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The Minimum Energy Transport Activity Access Model

Intended category: Beyond today's infrastructure

Abstract

A reduction in the energy intensity of private transport is necessary to manage the uncertainties of future availability of oil supplies. The built environment and transport infrastructure of an urban form will determine the extent to which low impact adaptations to these constraints are possible, and hence the resilience of residents to fuel price shocks and constraints.

This paper introduces the concept that the underlying geographic form of an urban area and its transport networks is characterised by an *Active Mode Accessibility* that could service some proportion of the resident transport activity system. The active mode accessibility is a non-dimensional measure of the proportion of trips that can be reached by active modes, given the population demographics of the study area. Greater active mode accessibility implies greater resilience to shocks and constraints. This paper introduces a spatial method for measuring the active mode accessibility within a selected study area, a GIS-based tool for applying the method, and presents two case studies. Model results and analysis are relevant to the redevelopment of existing areas and during the planning of new developments.

The Central Christchurch study presents an Active Mode Accessibility of 100%, as there are a wide range of local facilities available for every activity. The study of Rolleston township presents a significantly lower Active Mode Accessibility of 62%, due to a lack of local facilities for many activities, and in particular, education.

Although the model is still under development, it clearly indicates that it is not the distribution of facilities, but the lack of local pre-school and secondary education facilities which drastically reduces the resilience of Rolleston. The high facility density of the central city, for all activities, indicates that the residents of the central city area are extremely resilient to both fuel price shocks and constraints.

1. Introduction

The peaking of world oil production is imminent; the International Energy Agency (IEA) calculates that conventional oil production will plateau before 2030, while a meta-analysis of peak oil prediction dates undertaken by Krumdieck et al. presents a 100% probability that the peak will occur before 2030 (IEA & OECD, 2009; Krumdieck, Page, & Dantas, 2010). Furthermore, alternative fuels are unable to account for the resulting energy shortfall (IEA & OECD, 2009; Krumdieck & Dantas, 2008). Contemporary urban forms have been designed under the assumption that transport energy is cheap and readily available. Fuel price shocks and growing transport fuel prices will affect access to goods and services, and will create significant flow-on social and economic costs if users cannot adapt (Auckland City Council, 2008; Connor, 2009; Gusdorf & Hallegatte, 2007; Harward & Mussen, 2008).

Energy consumption of the household travel sector is strongly related to the design and layout of the urban form (Bento, Cropper, Mobarak, & Vinha, 2003; Cao, Mokhtarian, & Handy, 2009; Frank, 2004; Sharpe, 1978). Residents will adapt to energy and emissions constraints, but there are limits to the extent of adaptation possible, which are defined by the urban form.

The hypothesis of this research is that the underlying geographic form of an urban area and its transport networks, the 'Urban Form', has an active mode accessibility that could service some proportion of the resident activity system. The active mode accessibility is a non-dimensional measure of the proportion of trips that can be reached by active modes, given the population demographics of the study area. Greater active mode accessibility implies greater resilience to shocks and constraints. This paper introduces a spatial method for measuring the active mode accessibility within a selected study area, a GIS-based tool for applying the method, and presents two case studies.

2. Background

2.1 Transport energy consumption and the urban form

The transport energy consumption of an individual is a product of both the travel modes utilised and destinations selected, which are in turn dependent on individual behaviour and built environment factors. Although transport behaviour is complex and varied, certain links with urban form are apparent, for example; residents of highly walkable neighbourhoods[1] tend to engage in a greater number of shorter trips, which are easier to make by active modes. As a result, they partake in approximately twice the number walking trips per week compared to residents of low walkable neighbourhoods (Cao, et al., 2009; Ewing & Cervero, 2010; Frank, Chapman, Bradley, & Lawton, 2005; Sallis, et al., 2004).

Figure 1 indicates the differences between walkable and non-walkable urban forms in Christchurch; the Central City has a more connected transport network (greater effective distance covered for the same walking time), and a much greater range and number of destinations available. Studies show that the most influential factors relating to fuel consumption are destination proximity, and the availability and practicality of alternative (non-car) modes. Both of which are complex products of population density, network connectivity and land use mix (Bento, et al., 2003; Ewing & Cervero, 2010; Frank, et al., 2005; Gordon, 2008; Kenworthy, 2003; Sallis, et al., 2004).

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[1] Walkable neighborhoods are those that feature higher: population density, network connectivity and land use mix (Sallis, Frank, Saelens, & Kraft, 2004).

