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1 INTRODUCTION

Within transport planning, accessibility is generally defined as the ease with which people from specific locations can travel to participate in activities using a mode of transport. The problem with most measures of accessibility is that they lack the capability to evaluate the impacts of transport policies that can directly influence travel decisions.

There is a need for measures of accessibility to be more sensitive to transport policies. This paper will discuss a framework to develop a measure of accessibility that not only takes into consideration the travel behaviour of individuals but also other factors that are sensitive to transport planning policies. Such a measure will provide a valuable tool for transport planners to evaluate physical improvements to road networks and to evaluate and compare policies in terms of their relative cost of implementation, usefulness, efficiency and effectiveness.

The framework focuses around travel information collected through travel diaries that indicate the travel patterns of individuals within households. Discussion will incorporate how such information can be used to develop behavioural models that reflect travel decisions by individuals. Traditionally, accessibility measures have been developed and used for inclusion in travel demand and land-use/transport models. The framework discussed in this paper in many respects follows the framework used for travel demand models however rather than determining trip frequency, the focus is on determining the ease or benefit people obtain from the travel choices they make. An example of a simplified form of the framework is also presented and discussed.

2 DEFINING ACCESSIBILITY

Beyond the above definition generalised in transport terms, there are many more specific definitions reflecting different views and perceptions of the concept. Given the above definition, the connection and importance accessibility has within transport and urban planning will now be demonstrated.

The structure and characteristics of a transport network directly affects accessibility within that network. Accessibility is suited for indicating the usefulness, effectiveness and efficiency of a transport network for all modal types.

Furthermore, accessibility is one of the most important factors considered within the location choice decision process shaping land-use patterns (Martinez, 2000; Ortuzar et al, 2000; Wegener, 1996). For example, people base their decisions of where to reside (or locate their business) on the ease of accessing the services (or clientele) they desire. Accessibility is a function of land-use patterns and of the transport system (Morris et al, 1979) making it useful in the planning and development of policies associated with transport networks and in determining land-use configurations within the urban space. Therefore, accessibility provides a connection between the transport network and land use to determine the effects each has upon the other.

From the above discussion of accessibility within the framework of transport/land-use modelling, the simple definition of accessibility given in the introduction can be expanded to being the *ease* with which *people* from specific locations can travel to participate in *activities* at a *destination* using a *mode* of transport at a specific *time*. The *ease* of participation in activities is what is determined to give accessibility and refers to any benefits or costs associated with travel. Such benefits and costs may be monetary, temporal and related to convenience and comfort to name a few.

The definition of *ease* acknowledges the variation in characteristics and socio-economics of individuals, influencing activity and travel choices they make that impact their accessibility. Accessibility will vary according to a combination of activity, location, mode, and time choices made. Furthermore, people place different priorities on different activities according to their own situation. As an example, a full-time worker is likely to place a higher priority on work trips than a person who is semi-retired though the latter may place a higher priority on social/recreation type activities. Not only does the importance placed on activities vary but certain costs and benefits associated with choices will vary between individuals. For example a high-income earner may place higher importance on time and less importance on money than compared to a low-income earner.

Activities include work, education, shopping, social and recreation where accessibility will be different for all these activity types because of their location and their importance to the individual. Activities not only vary due to the importance placed upon them but also by their availability and their nature. In developing activity-based models, Bowman and Ben-Akiva (2001) based travel patterns around primary trip purposes. Reflecting the importance of different trip purposes in gravity-based accessibility measures has also been done, where the exponent part of the cost component was assigned different values according to the trip purpose (Hansen, 1959).

Properties of destinations will vary in location, size, the properties of nearby locations, and provisions for various transport modes.

Each transport mode varies according to costs, benefits and perceptions. Obvious differences among modes are travel speeds and waiting times. Furthermore, different modes of motorised transport exhibit different properties such as operating to fixed timetables and/or locations.

The availability of activities, the attractiveness of areas, and the state of the transport system will vary throughout different times of the day and throughout different days of the week. Activities that operate during specific periods of the day will only be accessible during those periods. If a person is participating in an activity of high priority, then any activity of lower priority during that same time period may be available but no matter how spatially close the activity may be to the individual, the activity of lower priority is not accessible.

To summarise, accessibility is more than just overcoming spatial separation between locations. It also acknowledges the differences between individuals for whom the measure is calculated, the activities to which individuals need access, the properties of the locations of activities, the modes of transport that overcome the separation between individuals and activities, and importantly, but often neglected, the effects of time on accessibility.

3 TRANSPORT AND URBAN PLANNING

This section investigates transport and urban planning in the context of accessibility. It will discuss how improvements in the transport system and smarter planning in terms of land-use allocation can be made to improve accessibility. Since accessibility is a function of both the performance of the transport system and the land-use patterns (Morris et al, 1979), the methods used to improve both components of the urban space will be discussed.

3.1 IMPROVING THE TRANSPORT SYSTEM

Transport systems around the world are continuously under review and improved to cater for the increasing demands imposed upon them. A common method chosen is to enhance infrastructures in the way of building roads, bridges, or even infrastructure to support other modes of public transport such as rail. The most significant limitations when using this method is the spatial constraints, particularly in highly populated cities.

An alternative method for improving transport systems is the use of Intelligent Transport Systems (ITS). The purpose of ITS is to better utilise the current infrastructure through the deployment of the latest technologies. ITS includes the deployment of technology to: improve travel demand management; provide information to drivers via in-vehicle navigation systems and variable message signs; or to enhance the efficiency of traffic systems such as public transport.

3.2 ROAD PRICING

Road pricing adopts the principle that road users pay for parts of the transport network they use. Benefits associated with the deployment of road pricing strategies, include (Sturt and Bull, 1993):
demand for use of roads by private vehicle can be reduced with the introduction of, and the increase of the price of road usage;
efficiently allocate road space to different classes of road users using various pricing schemes; and
distribute traffic over different times of the day by varying the price between peak and off peak times.
Another benefit of road pricing is that it can promote more efficient travel by households where members make more ride sharing trips and combine trips into trip chains. These benefits aim to reduce congestion on transport networks either by reducing or effectively distributing traffic on a transport network.

