approaches to Travel Analysis*. D. Ettema and H. J. Timmermans. Oxford: Pergamon.
- Ellegard, K. (1999). A time-geographic approach to the study of everyday life of individuals – a challenge of complexity. *Geojournal* 48: 167-175.
- Ettema, D., and Timmermans, H., Ed. (1997). *Activity-Based Approaches to Travel Analysis*. Oxford: Pergamon.

- Forer P.C. (2002). Timelines, environments, and issues of risk in health: the practical algebra of (x,y,t,a). In: Briggs, D.J., Forer P.C., Jarup, L., and Stern, R. (eds.) *GIS for Emergency Preparedness and Health Risk Reduction*. NATO Science Series, IV. Earth and Environmental Sciences. London, Kluwer Academic Publishers: 35-60.
- Forer, P.C. (1998). Geometric approaches to the nexus of time, space, and microprocess: Implementing a practical model for mundane socio-spatial systems. IN *Spatial and Temporal Reasoning in Geographic Information Systems*. Editors M.J. Egenhofer and R.G. Golledge. New York, Oxford University Press: 171-190.
- Forer, P.C. and O. Huisman (2000). Space, time and sequencing: substitution at the physical/virtual interface. IN *Information, Place, and Cyberspace: Issues in accessibility*. D. G. Janelle and D. Hodge. Berlin, Springer-Verlag.
- Forer, P.C., G Glen and O Huisman (2003): What Map-enabled Surveys, Internet Mapping and GIS Can Reveal About Human Lives. *Proceedings of the 24th New Zealand Geographical Society Conference*, July 2003, Auckland, New Zealand).
- Golledge, R., G. and R.J. Stimson, (1997). *Spatial Behavior: A Geographic Perspective*. New York, The Guilford Press.
- Hagerstrand, T. (1970). What about people in regional science? *Papers of the Regional Science Association* 24: 7-21.
- Hendricks, M., M. Egenhofer, et al. (2003). Structuring a Wayfinder's Dynamic Space-Time Environment. Conference on Spatial Information Theory (COSIT '03), Kartause Ittingen, Switzerland, September 2003. *Springer Lecture Notes in Computer Science* Vol. 2825: 75-92
- Hensher, D. and P.R. Stopher (1979). *Behavioural Travel Modelling*. London, Croom Helm.
- Huisman, O. and P Forer (1999): Student Access and Campus Geographies: Operationalising Time-Geography for the study of university student life. *Proceedings of the 20th New Zealand Geographical Society Conference*, July 1999 (Palmerston North New Zealand) NZGS, Hamilton.
- Huisman, O. and P. Forer (1998). Computational agents and urban life spaces: a preliminary realisation of the time-geography of student lifestyles. *Proceedings GeoComputation 98*, Bristol, UK. (CD-ROM).
- Janssens D., Wets G., Brijs T., Vanhoof K., Timmermans H., Arentze T.A. (2004) Improving the performance of a multi-agent rule-based model for activity pattern decisions using Bayesian networks. IN: *Electronic proceedings of the 83rd Annual Meeting of the Transportation Research Board*, Washington, D.C., USA, January 11-15, 2004.
- Jones, P.M., M.C. Dix, M.I. Clarke and I.G. Heggie (1985), *Understanding Travel Behaviour*. Aldershot, England: Gower Publishing.
- Kwan, M.-P. (1999). Gender and Individual Access to Urban Opportunities: A Study Using Space-Time Measures. *The Professional Geographer* 51(2): 211-227.
- Kockelman, K.M. and S. Krishnamurthy (2004). A new approach for travel demand modeling: linking Roy's Identity to discrete choice. *Transportation Research Part B* 38: 459-475.
- Laube, P., M. van Kreveld and S. Imfeld (2004). Finding REMO - Detecting Relative Motion Patterns in Geospatial Lifelines. In: P.F. Fisher (Ed.): *Developments in Spatial Data Handling, Proceedings of the 11th International Symposium on Spatial Data Handling*, Leicester, UK, 23rd - 25th August 2004. Springer, Berlin-Heidelberg, p.201-214.
- Lenntorp, B. (1978). A time-geographic model of individual activity programmes. IN *Human Activity and Time Geography*. Editors T. Carlstein, D. N. Parkes and N. J. Thrift. London, Edward Arnold: 162-180.
- Lee, M.S. and McNally, M.G. (2003). Measuring physical accessibility with Space-Time Prisms in GIS: A case study of access to health facilities. *Proceedings annual meeting of the Transportation Research Board 2003*.
- Mey, M.G. and H. ter Heide (1997). Towards spatiotemporal planning: practicable analysis of day-to-day paths

