REDUCED CO2 FROM SUSTAINABLE HOUSEHOLD TRAVEL

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TECHNICAL REPORT

OBJECTIVE 3

Milestone 2

Operational Definition of Accessibility

Otto Huisman

Centre for Social and Health Outcomes Research and Evaluation
& Te Ropu Whariki
P O Box 6137, Wellesley St, Auckland

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1 EXECUTIVE SUMMARY

This research focuses on two main strategies to reduce fuel use, and consequent CO2 emissions; Transportation Demand Management (TDM), and Transportation Supply Management (TSM). TDM strategies aim to reduce travel demand rather than increasing transportation capacity and focus on alternatives such as ride sharing, flexitime, increased transit usage, walking, and bicycling. TSM strategies focus on increasing the efficiency, safety, and capacity of existing transportation systems. VFC is a quantitative measure of aggregate fuel consumption used as an indicator for transportation policy and planning.

Objective 3 contributes to the programme outcome by quantifying the social impacts of reduced fuel use. It is heavily dependent on Objectives 1 and 2 to provide key social and behavioural parameters underlying human activities and components of travel behaviour. Objective 3 has the basic premise that the social impacts of strategies designed to alter TSM, TDM or VFC, can be assessed by measuring changes in the spatial distribution of accessibility. A key component of this objective is to develop a GIS-based household-level model of accessibility which will be used to assess the social impacts of future travel under reduced fuel consumption scenarios. The household-level model will be capable of implementation independent of the method used to reduce fuel use, and applicable to all types of settlements and localities.

This technical report establishes a conceptual and operational definition of accessibility which will form the basis of the model. It reviews key concepts, measures and models in relevant application settings, and discusses key issues in the way access is conceptualised in the literature. It is noted that there are a bewildering array of access models, measures, and definitions, many of which focus the specific components of access relevant to their application. These range from evaluations of transportation networks, to locational issues for siting public facilities, and assessments of equity in access to medical care. Within these studies, accessibility has often been conceived as an aggregate-level concept representing a *property of a place* (in terms of 'how accessible' it is, or 'how accessible' other places are to get to).

The key issue is that concepts of access and the measures which have been employed are quite different (Weibull 1980, Hanson and Schwab 1987). Access is a multi-scale phenomenon: at the individual level people create access in terms of being able to get to specific places for meaningful periods of time. At the household level this brings about issues of daily routines and intra-household scheduling constraints which are particularly difficult to measure and quantify. At the city-wide level, it is often 'patterns' of access which are of interest. These should be seen as processes which emerge from the aggregate actions of individuals rather than as properties of specific locations.

This review conceives access as a space-time phenomenon which is both a key component in, and a result of, complex individual and household-level activity scheduling. In the aggregate, these are responsible for traffic flows and consequent congestion and pollution. An operational definition is proposed, based on a household-level conceptualisation of *spatial opportunity* (Breheny 1978), Hägerstrand's (1970) concept of the *space-time prism*, and Pirie's (1979) definition of accessibility as created within existing activity routines. These will be used as the foundations of a GIS-based simulation model of urban accessibility.

2 ACCESSIBILITY AND TRANSPORTATION

Accessibility is a significant concept employed to understand patterns in the location of facilities and to indicate broad features of the behaviour of people, as well as evaluating the ability of services to meet people's needs. Questions such as what can be accessed, when, by whom, and at what cost have been focal for geographers, transport engineers and planners alike (Breheny 1978, Pirie 1981, Geertman and van Eck 1995, Huisman and Forer 1998).

Applications of accessibility models range from generic statements such as travel behaviour measures (see Hensher and Stopher 1979) to evaluating the geometric structure of transportation networks (Garrison 1960, Miller 1994) to a focus on accessibility for specific social groups such as the car-less (Forer and Kivell 1981) and the disabled (Church and Marston 2003). Recent years have seen the growing use of accessibility models for transportation policy impact assessment, as integrated land-use, transportation, and air-quality planning gradually become common practice in urban areas (Lee and McNally 2003, Miller 2004).

Accessibility involves a large number of complex and interacting relationships that are often difficult to quantify and analyse. Traditionally, accessibility has generally been conceived as an aggregate concept, built upon generalised notions of human behaviour (Pirie 1979, Pooler 1995). While the definition of accessibility is widely debated, most of these models measure access as physical separation of individuals and key activity locations in terms of absolute or relative travel distance or cost (Ingram 1971). These studies generally conceives an individual's ability to *get to* a facility as a measure of mobility or 'reach' while people's ability, *en masse*, to get to a place, to be a measure of that place's accessibility.