A reduction in congestion along transport networks may reduce travel times, leading to improved accessibility. However, road pricing can also increase the cost of accessing activities thus having the potential to negatively impact accessibility.

3.3 SMARTER PLANNING

Accessibility can be improved within a city by regulating or influencing efficient land-use. For example, in the Netherlands a system was developed and implemented where mobility profiles (one of three classifications A, B or C) are assigned to businesses reflecting the type of traffic, namely private vehicle or public transport that the business generates. Accessibility profiles are also assigned to various locations. Again three classifications (A, B and C) are used to reflect the type of transport (private and public) that is more accessible (or possibly they wish to be accessible). Once classified, businesses are matched with the best location according to their mobility and accessibility profiles, respectively. The aim of the policy is to locate land-uses (businesses) of high trip intensity to areas of high accessibility via public transport ('A' class locations), land-uses that produce a moderate number of trips to locations of moderate levels of accessibility via both private and public transport ('B' class locations), and freight transport related businesses where accessibility via public transport is not important into locations of low accessibility, ie accessible by private vehicle more than public transport ('C' class locations) (Sturt and Bull, 1993).

The London Planning Advisory Committee are also attempting to use a similar method to the A-B-C planning by assigning Public Transport Accessibility Level (PTAL) to areas. The primary aim is to encourage developers into areas that are well serviced by public transport. In the case where a developer wishes to build in an area poorly serviced by public transport, the developer must fully fund improvements to the local public transport to improve the area's PTAL (Sturt and Bull, 1993).

The land-use policies discussed above promote efficient land-use, creating more 'spatially efficient' cities. An alternate method for creating more 'spatially efficient' cities is to make cities more 'compact'. It has been shown that urban density needs to be at least 30 to 40 people per hectare to draw people to the streets and support reasonable levels of transit services (Cervero, 1997).

In addition, the aesthetics of a city is very important in order to promote activity within a city and encourage other forms of non-motorised mobility. 'New Urbanism' looks at a finer detail of what makes a neighbourhood more enjoyable with street patterns suited for pedestrians, open spaces, civic spaces, commercial cores within walking distance of most residents, and aesthetics (Cervero, 1997).

4 REVIEW OF ACCESSIBILITY MEASURES

A significant amount of research focuses on advancing the methods used for calculating accessibility and how to identify and encourage its use in transport and urban planning. There are two possible directions with respect to calculating accessibility measures (Morris et al, 1979): one where the measure is *supply* based, or a measure that also contains a contextual component representing *demand*.

Supply-based measures of accessibility measure the accessibility to opportunities based solely on the properties of the physical transport and traffic system. As an example, one may calculate the accessibility from one location to another based on the travel distance and time between locations, parking availability and the size of the opportunity at the destination. A measure with a contextual component however includes non-physical characteristics of the urban system such as the population in regard to travel behaviour and the choices of travellers.

There are a number of methods used for calculating accessibility. The primary objective below is to review accessibility measures with a particular emphasis on composite measures of separation. Both supply-based measures as well as the combined supply-demand measures will be reviewed.

4.1 TOPOLOGICAL

Topological accessibility, also referred to as *geometric accessibility*, is defined as the 'nearness' or 'propinquity' between geographic locations (Jiang et al, 1999). Topological measures traditionally refer to accessibility as being the number of links connecting one vertex to another in a connected graph (Pirie, 1979). The fewer links required, the more accessible the vertex is within the network.

A number of topological measures exist based on deriving shortest path matrices that indicate the shortest number of links required to be passed to reach another vertex (Briggs, 1972). The topological measures can also be calculated using travel distances and travel times of the transport network. Ingram advanced the Shimbel index (indicates the minimum number of links required to be passed to visit all vertices) by defining a function for travel distance rather than simply using travel distance alone. The preference of closer locations can be represented and show the decrease in attraction of locations as the intervening distance increases (Ingram, 1971).

Topological measures have been further developed for the desktop environments of Geographic Information Systems (GIS) to enhance proprietary GIS products that do not support such accessibility measures (Jiang et al, 1999).

4.2 SPACE-TIME FRAMEWORK

The Space-Time framework is a concept first developed by Hagerstrand (1970) that introduces the constraints of time with space to determine the behavioural possibilities of an individual (Miller, 1991). Space-Time prisms are three-dimensional objects with an x-y plane representing space and a z-coordinate representing time.

The space-time framework makes the following assumptions (Miller, 1991):
events undertaken by an individual have a spatial and temporal component; and
individuals can only experience or participate in activities at a single location in space at a single point in time.

The basic data requirements for the space-time framework are: time available for activities; distance between relevant locations; and velocities of travel between locations (Miller, 1991). Data representing constraints of space and time on people can also be used to determine the availability of activities to people (Jones, 1981).

Jones identified two approaches for determining space-time prisms: *sequential* and *non-sequential*. Both approaches consider the spatial and temporal options available to a person. The sequential approach considers activities sequentially whereas the non-sequential approach only partially considers activities sequentially. Therefore the non-sequential approach does not take into account that the participation in one activity may prevent participation in another (Jones, 1981).

Lenntorp was one of the first to operationalise the space-time framework through the development of PESASP (Program Evaluating the Set of Alternative Sample Paths). The PESASP model estimates the total number of space-time paths an individual could follow considering the set of activities and their durations, the transport network and the distribution of activities (Recker et al, 2001).

The space-time framework was further developed to consider the transport system so that only relevant areas that could be reached are considered. This approach was used for faster calculations and enabled ease of implementation within a GIS (Miller, 1991).

4.3 POTENTIAL ACCESSIBILITY

Potential accessibility defines accessibility as (Hansen, 1959):
"the *potential* of opportunities for interaction" and "is a measure of the *intensity of the possibility of interaction*".

The potential accessibility measure is derived from the singly-constrained gravity-based model used in travel demand models. An analogy is made between the gravity-based model and Newton's Law of Universal Gravitation where, in brief, the force between two bodies is proportional to their masses and inversely proportional to their separation. In analogy with transport, the number of trips made between two locations is proportional to their sizes and inversely proportional to their distance apart. This analogy was originally derived by Hansen where he discussed a simple land-use model based on accessibility to determine development and population growth in a region based on employment and travel times (Hansen, 1959).