through space and time. *Environment and Planning B* 24: 709-723.

Miller, H. J. (1991). Modelling accessibility using space-time prism concepts within geographical information systems. *International Journal of Geographical Information Systems* 5(3): 287-301.

Miller, H.J. (2004). Activities in space and time. IN: P. Stopher, K. Button, K. Haynes and D. Hensher (eds.) *Handbook of Transport 5: Transport Geography and Spatial Systems*, Elsevier Science.

Openshaw, S. (1996). Developing GIS-relevant zone-based spatial analysis methods. *Spatial Analysis: Modelling in a GIS Environment*. P. Longley and M. Batty. Cambridge, GeoInformation International: 55-73.

O'Sullivan, D., A. Morrison and J. Shearer (2000). Using desktop GIS for the investigation of accessibility by public transport: an isochrone approach. *International Journal of Geographical Information Science* 14: 85-104.

Parkes, D. N. Thrift N. J. (1980). *Times, Space and Places: A Chronogeographic Perspective*. Wiley & Sons: UK.

Pooler, J. (1995). The Use of Spatial Separation in the Measurement of Transportation Accessibility. *Transportation Research A* 29(6): 421-427.

Portugali, J. and I. Benenson (1997). Human Agents Between Local and Global Forces in a Self-Organizing City. IN *Self-Organization of Complex Structures: From Individual to Collective Dynamics*. Editor F. Schweitzer London: Gordon and Breach: 537-547

Pred, A. (1982). Social reproduction and the time-geography of everyday life. IN *A Search For Common Ground*. Editors P. Gould and G. Olsson. London, Pion.

Ryan, S. and M. G. McNally (1995). Accessibility of Neotraditional Neighborhoods: A Review of Design Concepts, Policies, and Recent Literature. *Transportation Research A* 29A, Number 2: 87-105.

Schærström, A. (1996). Pathogenic paths? A time geographical approach in medical geography. *Ph.D Thesis*. Lund University Press, Sweden.

Schweitzer, F., J. Zimmermann, H. Mühlenbein. (2002). Coordination of Decisions in a Spatial Agent Model. *Physica A* 303: 189-216.

Shaw, S.-L. and X. Xin (2003). Integrated land use and transportation interaction: a temporal GIS exploratory data analysis approach. *Journal of Transport Geography* 11(2): 103-115.

Takahashi LM, D. Wiebe and R. Rodriguez (2001). Navigating the time-space context of HIV and AIDS: Daily routines and access to care. *Social Science & Medicine* 53(7):845-63.

Theriault, M., C. Claramunt (2002) A-M. Seguin and P. Villeneuve (2002) Temporal GIS and statistical modelling of personal lifelines. *Symposium on Geospatial Theory, Processing and Applications*, Ottawa, Canada 2002.

Vause, M. (1997). A rule-based model of activity scheduling behavior. IN *Activity-based Approaches to Travel Analysis*. Editors D.F. Ettema and H.J. Timmermans. Oxford: Elsevier Science: 73-88.

Veldhuisen, K., H.J.P. Timmermans and L.L. Kapoen (2000). RAMBLAS: a regional planning model based on the micro-simulation of daily activity travel patterns. *Environment and Planning A* 32: 427-443.

Weber, J. and M.-P. Kwan (2002). Bringing time back in: A study on the influence of travel time variations and facility opening hours on individual accessibility. *The Professional Geographer* 54(2).