'Traditional' measures are based upon generalised and aggregated descriptions of the individual formulated in Gravity-type models developed by Hansen (1959), for a variety of conceptual and computational reasons. *Conceptually*, the fundamental notions underlying structure and functioning of cities and urban areas (our paradigms) differed considerably from those of today. *Computationally*, the technology (hardware, software and techniques) for implementing enhanced concepts and models was still in its infancy. Typical inputs to these models include census variables such as car ownership indices, average income criteria, and summary populations in the form of zonal data (Openshaw 1996). Outcomes of models are therefore highly dependent on the spatial arrangement, size and consistency of these zones over time.

Even though cities are no longer monocentric or dominated by a single land use, and activities are fragmenting from locations with rapidly developing transport and communication technologies, many of our current measures still operate on zonal data and derive from the 'gravity' type of accessibility model (Pirie 1979, Handy and Niemeier 1997). Arguably, these are highly limited in their usefulness, since human activities are a part of broader, dynamic socio-spatial processes unfolding in space and time: people's daily lives are made up of varying combinations of work, recreation and family activities. In practice, accessibility is more about limited time "budgets" available for travel and participation in both individual and household activities such as work, family, and leisure (Forer and Kivell 1981, Szalai 1982) than traditional 'place-based' measures would have us believe.

The following section reviews existing measures and provides a brief assessment of their usefulness in the current research context.

3 EXISTING MEASURES OF ACCESSIBILITY

A wide array of access measures exist, and have been applied to a similarly broad range of problems. These include access to employment opportunities (Hughes 1991), evaluation of transportation networks (Garisson 1960, Robinson 1977, Portier et al. 1994), or particular transportation modes such as Public Transportation (Forer 1979, O'Sullivan et al. 2000), access to primary Healthcare (Brabyn and Skelly 2003), access to public facilities for particular social groups (Khan 1992, Janelle et al. 1998, Weber and Kwan 2002, Church and Marston 2003); or as an input into the planning process (Breheny 1978, Pirie 1981, Truelove 1993, Ryan and McNally 1995).

As noted by a variety of authors, accessibility and its related concepts are seldom clearly distinguished in the literature. In fact the problematic nature of providing a clear and widely accepted definition of these concepts is well documented (see Pirie 1979, Pooler 1987, Handy and Niemeier 1997 for extensive reviews). Specifically, the distinction between accessibility and mobility is rather blurred: many authors have noted that little attention has been given to clearly distinguishing these terms, however 'mobility' is frequently represented as the number of trips made by a person or household over a specified period of time (Litman 2003). Mobility may be regarded as both a component of accessibility, in terms of the relative propensity of people to travel, as well as an outcome of an activity-scheduling process in which accessibility plays a key role. With regard to the concept of accessibility, Weibull (1980: 53) notes the existence of:

> *"a gap between the general and sometimes vague verbal definitions of the concepts and the very specific numerical indicators in use"*

Many of the definitions and measures of accessibility are application-specific (Pirie 1979, Hanson and Schwab 1987, Lee and McNally 2003). This has considerable implications for the current research, and justifies a brief review and critique of existing measures, and a re-examination of concepts of access and interaction in the context of people's daily lives, building on the notion that the individual lies at the core of processes that operate within a city. Traditional access measures can be broadly classified into the following three categories (Pirie 1979, Breheny 1978, Pooler 1995, Church and Marston 2003, Huisman 2006):

1. Reach or distance-based measures
2. Gravity-based measures
3. Opportunity-based measures

The ensuing sections will briefly examine these in turn.

3.1 Distance or ‘reach’ measures

The ability of individuals to gain access to the services and facilities they require is often referred to as ‘reach’ (compare Pirie 1979, Dijst and Vidakovic 1997). Essentially, ‘reach’ refers to simple measures of spatial separation, modelled in the form of distance, between individuals and their activities.

Many studies have developed indices based on Euclidean distance (Sartell 1983). More complex measures of spatial separation calculate distance in terms of topological network travel time or cost (Pooler 1995), making it possible to represent access of particular locations *relative* to one-another in terms of the travel time between them (Ingram 1971). Sometimes the measures use a weighted distance function (see Pooler 1987 for an extended discussion). This type of accessibility measure is usually given by:

$$A_i = \sum_j D_{ij}^{-k} \qquad \textbf{(1)}$$

Where:

$\boldsymbol{A}$ is accessibility of zone i
$\boldsymbol{D}$ is distance from the centroid of zone i to the centroid of zone j
$\boldsymbol{j}$ is a set of zones
$-\boldsymbol{k}$ represents the distance decay weighting on the accessibility of zone i

In contrast to the relative reach measures discussed above, *integral* measures represent the relationships between one point and all others in the study area, again based on distance, average travel time, or cost. This is used to derive a type of access ‘surface’ that illustrates variations in access over space. ‘Potential’ surfaces are examples of this type of measure (Pooler 1987). While the Distance and Reach types of indices are accurate in terms of their measurement of separation or reach, they are highly generalised, and usually adopt zone centroids as the origin of travel. These can be implemented relatively easily within GIS (de Jong and Ritsema van Eck 1996).