Wilson (1967) was first to deduce that accessibility and attractiveness could be derived from the doubly-constrained gravity model used for calculating trip distribution in travel demand models. Let T_{ij} be the number of trips from zone *i* to *j*, O_i and D_j the size of the relevant attributes (such as population, jobs, shops) at the origin *i* and destination *j* respectively, and $f(C_{ij})$ a function of the cost of travelling from *i* to *j.* The trip distribution function derived from a doubly-constrained gravity model is

$$T_{ij} = A_i B_j O_i D_j f\left(C_{ij}\right) \qquad \textbf{Equation 1}$$

where

$$A_i = \left[\sum_j B_j D_j f\left(C_{ij}\right)\right]^{-1} \text{ and } B_j = \left[\sum_i A_i O_i f\left(C_{ij}\right)\right]^{-1}.$$

Wilson examined the properties of this formulation and deduced that the denominator of A_i is a measure of accessibility and the denominator of B_j is a measure of attraction. This is further discussed by Martinez (1995) who described an economic framework, which combines both accessibility and attractiveness from a trip distribution model into a single measure called *access*.

One early criticism of the gravity model was that it was not scientifically based. Wilson used entropy maximisation theory to derive the gravity model. The benefit of this derivation of the gravity model was it gave a scientific basis to the gravity model, allowing for a direct comparison of the derivations of other methods to compare assumptions, and also to be able to derive a negative exponential function for generalised cost (Wilson, 1967).

Weibull (1976) formulated a measure of accessibility by first specifying the desirable properties for the measure and then deriving the measure from these properties. Six axioms were defined, which were used to establish the mathematical form of the measure. The mathematical form derived and used to represent accessibility to jobs in Stockholm was

$$A_i = \sum_{j=1}^{n} f\left(d_{ij}\right).\frac{D_j}{e_j}$$ **Equation 2**

where A_i is accessibility, $f(d_{ij})$ is the distance function, D_j is the opportunities in zone j and e_j is the demand potential formulated (in the travel to work case by two possible modes of transport) as

$$e_j = \sum_{k=1}^{n} \left[p_1\left(d_{kj}^1\right).h_k^1 + p_2\left(d_{kj}^2\right).h_k^2\right].$$ **Equation 3**

The above formulation of accessibility is similar to the Hansen measure except it is divided by the demand potential for the zone representing the demand side of the measure (Weibull, 1976).

4.4 BEHAVIOURAL UTILITY

Behavioural utility is based on the assumption that individuals are rational entities and will make choices based on maximising their own satisfaction or in the case of choice modelling, maximising utility. The foundation of choice modelling is that there exists observable influences or attributes and there are those that are unobserved by the researcher.

The utility of an alternative is derived from the observable attributes weighted by their contribution to represent their influence on the choice. The unobserved attributes are considered to be random variables on the real line that are estimated from a distribution representing the sampled population. Given that the utility of an alternative is a best estimate due to the random component, the results are probabilistic rather than deterministic, giving the likelihood of one alternative being chosen from all others.

A measure of accessibility can be derived from the derivation of marginal choice probabilities in logit models of multidimensional choice (Ben-Akiva and Lerman 1985). This measure of accessibility, which is also called the *inclusive value* or *logsum*, has the form

$$V_n^{'} = \ln \sum_{i \in C_n} e^{V_{in}}$$ **Equation 4**

where $V_n^{'}$ is the systematic component of the maximum utility for an individual n and V_{in} is the systematic component of each secondary choice i in the set of choices C_n. This measure represents in a single value the benefit an individual obtains from a set of alternatives. As an example, in a joint modal-destination choice this measure of accessibility will give for each mode of travel a value of its worth by considering the utility derived by an individual for every destination that mode does or can visit.

It has been proven that the logsum measure satisfies the following two properties (Ben-Akiva and Lerman, 1985):
Monotonicity with respect to choice set size, which means that an individual will be no worse off with any additional choices; and

Monotonicity with respect to the systematic utilities, which means that if the utility of any of the alternatives increases then accessibility will not decrease.

An issue with the logsum technique is that there are no units associated with the value making it difficult to interpret. Furthermore, the logsum value derived is only useful to that model and cannot be compared to values derived from any other model. Because of this, when using values derived from the logsum, one must take care to define the model specifications before interpreting the accessibility measures (Ben-Akiva and Lerman, 1985).

4.5 ECONOMIC BASED

An economics-based measure, called *Consumer Surplus* uses economic rationality and theory to determine accessibility. Consumer surplus is used to quantify the benefits derived from changes in travel costs. It is formulated by determining the change in demand (travel) given a movement in price along a demand curve.

A method introduced in the London Transport Study to estimate the change in consumer surplus is the rule-of-a-half method, which is formulated as (Williams, 1976)

$$\Delta S_{ij} = \frac{\left(T_{ij}^{0} + T_{ij}^{1}\right)}{2}\left(C_{ij}^{0} - C_{ij}^{1}\right) \qquad \textbf{Equation 5}$$

Neuberger (1971) formulated the consumer surplus by taking the integral of demand for trips with respect to cost over a cost change c^0 to c^1 for travel from i to j

$$\Delta S_{ij} = -\int_{c_{ij}^{0}}^{c_{ij}^{1}} D(c)\,dc_{ij} \qquad \textbf{Equation 6}$$

This formula allows for the demand function to be non-linear giving an exact estimate of consumer surplus. The demand function used was the singly-constrained gravity model. Williams extended this further by using the doubly-constrained gravity model.

