Evaluating urban transport and land use policies through the use of an accessibility modelling framework

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Abstract: This paper discusses a framework used to develop measures of accessibility that take into consideration the travel behaviour of individuals in addition to other factors that are sensitive to transport and urban planning policies. The accessibility framework determines the benefit or need for an individual or group of people to travel to an activity. The framework revolves around a hierarchy of decisions individuals make when deciding to participate in an activity. The behavioural models within the accessibility framework are built from travel information collected through travel diaries that indicate the travel patterns of individuals within households. The framework is activity-based rather than trip-based. The capabilities of the accessibility framework to evaluate transport and land use policies are demonstrated to evaluate the impacts of (1) a major road project and (2) a land use policy (aimed at increasing regional employment opportunities) in metropolitan Adelaide. The results from the accessibility framework show how the impacts of the initiatives are distributed across the metropolitan area.

Introduction
Most measures of accessibility 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 discusses a framework used to develop measures of accessibility that take into consideration the travel behaviour of individuals in addition to other factors that are sensitive to transport and urban planning policies.

This paper provides a discussion on accessibility and how it is defined in the context of our research. A review of accessibility measures is then undertaken to explore supply-based and supply/demand-based measures that currently exist. Following is a discussion of the accessibility framework, which was developed to combine the strengths of the measures reviewed and to measure activity from the individual-to-activity perspective rather than location-to-location perspective. The accessibility framework is first applied to metropolitan Adelaide to determine the levels of accessibility that existed in metropolitan Adelaide in 1999. The capabilities of the accessibility framework to evaluate transport policies are then demonstrated to evaluate the impact of the Adelaide-Crafers Highway for road users in metropolitan Adelaide. This paper shows how the benefits from the highway are distributed to road users throughout metropolitan Adelaide and how the accessibility of residents in the Stirling Local Government Area (LGA) to their activities is improved. The paper concludes with a discussion of the research reported in this paper and topics for further research to advance the accessibility framework developed.

Accessibility
Within transport planning, accessibility is generally defined as the ease for people to participate in activities from specific locations using a transport mode (Dalvi, 1978; Koenig, 1980; Niemeier, 1997). This definition of accessibility can be expanded to being the ease for people to participate in activities from specific locations to a destination using a mode of transport at a specific time.

The above definition of accessibility acknowledges that people vary in socio-economic and behavioural characteristics that influence the activity and travel choices they make. Accessibility varies according to the characteristics of individuals and the activity, location, mode and time choices they select.

The ease of participation in activities is estimated to determine accessibility and refers to any benefits or costs associated with travel. Such benefits and costs may encompass money, time, convenience and comfort to name a few. The ease of accessibility is subject to the remaining components as indicated in italics, namely people, activities, destinations, modes and time.

Accessibility is different for all activity types because of their location, availability, and their importance to individuals. Properties of destinations vary by the spatial separation of their location with respect to the location of individuals and by the characteristics of the destination itself. Each transport mode varies in
relation to costs, benefits and perceptions. Obvious differences among modes are travel speeds and waiting times associated with each mode. Motorised forms of transport exhibit different properties such as operating to fixed timetables and/or locations or being flexible to allow travel to occur between any two locations at any time. The availability of activities, the attractiveness of areas and the state of the transport system vary throughout different times of the day and between different days of the week.

In summary, accessibility is more than just overcoming spatial separation between locations, it also acknowledges the differences between the people for whom the measure is calculated, the activities to which people need access, the properties of the locations of activities, the modes of transport that overcome the spatial separation between people and activities and the effects of available time on accessibility.

**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, Dumble and Wigan, 1979): one where the measure is supply based; and the other where the measure 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 and the arrangement of land-uses. A combined measure that incorporates a contextual component representing demand however includes non-physical characteristics of the urban system such as the population’s characteristics and their travel behaviour.

The accessibility measures shown in Table 1 are in common use. In one form or another they are dependent on the following three components:

- traveller (individual or group)
- transport system (transport mode, traffic and network characteristics)
- land use (characteristics of land uses at origins and destinations).