3.2 Gravity-based measures

While the measures presented above are based on measures of spatial separation alone, classic Gravity-type models take the notion of spatial separation one step further and consider assumptions of attractiveness of the destination, as well as some friction of distance. Gravity-based formulations are one of the most popular of accessibility measures, and are usually based on inter-point network distances or travel times, and augmented with a measure of attractiveness at the other points or nodes (representing destinations) in the form of weightings (Chorley and Hagett 1967, Robinson 1977).

Applications include ‘travel behaviour’ and ‘travel demand’ models (Hensher and Stopher 1979) and derivatives of Reilly’s original model of retail gravitation (Reilly 1953), although Hansen’s (1959) model to predict the location of population in residential zones of an urban region is widely regarded as the first ‘classic’ formulation of a gravity model.

Similar to the reach measures above, an impedance function is employed to represent the effort required to overcome ‘space’ in terms of distance or travel time or cost, and provides a measure of the relative accessibility of each location. Utility or net-benefit measures are a type of gravity-based measure which attempt to quantify the relative utility possessed by specific locations. Examples include a range of travel-demand based measures (Hensher and Stopher 1979). The access index for gravity-type models is given by:

$$A_i = \sum_j O_j c_{ij} \tag{2}$$

Where:

A is accessibility index for zone *i*
O corresponds to the mass of opportunities at destination zone *j*
Cij represents the costs of travel between zones *i* and *j*

3.3 Opportunity measures

Opportunity measures are essentially measures of opportunities available within a certain distance, travel time, or cost at specific demand locations. These are quite simple to implement within the current generation of GIS in the form of isolines or isochrones derived from network analysis. Resulting indices represent levels of service provision or choice within specific distance or travel time criteria (Wachs and Kumagai 1973).

Breheny (1978) illustrates measures of spatial opportunity in relation to planning decisions and facility location problems. He identifies two distinct categories of ‘opportunity’ measures: those incorporating attenuation assumptions (or behavioural functions such as distance decay), and those that do not. The first category effectively calculates measures with decreasing weightings over this restricted distance, which might be a 5km or 10km radius of a specific demand location. The second category of measures treats all locations within this distance or search radius as equally accessible.

The opportunity measure for a zone is calculated as the sum of opportunities available at other locations (j), and may be factored by a distance decay function based upon the distance of travel time between i and j as below. Further expanding on the k function in equation 1, the example adopts the frequently used negative exponential form of the distance decay parameter (Church and Marston 2003):

$$A_i = \sum_{j=1} O_j^{\;-\lambda t_{ij}} \tag{3}$$

Where:

A is accessibility index for zone *i*
O corresponds to the mass of opportunities at destination zone *j*
$-\lambda t_{ij}$ represents the deterrence (decay) function

3.4 Discussion

A variety of traditional measures incorporating distance and travel time have been implemented using the current generation of GIS and other spatial modelling tools (Miller and Wentz 2003). Census data are usually readily available and many of these measures and models are still regularly used in determining access to primary healthcare (e.g. Brabyn and Skelly 2003), the evaluation of access to public facilities (Truelove 1993), and transport modelling applications (Werner 1985, Shaw and Xin 2003). While traditional models have their purposes, they have significant limitations and there are several issues with using these models as the basis of policy decisions and evaluation:

1. *They commonly contain very limiting assumptions*. Many incorporate assumptions or gravity-type formulations whose parameters are derived from behavioural data (Breheny 1978). Most include 'attenuation assumptions' in the form of weightings reflecting preference or attractiveness criteria (Knox 1980, Pooler 1987). However, it should be noted that observed behaviour is already constrained by the nature of the transport system in which it takes place, including the relative distribution of facilities and opportunities, which may not reflect preference. As a consequence measures based on observed or predicated behaviour may include inequalities or phenomena which themselves derive from the current transport system, and they will relate more to demand for travel than access to services and activity locations (Breheny 1978).
2. *Many are highly aggregate*. They generally assume travel from a zone centroid, neglecting the distribution of activity sites within a zone. This also assumes that all individuals within the zone have the same set of opportunities, and that facilities, population and activities are equally distributed within a zone.
3. *Most have static notions of space, usually as distance between origins and destinations*. Traditional approaches treated accessibility as strictly a physical or spatial construct. Many use Euclidean space and use measures of distance, although other surrogates for 'distance' were adopted, such as travel times or costs. Time is frequently ignored or used as a generalised cost. These measures can provide useful statements about the general spatial distribution of 'reach' or separation, however they tell us relatively little about the actual role that distance (or in this case, travel time) plays in access to facilities, and the structure of people's activities in space and time. The net result of such studies often constitutes little more than an evaluation of the existing transport infrastructure.