For the single-constraint case and using the negative exponential cost function given changes in cost from c^0 to c^1, change in consumer surplus becomes (Jones, 1981)

$$\Delta S = -\frac{1}{b}\sum_{i=1..n}\left[O_i \ln\left(\sum_{j=1..n} B_j e^{-bc_{ij}^{1}}\right) - O_i \ln\left(\sum_{j=1..n} B_j e^{-bc_{ij}^{0}}\right)\right] \qquad \textbf{Equation 7}$$

which becomes

$$\Delta S = \frac{1}{b}\sum_{i=1..n} O_i \ln\left(\frac{A_i^{0}}{A_i^{1}}\right) \qquad \textbf{Equation 8}$$

or in the double-constraint case

$$\Delta S = \frac{1}{b}\left[\sum_{i=1..n} O_i \ln\left(\frac{A_i^{0}}{A_i^{1}}\right) + \sum_{j=1..n} D_j \ln\left(\frac{B_j^{0}}{B_j^{1}}\right)\right] \qquad \textbf{Equation 9}$$

where A_i is accessibility at the origin and B_j is the attraction of the destination. Considering this formulation, consumer surplus can be thought of as the change in the natural logarithm of accessibility. Furthermore, the consumer surplus has a similar form to Equation 4, which should be expected since the distribution of cost decay according to distance in the gravity model is the same distribution used in logit models.

Work on consumer surplus was further refined by Martinez where access is made up of accessibility (defined as the benefit obtained from visiting activities) and an attractiveness component (which is the benefit obtained from being visited). Based on the assumption

> "households and firms are rational entities which maximize net benefit under available information",

Martinez explains, in an economic context, how variations in the transport system and variations in the land-use may affect accessibility and attractiveness of two locations relative to each other. Two scenarios are examined by Martinez; a short-run case whereby land-use does not change in response to transport changes, and a long-run case whereby the transport system and land-use can both vary. A framework was constructed to determine consumer surplus for both scenarios (Martinez, 1995). Work by Williams was further extended to determine consumer surplus by relaxing the assumption that land-use is fixed, giving the following pseudo-rule-of-a-half (Martinez, 2000)

$$\Delta S = \frac{1}{b}\left[\sum_i \left(\frac{O_i^0 + O_i^1}{2}\right)\ln\left(\frac{A_i^0}{A_i^1}\right) + \sum_j \left(\frac{D_j^0 + D_j^1}{2}\right)\ln\left(\frac{B_j^0}{B_j^1}\right) + \left(T^0 - T^1\right)\right]. \quad \textbf{Equation 10}$$

5 CONCEPTUAL FRAMEWORK

From the review of accessibility measures in the previous section, it is evident that accessibility is dependent on three components, namely the:
Traveller (individual or group);
Transport system (mode, roads and traffic characteristics); and
Land-use (characteristics of land-uses at origins and destinations).

Accessibility measures are commonly trip-based in that they consider the accessibility from one location to another. Although the trip-based concept is important and useful in transport planning, there is also a need for an activity-based measure of accessibility that focuses on accessibility of people to activities.

The more advanced measures such as the gravity-based measure include characteristics of locations of activities that make them more attractive for visitors, however the properties of the activity itself and the importance of that activity to the individual also needs consideration.

One way of looking at accessibility is that if there is no individual then there is no need for accessibility. Since accessibility is for the individual, then the characteristics of that individual should be considered in determining any measure of accessibility. The behavioural-based measures consider the individual, however most measures only do so as a by-product of a travel demand model and so are very limited in what they can be used for in transport and urban planning. The behavioural-based measures provide a technique that can allow for the determination of the influence of factors on accessibility and also allow for measures of accessibility to be dissected to enable the various components of accessibility to be analysed. Such a measure of accessibility allows the transport or urban planner to have the ability to determine what is affecting accessibility in specific areas and test policies that may remedy the problem.

The time-space prism concept is useful in accessibility as it considers both spatial and temporal separation. This is a step forward in terms of determining what is realistically accessible to an individual however it still lacks the behavioural foundations and does not fully consider characteristics of activities at locations.

The types of measures of accessibility discussed above all have their strengths and their weaknesses. It appears that the weakness of one type of measure may in fact be the strength of another. The accessibility framework in this paper aims to combine the strengths of each of these measures for use in transport and urban planning. The aim is to have a framework where policies related to transport and urban form can be tested and implemented to improve accessibility for all socio-economic groups.

A framework that could be used to develop an accessibility-based planning tool will now be discussed. There are three components to the framework: the Data; GIS; and Behavioural models.

5.1 DATA

Data related to the transport system provides information on the transport infrastructure, traffic characteristics and modal systems operating within the transport system. Such spatial information includes the road network, the public transport system (particularly the level of service offered), provisions available for non-motorised forms of transport (such as dedicated bicycle lanes), and provisions for private motor vehicles (such as parking).

Information on land-use gives an indication of what and how much is offered for activities at various locations. Such information can give the density or concentration of activity offered in areas. These can include densities of population, employment, education enrolment places, retail facilities, social and recreation facilities, and health facilities and services.

Revealed preference provides information on the socio-economic and behavioural characteristics of the population in various areas of the urban space. Travel diaries can reveal travel behaviour characteristics for a population sample that can be extrapolated to the entire population by use of surveys such as national census data collections, which are focused on capturing socio-economic characteristics of the entire population.

5.2 GIS

A GIS is a platform well suited to the integration of datasets (Thong and Wong, 1998). Data processing and data merging allows information to be visualised in a geographical sense for ease of comprehension. Such a system allows users to take advantage of the geographical properties of the data to perform further querying and analysis using tools and functions based on geometry theory. These tools are readily available and easy to use within a GIS environment. The spatial representation of results on a map can enhance the interpretation of results.

As alluded to in the discussion of the datasets, most of the data have associated spatial components providing information at various locations within an urban system. The GIS component provides two functions, firstly it allows for the analysis and preparation of spatial data related to land-use and transport for use in the behavioural models, and secondly it is used to analyse the urban system using the estimated measures of accessibility

5.3 BEHAVIOURAL MODELS

The behavioural models incorporate into the accessibility framework the preferences and needs of individuals travelling and participating in activities within an urban space. The behavioural models obtain information through GIS and through revealed preference data such as travel diary surveys.

The flow chart presented in Figure 1 suggests a possible framework to capture the choices individuals make that influence their accessibility to activities. The choices made are represented in the rectangular boxes, oval shapes represent properties of the traveller, and the rounded edge rectangular boxes represent alternatives of a choice set.