In addition, a temporal component is also used explicitly on occasion (e.g. Guers and Van Wee, 2004). In this study the influence of time is determined by the three identified components as listed above.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
<th>Typical formulation</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topological</td>
<td>Supply</td>
<td>Proximity of geographic locations in a network</td>
<td>( A_{ij} = \min \sum_{e} \delta_{eij} C_{e} ) where ( \delta_{eij} = \begin{cases} 1 &amp; \text{if } e \text{ is on the minimum path from } i \text{ to } j \ 0 &amp; \text{otherwise} \end{cases} )</td>
<td>Jiang, Claramunt and Batty (1999)</td>
</tr>
<tr>
<td>Space-time</td>
<td>Supply</td>
<td>Finds the constraints of time with space to determine the behavioural possibilities of an individual</td>
<td>( A'<em>{ij} = \begin{cases} A</em>{ij} &amp; \text{if } T \geq t_{ij} + t_{ij} \ 0 &amp; \text{otherwise} \end{cases} ) ( t_{ij} = d_{ij} / v_{ij} ) is the travel time from ( i ) to ( j ); ( T ) is the total time available and ( t_{ij} ) is the time required at the destination</td>
<td>Jones (1981), Miller (1991)</td>
</tr>
<tr>
<td>Potential accessibility</td>
<td>Supply</td>
<td>All possible opportunities that exist weighted by a cost function</td>
<td>( A_{ij} = O_{ij} f(C_{ij}) )</td>
<td>Hansen (1959)</td>
</tr>
<tr>
<td>Behavioural utility</td>
<td>Demand/Supply</td>
<td>The derived benefit from available alternatives given their preferences</td>
<td>( V_{n} = \ln \sum_{i \in C_{e}} e^{V_{i}} ) (the ‘inclusive value’)</td>
<td>Ben-Akiva and Lerman (1985)</td>
</tr>
<tr>
<td>Economic</td>
<td>Demand/Supply</td>
<td>The change in benefit attributed to a change in the urban system</td>
<td>( \Delta E(CS) = \frac{1}{\alpha} \left[ \ln \left( \sum_{j=1}^{t} e^{V_{ij}} \right) - \ln \left( \sum_{j=1}^{t} e^{V_{ij}} \right) \right] )</td>
<td>Train (2002)</td>
</tr>
</tbody>
</table>
See Primerano and Taylor (2004, 2005ab) for full descriptions of the accessibility measures.

**Accessibility Framework**

An accessibility framework was developed to combine the strengths of existing accessibility measures for use in transport and urban planning. The aim was to have a framework where policies related to transport and urban form could be tested and implemented to improve accessibility for all socio-economic groups. The method used to develop the accessibility framework was activity-based rather than just location-based. This means that the accessibility framework determines the accessibility of an individual to an activity rather than the accessibility between locations. Considering accessibility in this way implies 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).

Policies aimed at improving accessibility for people by targeting issues of social welfare and social exclusion need to consider the characteristics of the people for which the policies are targeted towards. Without considering the travel patterns of people, there is no indication of the extent that policies will be received or target the people for whom they were intended.

**Data**

Data related to metropolitan Adelaide used to develop the accessibility framework and to model the Adelaide-Crafers Highway included:

- information on the metropolitan Adelaide transport system that includes the road network, the public transport system (particularly the level of service), and provisions available for private motor vehicles (such as parking)
- land-use datasets depicting population, employment, education enrolment places, retail facilities and social and recreational facilities in Adelaide to provide an indication of what and how much is offered for activities at various locations, and
- revealed preference data on the socio-economic and behavioural characteristics of the population in various areas of the urban space.

The revealed preference data used were 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 9000 homes, representing two per cent of all private dwellings, was randomly selected. The final information gathered also included household and personal characteristics of participants.

**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. Analysis of the MAHTS99 data revealed the travel behaviour characteristics of the metropolitan area population and provided insight into:

- the relationships between decisions made by individuals
- data preparation for development of the behavioural models, and
- the influence of variables on the decision making process to aid development of behavioural models.

The flow chart presented in Figure 1 shows the framework used to capture the choices individuals make that influence their accessibility to activities. The choices are represented in the rectangular boxes, the properties of the traveller are represented by the oval shapes, the alternatives of a choice set are represented by the rounded edge rectangular boxes, and the procedures used to restrict the choice sets of individuals based on their characteristics or their situations anytime during the survey period are represented by the diamond-shaped boxes. Five types of travel choices were modelled, these were: activity choice; time period choice; trip-base choice; location choice and mode choice. All models are multinomial logit with exception of the mode choice models, which are nested logit.
The choice models in Figure 1 are represented in a hierarchical structure where the activity is the first choice made by the decision unit. The arrows indicate the flow of information between modelled choices 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 (Ben-Akiva and Lerman, 1985). The inclusive value represents in a single value the total user benefit to an individual given the alternatives available and the 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. The framework includes the characteristics of the individual and their household to take into consideration the differences in travel choices made by individuals and the influence of other household members and the resources available to the household. In addition, the choice of activity is also influenced by time of day, the possible trip-base from where travel to the activity can originate from, the possible location of such activities and the modal choice options available to the individual. To put it simply, the choice of activity is influenced by the benefits derived from all the options available to an individual to participate in an activity.