To summarise, traditional notions of accessibility developed during a time when the structure and functions of cities were considerably different than they are today, and at a time in which computing power was relatively less ubiquitous and sophisticated, and detailed data sets were not widely available. In general, these models and measures neglect the role of time, dynamics, and the influence of activity patterns (Pirie 1979, Werner 1985, Huisman and Forer 1998), however they remain as key inputs into policy decisions in fields such as transportation analysis (Robinson 1977, Pooler 1995) healthcare (Guagliardo and Roznio 2004), and analyses of spatial equity (Knox 1980, Truelove 1993).

4 ACCESSIBILTY AND HUMAN ACTIVITIES

4.1 Human activities

People are 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.

The literature shows that these activities and behaviours are shaped by a variety of forces: *opportunity* and *constraint* (Hagerstrand 1970), *choice* (Chapin 1974; 1978), *perception* (Golledge and Stimson 1997), and *routine* (Janelle et al., 1988). More generally however, since the 1970's, academics have recognised that human activities are a part of broader, dynamic processes unfolding in space and time. In practice, people's ability to interact with their environment and to utilise urban services and amenities can only take place through a careful trading of space and time to create the sequences of activities that will meet their needs. Pirie (1979: 308) has defined accessibility as:

> *"…a condition (a vacancy) in an activity routine which, either deliberately created or formed as a residual, permits travel to and from and participation in one or more activities".*

This definition suggests that accessibility and processes involving a person's activities are considerably more complex than the aggregate concept as which it is frequently conceptualised. It hints at issues of individual and household activity scheduling, and suggests that the ability to utilise services and facilities and to interact with others in their environment results from either scheduled activities or by discretionary time (Stephens 1976, Pirie 1979). These tasks are also constrained within a regime of necessary and competing personal activities, which are in turn mediated by mobility factors and transportation options (Chapin 1974, Forer 1979).

Changing research methodologies, new and better tools for modelling human processes, and the growing recognition that the adequate functioning of urban areas depends upon the scheduling of activities, services and facilities which people require have resulted in a new generation of access measures and models, known collectively as 'space-time approaches' (Mey and ter Heide 1997). Toolsets include GIS and other spatial modelling packages, and techniques are drawn from a range of fields including computer science and transportation (Batty et al 2003).

4.2 'Space-Time' approaches

Space-time approaches view all human activities as taking place in time as well as space. Moreover, people's activities are intimately linked to their spatial and temporal settings, since they are performed at specific locations, at specific times of the day, and for a given duration. Although not conceived of as an accessibility measure by Hagerstrand, the field of Time Geography, which developed from his seminal work (Hagerstrand 1970), has provided a better understanding of 'real' access (Lenntorp 1978, Miller 1991, Handy and Niemeier 1997, Huisman and Forer 1998). The Time-Geographic Framework offers the potential to integrate the spatial and temporal components of people's daily lives. 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 could include such inflexible options as having to be at work at a given time or attending an important appointment). Essentially, these fixed activities impose constraints upon an individual's activity pattern. 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.

To illustrate this, Figure 1(a) shows two activities and their spatial locations, A and B. Time is on the vertical axis and space on the horizontal. For the purposes of clarity the diagram only shows one dimension of space. In (b), the 'gap' between the fixed activities, known as the 'time budget', is in fact a *space-time* budget which also delineates which areas can be reached within a specific time period. Time budgets translate into a prism shape based the fact that traveling 'out' in a certain direction is limited by the ability to get back to the location of the next marker or activity on time.

As Figure 1(b) illustrates, 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 it's 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 is constant or not. In (b), we can note the relative hypothetical area of the prisms for both car travel and walking.

The prism provides the space-time 'boundary' for travel and stay in a given place. Figure 1(c) translates the area of the prism into meaningful activity durations at two locations ***T1-T2*** at location B and ***T3-T4*** at location C. Essentially, the geometry of the prism dictates the specific duration of time which can be spent at particular locations. Figure 1(d) shows an example of the alteration of a marker episode. The timing of an existing scheduled activity has changed from ***T2*** to ***T3***, and there is a consequent change in the prism area (reflected in accessibility). In three dimensions, the prism models the volume of space accessible to an individual during this episode of time (Huisman and Forer 1998; Huisman 2005). As noted by Miller (1991, p.288):

> *"The prism models the accessibility of an individual within a particular spatial and temporal context and can provide a valuable measure of individual accessibility."*

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 (Dijst 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).