The framework presented is activity-based rather than trip-based, with the objective to determine accessibility of individuals to activities. The highest level choice model within the framework is the activity. Furthermore, the framework is designed to determine accessibility rather than travel demand, which is the reason why trip frequency stage is not considered.

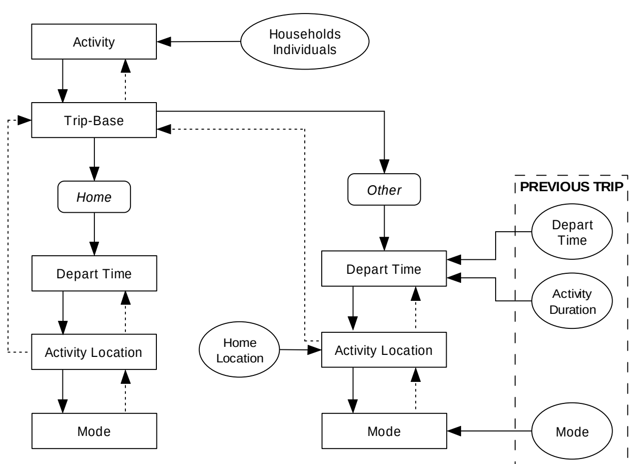

Figure 1 Behavioural model choice framework

The arrows in Figure 1 show the flow of information between modelled identities and attributes. From the lowest to the highest in the hierarchy of models, the upward flow of information (represented by dotted-lined arrows) is undertaken via the *inclusive value* (see Section 4.4 Behavioural Utility) determined for the lower layer. The inclusive value represents in a single value the total user benefit to an individual given the alternatives available and properties of factors that influence the choice of alternatives. Ultimately, this accessibility measure provides the benefit associated with participating in an activity. The more disaggregate models also provide the benefit of participating in an activity but at a finer detail. The downward arrows represent the trip choices made or attribute information, which transcend to the next model. For example, based on an individual's circumstances and other influential factors, the individual will select an activity and then based on their selection will choose where, when, and how to participate in that activity.

At the highest level in Figure 1, the characteristics of the individual and their household must be taken into account. From analysis of travel data in South Australia, there is a clear indication that at different stages of an individual's life cycle, different activities are more important than others. The analysis further showed that choices made by individuals are influenced by other household members and resources available to the household.

Trip chaining can be considered by modelling the trip-base of trips. In effect, the choice is whether to participate in an activity directly from home or from another location (which could be refined further by defining the base for all fixed and frequent activities such as work and education). In determining accessibility, it is important to include trip chaining since despite where one lives, the locations (and even duration) of their frequent activities may impact accessibility to certain activities.

Following the selection of a trip-base, a departure time is chosen. Both the trip-base and the departure time choices are influenced by the location of the activity. Once a location is chosen, the final decision is to choose a mode of travel. Introducing a route choice model can further disaggregate the framework. If the trip base is *other*, then a similar structure is followed except that the non home-based trip is influenced by the previous trip and the choice of location may still be affected by the location of the individual's home. The time and duration of previous trips will influence the departure time of the current trip. Likewise, the mode choice of the previous trip can influence the mode choice of the current trip (Bowman and Ben-Akiva 2001).

The inclusion of departure time in the model framework and allowing activity choice location of non home-based trips to be influenced by the home location, allows time and space constraints to be considered, particularly spatial constraints to the location of the home.

6 AN EXAMPLE OF THE FRAMEWORK

This section discusses an application of a simplified framework where modal choice, location choice and time period choice is modelled for home-based work trips for the Adelaide metropolitan area in 1999.

6.1 METROPOLITAN ADELAIDE

Metropolitan Adelaide is a multi-centred city with the principal focus for the economic and social activity of Adelaide and the state existing within the Adelaide Central Business District. Regional centres that function as main centres outside of the city centre are Elizabeth, Modbury, Marion, Noarlunga and Port Adelaide (Planning SA, 2002).

The socio-economic characteristics of people in different areas vary significantly. The majority of the population in outer areas are young families with elderly people forming significant parts of the population in older and some coastal suburbs. Affluent people tend to live in eastern and coastal suburbs whereas those with low incomes tend to live in the north, west and outer southern suburbs (Planning SA, 2002).

6.2 1999 METROPOLITAN ADELAIDE HOUSEHOLD TRAVEL SURVEY

The data used was collected from the 1999 Metropolitan Adelaide Household Travel Survey (MAHTS99). MAHTS99 was conducted by Transport SA to gather information on the population's travel behaviour for the purpose of planning Adelaide's transport needs (Transport SA, 1999).

The survey gathered information based around people's day-to-day activities over two consecutive days within the Adelaide Statistical Division. A sample of approximately 9,000 homes, representing 2% of all private dwellings, was randomly selected. The final information gathered included:
Household information including household type, household members and vehicles and bicycles available;
Personal information on each household member including occupation, location of occupation activities, work related information, disabilities, personal income and attitudes towards public transport; and
Travel information including where, when, how, why and cost of travel.

6.3 MODAL CHOICE MODEL

The modal choice model incorporates into the accessibility framework the benefit individuals receive from the mode choices available to them. The model developed is a nested logit model with eight alternatives as described in Table 1. The alternatives were divided into a two-level nested logit tree structure where non-motorised alternatives included walk and bike and motorised modes incorporated the remaining alternatives.

Table 1 The modal choice alternatives and their description

Mode	Description
Drive Alone (DA)	Drove the entire trip alone
Drive Passenger (DP)	Drove with passengers during part or all of trip
Car Passenger (CP)	Passenger in a car with driver a member of household
Ride Share (RS)	Passenger in car with driver from another household
Walk (W)	Walk and wheelchair trips
Bike (B)	Bicycle
Public Transport (PT)	Includes buses, trains, and tram
Taxi (T)	Includes standard taxi, access taxi and hire cars

The modal choice model developed for home-based travel to work is presented in Table 2. The coefficient for the inclusive value of non-motorised trips was normalised, with the coefficient estimate of the inclusive value for motorised modes indicating that the nested logit model is justified due to the dissimilarity of the inclusive value coefficients.