The time period choice model estimates the periods of departure time choice to an activity. This choice is influenced by the net benefit of the possible locations from which an individual can commence travel to the activity.

Trip chaining is considered by modelling the trip-base of trips. The choice is whether to participate in an activity directly from home or from another location. Modelling the trip-base considers the benefit of the
location of the home to activities and the benefit derived from linking trips to pursue activities from other locations. The choice of trip-base is dependent upon the opportunities at locations surrounding the location of the trip-base, hence the inclusive value from the location choice model feeds back into the trip-base choice model.

The choice of location is highly influenced by the individual’s ability to overcome the spatial separation between where they are currently and where they want to be. Hence, the decision of location choice for an activity is influenced by the mode choice alternatives available to the individual to overcome this separation.

The final decision is the choice of mode to travel to the location of the activity. The mode choice is also influenced by the mobility options available. Essentially, this procedure determines what mode alternatives are actually available to the individual using the MAHTS99 data (Primerano and Taylor, 2004, 2005ab).

The main flow of the decision process is described above, however there are variations to this depending on some of the decisions made along the way. The first of these variations is when the activity ‘education’ is chosen. The trip-base option was not modelled since the sample number of non home-based education trips was small (six per cent of education trips and 0.4 per cent of total trips were non home-based education trips). Hence, if education is the chosen alternative then the next decision is the choice of location for the activity. This leads to the time period choice model being influenced by the benefit of the possible opportunities or in this case, the number of enrolment places to education institutions available to an individual. From this point, the framework follows the home-based path as for all other activities.

The other variation occurs when the trip-base choice is made. There are two alternatives: either the trip originates from the home or from another location. If the trip originates from a location other than the home then the location choice and mode choice models slightly differ to their counterparts of home-based travel. The activity location choice for trips originating away from the home is influenced by the location of the home to consider that individuals away from their home will choose locations that will get them closer to home. The other variation is the restriction of the location choice set based on the space-time prism concept. It is considered that if an individual is away from their home, then they are limited in time and space by their current and next activity. The space-time prism concept was not used for home-based trips because it was assumed that a person could shorten their stay at home to spend extra time travelling.

The variation to the modal choice models of trips originating away from the home is the inclusion of the influence of mode chosen for the previous trip. It was assumed that if a person leaves the home using a particular mode of transport then that person would most likely use that mode of transport for most of their other travels until that person returns home (Bowman and Ben-Akiva, 2001).

**Accessibility in metropolitan Adelaide**

Overall levels of accessibility across metropolitan Adelaide can be defined by the inclusive values from the activity choice model (defined by the behavioural utility in Table 1). These values may be aggregated from the level of the individual traveller to the Local Government Area (LGA) and to a level for the entire metropolitan area. Each inclusive value is divided by the inclusive value for metropolitan Adelaide (with an inclusive value of 5.266) as a means of gauging the level of accessibility of each LGA in comparison with the rest of the LGAs. Figure 2 shows the base levels of accessibility for each area as compared to the entire metropolitan area, in 1999. The areas close to and including the Adelaide Central Business District (CBD) and Glenelg have the highest levels of accessibility. The Adelaide CBD has the highest accessibility level of all areas, which is to be expected as many activities are available within the Adelaide CBD and the population living in the Adelaide CBD are generally of a high socio-economic status. Areas found to have lower levels of accessibility are areas furthest away from the Adelaide CBD including Gawler, Willunga, and Noarlunga.

**Accessibility analysis of policy initiatives**

Two different policy initiatives were analysed using the accessibility framework, one regarding the road transport network and the other regarding land use policy:

- the impact of the new Adelaide-Crafers Highway link
- a proposed increase in employment in the northeastern LGAs of Salisbury, Tea Tree Gully, Munno Para, Campbelltown and East Torrens, to overcome a known deficit of local employment opportunities in that region.