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. 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 (also known as *revealed access)* can only occur within action spaces, through the mechanisms of individual perceptions and cognitive filters. We can visualise this in the form of a diagram (Figure 2).

It is difficult, both conceptually and operationally, to move 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 (Golledge and Stimson 1997). Instead of predicting behaviour, the set of opportunities can be modelled using time budget data derived from survey information, or by specifying a particular threshold value.

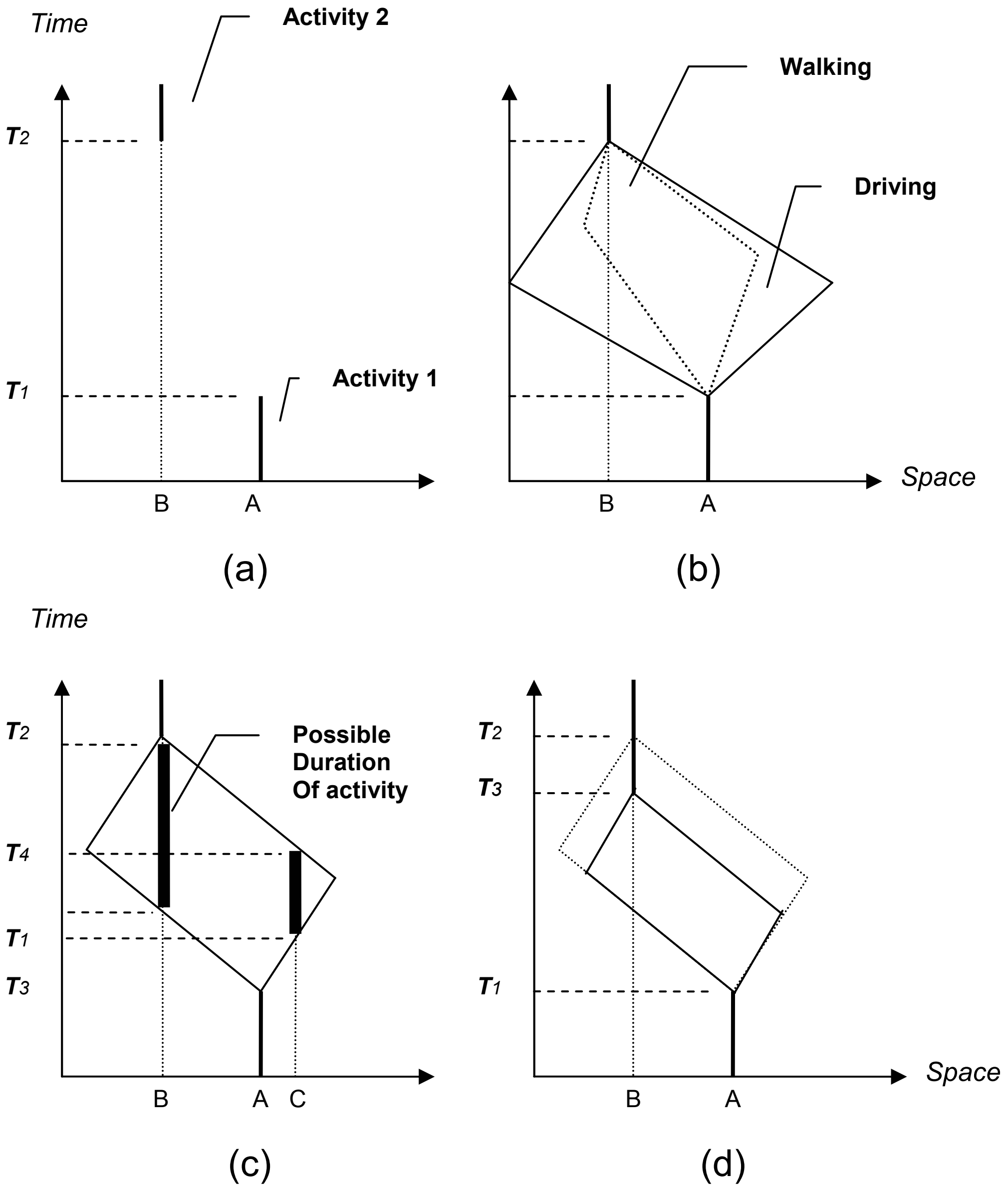
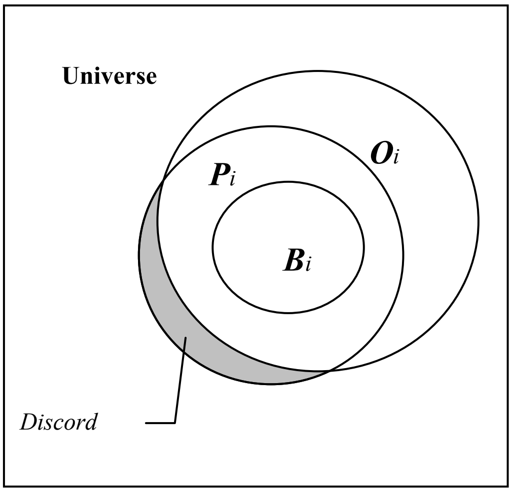