Table 2 Home-based work modal choice model

Variable name (units), alternative	Coefficient	Standard Error
Alternative Specific Constants		
Drive Passenger (DP)	-17.934	0.491
Car Passenger (CP)	-16.169	0.528
Ride Share (RS)	-4.992	0.425

Variable name (units), alternative	Coefficient	Standard Error
Bike (B)	-2.150	0.228
Public Transport (PT)	-7.145	0.535
Taxi (T)	-2.021	0.732
Alternative Specific Variables		
Travel time (min)	-0.105	0.003
Total Cost ($)	-1.017	0.004
Number of Stops	2.300	0.175
Out-Vehicle Time (min)	-0.047	0.008
Individual Specific Variables		
Work Park, DA	0.700	0.084
Work Park, DP	0.731	0.129
Work Pooling Scheme, RS	1.201	0.420
Household Specific Variables		
Number of Passengers, DP	9.950	0.356
Number of Passengers, CP	10.209	0.367
Number of Passengers, RS	3.587	0.395
Number of Passengers, PT	3.976	0.368
Number of Passengers, T	5.915	0.488
Number of Vehicles, CP	-0.258	0.079
Number of Vehicles, RS	-0.688	0.068
Number of Vehicles, B	-1.002	0.126
Number of Vehicles, PT	-0.859	0.062
Number of Vehicles, T	-1.812	0.297
Number of Adult Bikes, B	0.687	0.061
Inclusive Value		
Motorised	0.439	0.039
Non Motorised	1.000	

The alternative specific constants indicate the shares of each of the alternatives chosen relative to a referent alternative. In the case of the modal choice model, the *drive alone* and the *walk* alternatives are the referents for the motorised and non-motorised forms of transport, respectively. Given the negative sign of the alternative specific constants, the two referent alternatives are the most popular choices for home-based work trips within motorised and non-motorised mode forms.

The coefficients of variables associated with time and cost are negative, suggesting that a reduction will improve user benefit. Providing parking for workers has a positive benefit of driving into work while using a work-pooling scheme has a positive influence on ridesharing enabling the policy maker to influence such factors for each alternative. The higher number of passengers involved in a trip and the higher number of vehicles owned by households positively influence the motorised forms of transport excluding drive alone. Individuals within households with adult bikes are more likely to ride a bike to work, which although this is obvious it provides policy makers another tool to improve accessibility.

6.4 LOCATION CHOICE MODEL

The location choice model incorporates the benefit individuals receive from work related opportunities surrounding their home location into the accessibility framework. A multinomial logit model is used to estimate the user benefit from work location choices with seven alternatives representing the distance between the location of the individual's home to locations at varying distances away from the home (see Table 3). In order to reduce the number of alternatives from the 286 zones within the Adelaide metropolitan area, a technique called *Stratified Importance Sampling* was used whereby a location in each alternative group was chosen at random (Ben-Akiva and Lerman, 1985).

Table 3 Home-based work location choice model

Variable name (units), alternative	Coefficient	Standard Error
Alternative Specific Constants		
0 km (D1)	0.9927	0.1996
0 to 3 km (D2)	1.2176	0.2179
3 to 5 km (D3)	1.3517	0.2154
5 to 8 km (D4)	1.6839	0.2147
8 to 13 km (D5)	1.9869	0.2141
13 to 20 km (D6)	1.9821	0.2140
> 20 km (D7)		
Alternative Specific Variables		
Employment Density (Jobs per hectare)	0.0012	0.0001
Travel Cost ($)	-0.4891	0.0203
Park Cost ($)	0.2053	0.0337
Observation Specific Variables		
Public Transport Frequency	0.1242	0.0282
Personal Income ($,000 per year)	-0.0090	0.0016
Car Park Density (Car Park area per hectare)	0.0014	0.0002
Number of Passengers	-2.9498	0.1289
Car Licence	0.6830	0.1027
Household Specific Variables		
Household Income ($,000 per year)	0.0037	0.0008
Inclusive Value		
Modal Choice	1.4006	0.0389

The data used to calculate employment density for each zone was taken from the 1996 Australian Census and extrapolated to 1999 using factors calculated in MAHTS99 (Benham, 2001). In the location choice model, the employment density of a zone has a positive influence on user benefit.

Travel cost was calculated based on the cost of travel between zones and as expected, has a negative impact on user benefit. Parking cost on the other hand has a positive coefficient, which at first may seem unrealistic however in areas of high demand (particularly the Adelaide CBD) parking costs are higher. This suggests that parking cost reflects the popularity or demand for a zone rather than a disutility to the individual.

The observation specific variables and the household specific variable are included for all alternatives except for greater than 20 km from the home, which is the referent alternative. Public transport frequency is determined by rating bus stops in home zones from 1 to 6 (from highest to lowest) based on the number of public transport vehicles that arrive at the bus stop bound for the Adelaide CBD between 7:30 am to 8:30 am using methods in Sekhar (2002). A positive coefficient for public transport frequency suggests that individuals whose work locations are more than 20 km from the home require a higher level of public transport frequency. The negative coefficient of personal income suggests that the lower the personal income, the more likely an individual will travel less than 20 km to work. This could be influenced by young people travelling to work locations closer to home. Locations closer to the individuals home are likely to have higher car parking density. The number of passengers and car licences can be viewed simultaneously since when an individual travels as a passenger, a driver's licence for that particular trip is not required. The coefficient values of these two variables suggest lower passenger numbers are associated with travel to work for distances less than 20 km, hence more people may drive to work when within 20km of their work place rather than be a passenger.

The coefficient of the inclusive value derived from the modal choice modal is positive which suggests that the benefit derived from choice of modal alternatives positively impacts user benefit.

6.5 DEPARTURE TIME PERIOD CHOICE MODEL

The departure time period choice model estimates the benefits derived from departure times of travel between the home and the work locations (i.e. from home-to-work or work-to-home). The model is a multinomial logit with 6 alternatives where the referent alternative is departure before 6:30 am or after 9:00 pm in a day. The alternatives and the departure time period choice model are presented in Table 4.