![Figure 2 Levels of accessibility by LGA for individuals in 1999](image)

**Evaluation of the Adelaide-Crafers Highway**

The Adelaide-Crafers Highway was South Australia’s largest road project funded by the Federal Government under the National Highways program. The new route shown in Figure 3 was opened on the 5 March 2000 (well after MAHTS99) providing road users an alternate and more direct route between Adelaide and the hills towns such as Stirling and Mt Barker in the Mt Lofty Ranges. The Princes Highway is the major national road that connects Adelaide with Melbourne, Victoria. The new route, which also includes a tunnel through the hills provides a more gradual incline, is more direct and is shorter in distance.

The benefits to road users include improved travel times, reduced fuel costs, and increased safety and reduced accident costs (in particular through the bypass of Devil’s Elbow, a major accident black spot). The total length of the route improvement under the Adelaide-Crafers project was 8.3 km, a little over two kilometres shorter than the old route with estimated travel time reductions of five to ten minutes for the residents of the Adelaide Hills (approximately 10 000) and residents of more distant areas. It is estimated that in 2006 the annual road user benefits totalled $36 million with local businesses and residents accruing approximately $11 million of benefits per annum. In addition, benefits were also expected for freight and commercial vehicle operators (Transport SA, 2003).
Travel distances were updated for travel between Transport Area Zones (TAZ) in Stirling and all other TAZs in metropolitan Adelaide to reflect the distance reduction caused by the new highway. All travel distances to and from TAZs within Stirling were reduced by two kilometres except between TAZs within the Stirling LGA, which were left unchanged since although there would have been a reduction, it is uncertain how much that reduction would have been for travel within the Stirling LGA. Using the new travel distances, travel times and the fuel and taxi fare components of the travel costs were re-estimated. In cases where travel times were based on the start and end times of trips as given in MAHTS99, all such relevant travel times that were ten minutes or over were reduced by 7.5 minutes.

The impact of the Adelaide-Crafers Highway on metropolitan Adelaide is indicated in Figure 4. The charts in this figure show both the inclusive values (IV) and the estimated change in consumer surplus (CS) (both as defined in Table 1). In the top chart, the change in inclusive value represents the improvement in accessibility for each LGA area with respect to metropolitan Adelaide due to the construction of the highway. The change in consumer surplus, represented in the bottom chart, indicates the economic gain for each trip made by each resident with the introduction of the highway. Figure 2's bottom chart is sorted by the change in consumer surplus per person per trip values to show the residents of which area benefit from the highway the most per capita. It shows the true benefit derived from the policy on a per capita basis without the influence of other factors such as population size or other accessibility issues not addressed by the policy.

For metropolitan Adelaide as a whole, it is estimated that road users would have received cost savings of over $17 million dollars per year if the highway was opened in 1999. Compared to the estimate of $36 million per year by 2006 stated in Transport SA (2003), the estimate from the accessibility framework is reasonable considering the assumptions made to produce the behavioural model estimates during implementation, that trips that did not start or terminate within metropolitan Adelaide were not considered, and inflation from 1999 to 2006. Stirling benefits the most from the highway construction where each resident has on average a surplus benefit of over two minutes for every trip they undertake. This equates to an average surplus of just over 30 cents saved per trip per resident in Stirling. From the highway development it is estimated that residents of Stirling will accumulate a cost benefit of over $8 million per
year. This estimate is comparable to the estimated $11 million benefits to residents and local businesses quoted in Transport SA (2003) given the estimates from the behavioural models assumes that:

- the accessibility framework excludes trucks as a mode of transport;
- there is no benefit for intrazonal travel; and
- no cost benefits are derived from the additional safety and comfort the highway provides road users.

Figure 4 indicates that the overall accessibility level of Stirling (with a new inclusive value of 5.252) as compared to the other LGAs in metropolitan Adelaide. This is just under the average accessibility level for the whole of metropolitan Adelaide (which is an inclusive value of 5.272 in the new network). From the map in Figure 5, the other areas that benefit greatly from the new road are East Torrens, Burnside, Unley and Mitcham, which are close to where the highway commences. The majority of areas benefiting least from the highway development are those areas from the southwest along the coast to the northeast of metropolitan Adelaide.

Figure 4: Change in accessibility (Inclusive Value) (top) and in consumer surplus (bottom) of metropolitan area LGAs from the opening of the new Adelaide-Crafers Highway
Evaluation of employment growth in the Northeast Metro

As discussed by Primerano and Taylor (2005a), the northeastern LGAs such as Salisbury, East Torrens and Tea Tree Gully are home to about one fifth of the total labour force in metropolitan Adelaide but have only about ten per cent of the jobs. Workers in these LGAs have to travel further to reach employment, as suggested in Table 2.