Figure 1: Activities, space-time prisms and accessibility
Source: Huisman (2005)



U represents the physical universe (the finite set of opportunities which exist).

O*i* represents the total action space (opportunities) available to individual ***i*** with a given time budget and travel mode.

P*i* represents the perceived set of opportunities available within the action space for individual ***i***.

B*i* represents observed behaviour or activity pattern for individual ***i***.

Figure 2: Opportunities, perceptions and behaviour as a nested hierarchy
Source: After Johnston (1976).

4.3 Related Components of accessibility

4.3.1 Mode availability

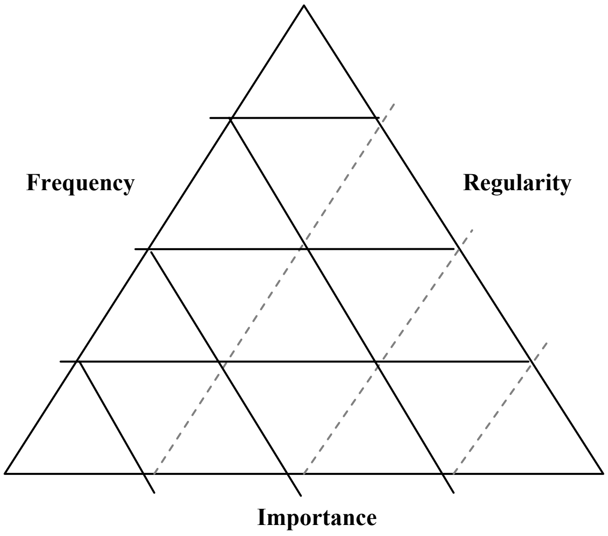
Transportation modes are a fundamental component of access and mobility. Transport technologies play a key role in both mobility and the cost of travel. Specifically, faster transportation modes allow us to trade off *less* time for *more* space. Currently, the conditions underlying people's daily lives are undergoing both revolutionary and fundamental transformations due to the emergence of new information technologies and concomitant improvements in transportation systems (Forer and Huisman 2000, Couclelis and Getis 2000, Hjorthol 2002). Forer and Kivell (1981) examine space-time accessibility for the urban house-spouse in Christchurch, illustrating the role of public transport in mediating access to public facilities. Other studies have also focussed on public transport, including work by O'Sullivan et al. (2000) on evaluation of multimodal accessibility using isochrones.

4.3.2 Motivation and need to travel

Black et al., (1982: 1358) note that "Urban activities are the outcome of individual propensity and opportunity to participate". These motivational forces (propensity) are conditioned by a variety of individual-level factors such as life-style, attitudes, age and income. Related work on Activity-based Approaches to travel analysis (also known as Activity-Analysis or AA), conceives travel as a means to engage in necessary activities outside the home (Ettema and Timmermans 1997).

These approaches derive from early work by Chapin (1974) on activities and activity choices. However, they generally focus upon travel as a derived demand (Wang and Cheng 2001). Many activities are not always necessary, and are likely to vary significantly in their relative importance to a household, not to mention between different household types. Related work by Jones et al., (1985) used game-theory to simulate intra-household scheduling and decision processes. These were then used to formulate a simulation model known as the Household Activity Travel Simulator (HATS).

Figure 3
Classification of nature of activities



As noted in the literature, human activities range in importance from the purely discretionary to the absolutely essential. Moreover, the importance of certain activities is likely to vary considerably for different individuals. It has been noted that many activities (those occurring on a daily basis) are routinised (Stephens 1976). The pyramid diagram (Figure 3) illustrates this in terms of a threefold classification of the nature of human activities. These range from discretionary trips taken during a weekend, to regular, repetitive journeys such as the home-work trip.