Table 4 Home-based work departure time choice model

Variable name (units), alternative	Coefficient	Standard Error
Alternative Specific Constants		
0630 to 0900 (TP1)	0.8671	0.0827
0900 to 1500 (TP2)	0.8171	0.0803
1500 to 1600 (TP3)	-0.2893	0.0730
1600 to 1830 (TP4)	0.8140	0.0627
1830 to 2100 (TP5)	-0.6803	0.1226
Other times (TP6)		
Alternative Specific Variables		
Travel Time (min)	-0.0285	0.0039
Individual Specific Variables	0.2053	0.0337
Male, TP1 TP4	-0.2291	0.0454
Male, TP6	0.4425	0.0711
Personal Income ($,000 per year), TP1 TP5	0.0042	0.0010
Vehicle User, TP1 TP2	0.1500	0.0556
Vehicle User, TP5	-0.3436	0.1200
Company Car	1.0647	0.1285
Car Costs	0.8946	0.1472
Full-Time, TP1 TP4	0.4868	0.0543
Full-Time, TP2	-0.5439	0.0634
Professional, TP1 TP2 TP4 TP5	0.4637	0.0548
Household Specific Variables	0.6830	0.1027
Pre-Schoolers, TP2 TP3	-0.1754	0.0510
Kids, TP3	0.2331	0.0736
Inclusive Value	0.0037	0.0008
Location Choice	0.0477	0.0167

Where possible, travel time for different time periods were calculated by considering the average speeds of individuals based on their age, sex, and travel mode. The coefficient of travel time suggests a negative impact on user benefit.

The coefficients of individual and household specific variables in Table 4 were calculated for specific alternatives. Males are more likely to do work travel in the fifth time period whereas females are more likely to travel during the first and fourth time periods. Individuals with higher personal income are more likely to undertake their work travel in the morning peak period (first time period) and during early evening (fifth time period). Vehicle users are those who have a vehicle for their exclusive use. Vehicle users are likely to travel during the first two periods (this could be due to other travel for other household members such as children) but are less likely to travel during the fifth time period. Having a company car and fuel costs provided positively influences user benefit. Full-time workers are more likely to travel during the first and the fourth period but less likely to travel during the second time period. Professional individuals (where their Australian Standard Classification of Occupations (ASCO) number indicate they are professional, associate professionals, or managers and administrators) are likely to travel during the first two time periods and the fourth and fifth time periods. Individuals belonging to households with children not going to school are more likely to undertake work travel during the second and third time period and households with children under the age of 16 will tend undertake work travel during the third time period (when school is finished for the day).

The coefficient of the inclusive value derived from the location choice modal is positive suggesting that the benefit derived from choice of locations for work positively impacts user benefit.

6.6 RESULTS

The inclusive values from each of the three models were calculated for each observation, averaged for each zone, and imported into a GIS. The inclusive values are an index representing levels of accessibility and do not have a unit of measure. The results are viewed by comparing inclusive values between zones rather than examining an absolute value of accessibility. With this in mind, the accessibility levels of areas will be compared to determine areas in the lower, in between, and higher levels rather than identifying poor or excellent areas in terms of accessibility.

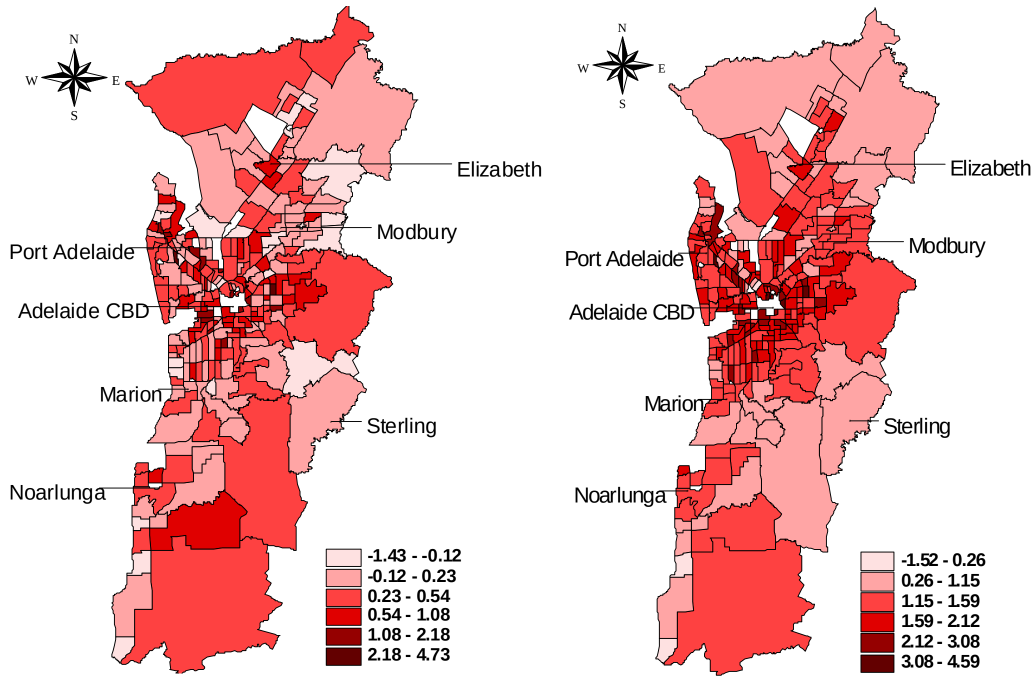

Figure 2 The maps represent the benefit derived from the modal choice alternatives (left) and the work location choice alternatives (right) available to an individual in the Adelaide metropolitan area in 1999

The maps presented in Figure 2 represent the inclusive values derived from the modal and the location choice models. The rationale behind presenting the two maps is to show the contribution of modal choice alternatives and location choice alternatives on accessibility to work. The modal choice model indicates good mobility along the north-west corridor from the Adelaide CBD to Port Adelaide. Other areas of high mobility are the north-east and south-west corridors from the Adelaide CBD. The Adelaide CBD and North Adelaide also have higher accessibility as well close proximity of the city along the east and parts of the south. Pockets of the outer areas, particularly near regional centres display reasonable (with respect to most outer areas) levels of mobility. The location choice model, which also includes benefits from modal choice alternatives via the modal choice inclusive value, indicates higher levels of accessibility around regional centres, particularly the Adelaide CBD and along traffic corridors. There are also pockets of high accessibility, especially in areas that are industrial such as the north-west and parts of the west, north and south.