Table 2: Comparisons of travel times and costs and work accessibility levels in 1999 between Salisbury, Tea Tree Gully and metropolitan Adelaide [source: Primerano and Taylor (2005a)]

<table>
<thead>
<tr>
<th>LGA</th>
<th>Average travel time (min)</th>
<th>Average travel cost ($)</th>
<th>Normalised work accessibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salisbury</td>
<td>24.29</td>
<td>$0.87</td>
<td>0.874</td>
</tr>
<tr>
<td>Tea Tree Gully</td>
<td>26.75</td>
<td>$0.84</td>
<td>0.968</td>
</tr>
<tr>
<td>Metropolitan Adelaide</td>
<td>23.11</td>
<td>$0.80</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The policy tested using the accessibility framework was a land use change to increase the numbers of jobs per labour force member in Salisbury, Tea Tree Gully and surrounding LGAs to a similar level to that of the metropolitan area at large. This involved increasing employment opportunities in Tea Tree Gully, Munno Para, Campbelltown and East Torrens by 200 per cent and by 50 per cent in Salisbury.

Figure 6 shows the cumulative probability distributions for travel to locations for work purposes for the LGAs of Salisbury and Tea Tree Gully both with and without the increase in local employment opportunities. The two cumulative distributions for the increased employment are both well above those for the pre-policy scenario for the respective LGAs. In the 5-8 km distance group, the proportion of...
residents of Tea Tree Gully able to reach their employment location with the increase in employment opportunities rises from 29 per cent to 40 per cent. For the same distance grouping, the increase for Salisbury residents was from 35 per cent to 39 per cent. The improvement in accessibility for Tea Tree Gully residents is due to the significantly greater increase of employment opportunities in that LGA – in the base case there are far fewer employment opportunities for Tea Tree Gully residents relative to the number of workers resident there.

The outcomes of the increase in employment opportunities around Salisbury and Tea Tree Gully are summarised in Figure 7. The two charts in this figure show the changes in inclusive values (IV) and consumer surplus (CS). The change in inclusive value represents the improvement in accessibility for each LGA due to the land use policy. The change in consumer surplus represents the economic gain for each trip made by each resident. This is the level of benefit derived from the land use policy by each resident of each LGA, on a per capita basis without the influence of other factors such as population. The greatest beneficiary to this policy was Tea Tree Gully, with significant benefits also accruing to Salisbury, Campbelltown and Enfield (A). The areas least affected (with many registering no change) were those distant from Salisbury and Tea Tree Gully in the south and west of the metropolitan area.

Conclusions
Accessibility was defined as the ease for individuals to participate in activities. The ease is influenced by five factors, namely: the individual; activities; destinations; transport modes; and time. A number of methods used to calculate measures of accessibility that were supply-based and those that included demand were identified and discussed. It was found that no single measure could cater for all the issues associated with transport and urban planning. This is where a framework using a hierarchical structure of discrete choice models could bring together all kinds of measures to address specific issues in planning. The accessibility framework combines the strengths of some of the existing methods of calculating accessibility measures to develop a powerful and sophisticated accessibility framework for policy analysis and evaluation.
The accessibility framework determines the benefit or need for an individual or group of people to travel to an activity. The framework revolves around a hierarchy of decisions individuals make when deciding to participate in an activity. The benefits of binding the framework around behavioural models include:

- incorporating the influence of the individual’s behavioural characteristics by considering their socio-economic characteristics and the influence of time and space constraints on their travel behaviour;
- user benefit estimates obtained from available choice alternatives of individuals; and
- allowing for the various components of accessibility to be dissected.

The accessibility framework was applied to metropolitan Adelaide to describe the levels of accessibility as they were in 1999. The framework was used to evaluate two different policies:

1. the impact of the Adelaide-Crafers Highway in terms of the distribution of benefit to road users in metropolitan Adelaide and specifically to the residents of the Stirling LGA
2. a policy to increase employment opportunities in the northeastern sector of the metropolitan area, especially in the LGAs of Tea Tree Gully and Salisbury.

Figure 7: Change in accessibility (Inclusive Value) (top) and in consumer surplus (bottom) of metropolitan LGAs from the increased employment opportunities in the NE suburbs of Adelaide
In each case the accessibility framework was able to identify the extent and spread of the accessibility and economic benefits from the policies. It has proved to be a powerful tool for assessing the effectiveness of policies to change levels of accessibility in a manner intended by the policy maker for both transport and land use policies.

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