4.3.3 Distance, and time and cost

Knox (1980: 368) has noted that : “it is evident that the costs – physical, financial or temporal – of overcoming distance to get to shops, jobs, and other ‘facilities’ can bring about quite substantial redistributions of the real income of residents of different parts of a city.” Measures of spatial separation of individuals and activities which underlie all ‘spatial’ models of accessibility include:

- Euclidean distance
- Network distance or topological distance
- Network travel time (constant speed, single mode)
- Dynamic network travel times (single mode)
- Dynamic, multi-modal network travel times

These can be implemented with varying degrees of sophistication in a GIS environment, subject to available data on traffic flows, bus routes, timetables, and estimates of intersection delays.

Studies using cumulative opportunity-based measures have generally focussed on a set of generally applicable facilities or activity locations, and assessed the total cost of accessing the nearest of each type (de Jong and Ritsema van Eck 2001), in terms of either Euclidean distance or travel time, or have adopted a fixed travel time budget in order to illustrate variations in other variables as a consequence of changes in mobility (Forer and Kivell 1981) or changes in scheduling (Forer and Huisman 2000, Recker et al 2001).

4.4 GIS and simulation models

New simulation tools and GIS techniques allow us to build models of real-world phenomena based on limited data sets. ‘Simulation models’ generate outcomes based upon certain inputs, and a set of rules about the ways in which the inputs are modified or influenced by some specific factor or variable. Recent years have seen the emergence of substantial work on the aggregate consequences of individual actions using simulation models (Conte and Gilbert 1995; Batty et al. 2003). One main advantage of these models is that these provide a way to circumvent the lack of detailed data on activities which plagues activity-based research, using a range of techniques such as stochastic (probability-based) or deterministic (rule-based) model parameters (Portugali and Benenson 1997).

Agent-based models (ABM) are a subset of the field known as multi-agent systems (MAS). Essentially these are simulations based on the aggregate consequences of micro-level interactions of sample populations. Broadly speaking, multi-agent systems are explicitly defined systems of interacting, and even ‘learning’ agents. The generic name for small scale (individual based) simulation is *micro-simulation.* Agents in this type of simulation could represent humans, vehicles in traffic, or a flock of pigeons. Models typically consist of a simulated environment and a set of procedural rules and parameters describing the set of possibilities and constraints (Dibble 1996). Microsimulation has the potential to provide us with an ongoing test-bed for the modelling and analysis of human processes, albeit at the abstract level, through calibrating models with data collected from surveys or other databases.

In terms of human processes, simulation models can be used to derive plausible choice sets derived from individual models, and to simulate choices from those sets (Ben-Akiva and Bowman 1998). Examples include the STARCHILD and MASTIC activity-based models (Dijst 1995; Dijst and Vidakovic 1997), and work by Janssens et al. (2004), that attempts to simulate complex human decisions relating to activity scheduling, choices, and travel behaviour. These are very attractive approaches for implementing micro-models with sparse data. These can be used as direct inputs into planning and policy assessment (Veldhuizen et al 2000).

5 OPERATIONAL DEFINITION AND MEASURE

5.1 Definition

While Pirie's (1979) definition of accessibility provides a useful conceptualisation, as noted in Section 1 the operational definition must reflect the intended application. In the current context, we need a quantitative model which can be used to assess variations (changes) in accessibility induced by strategies used to reduce fuel consumption, but which can be implemented independent of these strategies. The previous section has illustrated that the *Space-Time Prism* (STP) as defined by time budgets provides a behaviour-independent operational construct which has been used in measuring access in a number of GIS-based models. Implementation of this construct is not a simple translation from conceptual discussions above, and will be based on earlier work by the author and others (Huisman and Forer 1998, Forer and Huisman 2000).

Table 1 below illustrates three broad categories for the implementation of a household-level model of accessibility. Level 1 is a model based on the concept of reach. This type of model excludes contextual factors and demographic information such as household types, mode availability, and time budgets. Level 2 is a model of 'opportunities' based on the STP which fits within a dynamic, household-level formulation of Breheny's (1978) *spatial opportunity* concept. This can be modelled using GIS as action spaces. Level 3 seeks to derive key information from observed 'behaviour', using regression techniques to identify correlations between behavioural variables, which can subsequently be used as parameters for a simulation model. This is the most detailed, but as noted, most problematic approach.

The transition between these 'levels' of operational model is one of increasing complexity from (1) to (3). As noted, the difficulty with incorporating observed behaviour is that these are already the result of intra-household scheduling and individual preferences (Ettema and Timmermans 1997). While it is noted that activity-based research and behavioural modelling techniques have made significant progress since the 1970s, for the purposes of the current research these are deemed unsuitable for the reasons outlined above.