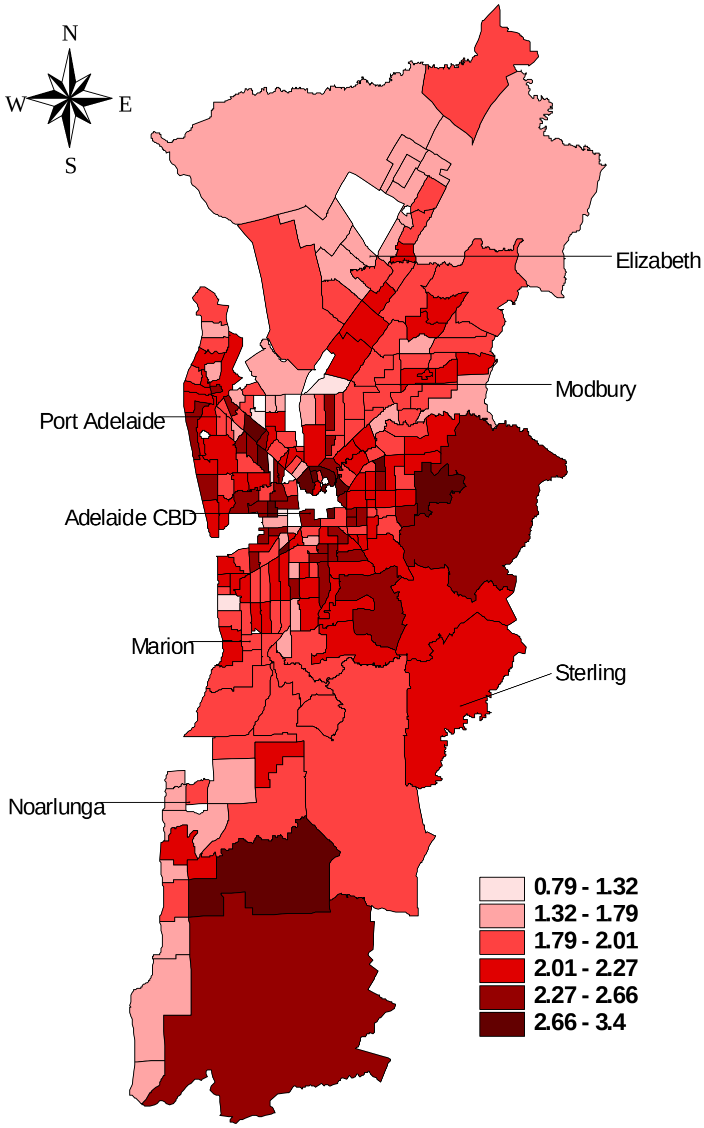

Figure 3 Work accessibility throughout the Adelaide metropolitan area in 1999

The map in Figure 3 represents the benefits individuals receive from departure time choices to work, which also includes the benefit derived from location choices and modal choices via the inclusive value of the location choice (which is influenced by the inclusive value of the modal choice model). Areas of high accessibility to work are the Adelaide CBD (particularly North Adelaide), the north-west corridor from the city to Port Adelaide, areas of close proximity to the city such as the west and south-east of the city, and McLaren Vale (a wine region south-east of Noarlunga). Areas of lower accessibility are the northern surrounding areas of Elizabeth, areas near Modbury, pockets of area surrounding the Adelaide CBD, and along the south-east coast down from Noarlunga.

7 CONCLUSION

This paper has investigated the concept of accessibility and its place in land-use/transport interaction. Accessibility has been defined as the ease of participation influenced by people, activities, destinations, transport modes and time.

Transport planning methods have also been investigated, in particular alternatives to road-based infrastructure developments. Alternative methods such as ITS, road pricing and smarter planning techniques were identified and discussed with particular attention to urban planning.

A number of methods used to calculate accessibility were identified and discussed. It could be argued that the space-time framework is the method that most closely identifies accessibility of individuals by identifying not only in space but also implicitly the constraints in time that individuals face. The behavioural and economic measures have the benefits of being demand- and supply-based and can be behavioural-based, relaxing the assumption that the population and zones are homogeneous. The behavioural-based measures provide a technique that can allow for the determination of the influence of factors on accessibility and also allow for measures of accessibility to be dissected to enable the various components of accessibility to be analysed.

A framework was presented based around a system of behavioural models representing the choice individuals make that influence their level of accessibility to activities. The framework considers the major strengths of each of the methods used to calculate accessibility in order to provide a tool that can be used in evaluating transport and urban planning policy. Binding the framework around behavioural models provides the following benefits:
the influence of the individual's behavioural characteristics by not only considering socio-economic characteristics of the population but also the influence of time and space constraints on their travel behaviour;
estimates user benefits obtained from the choice alternatives available to individuals;
allows for the various components of accessibility to be dissected to determine why areas have high or low accessibility and how to remedy the situation with the use of transport and urban planning policies; and
probabilities of selecting alternatives can be calculated to determine the likely time to work for a person in a specific area based on the decisions they would likely make.

A simplistic version of the framework based on home-based travel to work was developed and discussed. There were three behavioural models developed to estimate the user benefit derived by an individual from the choices of mode, location, and departure time periods available. The results demonstrate potential to calculate accessibility to identify areas of lower, in between, and higher levels of accessibility in urban areas. Future work will see the framework developed further to:
consider non-home based travel to further incorporate time-space principles and trip chaining behaviour;
calculate accessibility for activities other than work;
incorporate the influence of activities upon each other; and
to determine values of accessibility that have units of measurement by calculating consumer surplus and using the behavioural models to estimate travel times and costs based on the likely choices individuals will make.

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