5.2 Measure

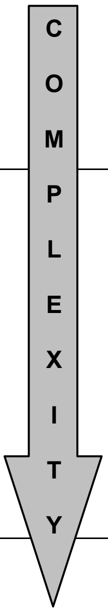
In the context of the current research, Level 2 an appropriate level of analysis at which the model will operate. Here the household is deemed as the appropriate unit of analysis (Williams 1989, Recker et al. 2001). The operational measure will be derived from the cumulative opportunities available to a household within specified or derived time budgets, represented as some function of the travel time and time available at a range of facilities and activity locations. The likely set of these which will be included in the model are:

- Educational
- Shopping
- Recreational
- Health
- Social
- Cultural

Table 1:

Options for household-level operational model

LEVEL 1	**"*Pure*" access model** (REACH) ▪ Fixed time budget ▪ Fixed mode ▪ Fixed activities
LEVEL 2	**"*Microsimulation*" model** (SPATIAL OPPORTUNITY AND CHOICE) ▪ Travel time based ▪ Fixed or calibrated mode availability ▪ Extensions: Calibrate with collected data - Frequency of use - Destination weightings - Household classification - Mode-dependent trips - Choice sets
LEVEL 3	**"*Behavioural*" model** (REVEALED ACCESS) ▪ Actual activities/trips ▪ Observed mode choice ▪ Observed time budgets ▪ Preference variables derived from actual trips



Using STPs and GIS-based techniques developed by the author (Huisman and Forer 1998; Huisman 2005) it is possible to derive remaining time available at a range of activity locations within a given time budget. This model will attempt to incorporate data from the Land Transport New Zealand (LTNZ) *Travel Survey* on household locations, and mode availability. It will attempt to incorporate multi-modal transportation options in the form of a GIS-based model of transport network for both public and private travel options, and incorporate rule-based techniques for simulating key components of accessibility (Vause 1997). These can be calibrated with LTNZ data such as mode choice for various types of trips, time budgets, and other indices derived from Objectives 1 and 2. The access index will be derived from an iterative simulation model which explicitly models travel mode for each activity. In general terms this model may be given as:

$$A_{ih} = \sum_{a} \sum_{j} O_{ja} T_{ijm} \tag{4}$$

Where:

A is the accessibility for a household at location i
h represents a household type
a represents a set of activities
T represents the travel time separating locations i and j
m represents the travel mode
O represents the opportunities (activities) available with mode

This household-level index can be aggregated to meshblock, area unit, or other spatial demarcation, using standard GIS point-in-polygon type queries or raster-based analyses using Map Algebra (Tomlin 1990), and may be 'grouped' or segmented by a range of variables including transport mode, household type and/or types of activities in order to examine accessibility in a relative form.

5.3 Discussion

The aim of the simulation model is to derive meaningful statements about what can be accessed for meaningful periods of time, and by a range of transport modes under various fuel consumption scenarios. It is important to note that this model does not aim to simulate activity choice or travel behaviour. Instead it seeks to describe the *range of choices* afforded to a household by specific modes of transport, a given time budget, and a dynamic transport system. Outputs will represent a robust and 'extendable' set of indicators which will provide a quantitative assessment of the impact of fuel reduction strategies for specific household groups. This will illustrate relative levels of accessibility for specific households, and potential changes in these levels as a response to policy changes, whether these are in the form of increased petrol costs, incentives to use alternative transport, or encouraging more efficient vehicles.

The model will be employed to examine the impacts of fuel reduction strategies through introducing changes in travel modes for specific trips, such as increased public transport use for discretionary travel, or other potential outcomes from fuel-reduction strategies. Utilising a space-time model will enable the examination of fluctuations in functional choice for households in terms of time available at the destination over space, and in response to potential mode shifts. This can be examined in relation to actual time spent on travel and activity participation by each household from New Zealand Travel Survey data.

5.4 Extensions

Table 1 illustrates several potential extensions to the Level 2 model. In the main these involve of calibrating the simulation model with collected data. Segmentation of activity types (destination/facility types and mode of travel) is as avenue worth investigating, as this might assist in translating 'pure' opportunities into likelihood of utilising them, providing a more 'realistic' measure of opportunity and choice. E.g.:

$$A_{ih} = \sum_{a} f_{ah} \sum_{j} O_{ja} T_{ijm} \tag{5}$$

Where:

fah is a set of weightings for an activity set *a* for household type *h*

These extensions can be incorporated through integrating weightings derived from key outputs from Objectives 1 and 2, and data from the New Zealand Travel Survey (LTSA 2004) (see equation 5). The degree to which these indices and variables from the LTSA survey and other key objectives can be incorporated within the proposed model will depend on their applicability for the task, and will be reviewed upon final collection.

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