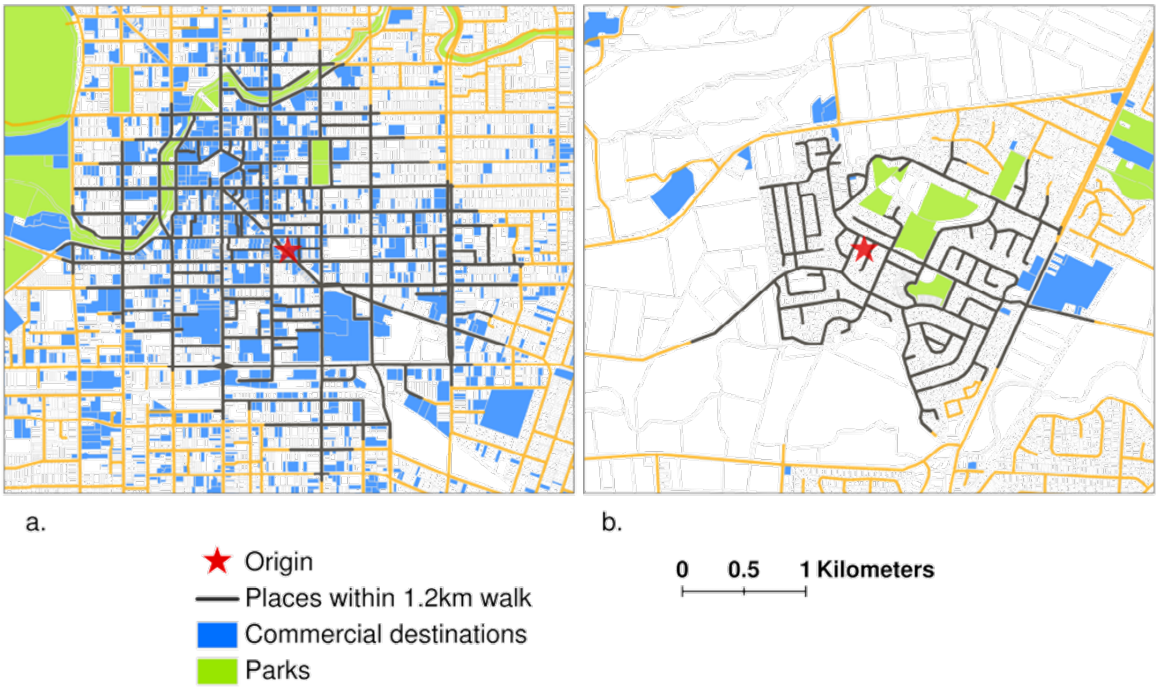


Figure 1. 15 minute (1.2 km) walk along the road network in a) the Christchurch Central City and b) Northwood suburb, Christchurch.

2.2 Transport adaptation and resilience

To reduce the effects of both high fuel prices and fuel shortfalls, private transport users may adapt their transport energy consumption (Krumdieck, et al., 2010). There are five methods of transport adaptation, each of which has an associated impact: modifying travel time to avoid network peaks; chaining trips; changing fuel type; shifting to a more efficient mode; and changing destination (Chatterjee & Lyons, 2002; Krumdieck, et al., 2010; Transportation Research Board, 1980). If none of the adaptation methods is possible for a certain trip, it must be forgone, with consequent impact upon the individuals' wellbeing. The extent to which a user can adapt their transport energy consumption to reduce costs or meet constraints, without forgoing activities, is transport resilience.

However, adaptation is limited by the adaptation capacity of the built environment and transport infrastructure (Chatterjee & Lyons, 2002; Gusdorf & Hallegatte, 2007; Transportation Research Board, 1980). A walkable form, such as that shown in ***Figure 1.a***, also allows residents greater adaptability; alternative modes are more viable, due to shorter distances and higher density, and a much greater range and number of destinations are available.

Short term fuel price increases tend to disadvantage lower income households disproportionately; particularly where inexpensive housing is situated in low density suburbs at the urban fringe - both far from destinations and not adequately served by public transport (Dodson & Sipe, 2005, 2006; Transportation Research Board, 1980). Supply disruptions which limit the availability of transport fuel, such as those experienced by western countries during the 1970's and in the UK in 2000, affect all residents; however, higher income households still have a greater range of responses available, such as purchasing a more efficient vehicle (Chatterjee & Lyons, 2002; Peskin, 1980; Transportation Research Board, 1980). Historically, during both disruptions, a large number of trips, including those for leisure, business and shopping, were forgone. This indicates a lack of transport resiliency, a result of urban forms which did not allow for user adaptation.

2.3 Current tools

There have been some recent developments with relevance to transport resilience, particularly:

- the integration of land-use and transport planning, such as in the URBANSim Project (Borning, Waddell, & Forster, 2006); and
- the use, and integration into planning, of accessibility modelling. Accessibility is defined as the ability to reach activities; as opposed to mobility, which is the ability to travel. Technically, accessibility assesses whether an activity or facility can be reached within a certain 'cost'; which may be a factor of distance, time or financial cost. Recent studies include (Mavoa, 2007; Pitot, Yigitcanlar, Sipe, & Evans, 2005; Vandenbulcke, Steenberghen, & Thomas, 2009):
    - measuring the service area of facilities via different modes;
    - investigating the service areas of Public Transport, and the facilities that are thereby accessible; and
    - considering the number of destinations that can be accessed from select origins by various modes, and how this may be affected by policy changes.

Furthermore, some recent Australian studies have investigated the spatial distribution of financial fuel price vulnerability within selected Cities:

- as a factor of socio-economic status, car dependence and vehicle use (Dodson & Sipe, 2005);
- as Dodson & Sipe (2005), but including the effects of mortgage in the vulnerability assessment (Dodson & Sipe, 2006); and
- as a factor of vehicle kilometres travelled, vehicle fuel economy, fuel use, modal split and income (Fishman & Brennan, 2009).

However, while these studies focus on understanding current transport behaviour, or investigating the spatial patterns of financial transport vulnerability, they do not assess the urban form properties that characterise transport resilience. It is proposed that the underlying geographic form of an urban area and its transport networks are characterised by an active mode accessibility that could service some proportion of the resident transport activity system. Determining the potential active mode accessibility will provide insight into the urban form influences that produce vulnerabilities to fuel shocks and constraints.

3 Method

3.1 Theory

Active mode accessibility is a behaviour-independent property of the built urban form; a factor of distances to destinations and the viability of active modes. Characterising this property for a study area will:

- indicate activities that lack facilities accessible by non-car modes;
- highlight possible modifications to the transport network to increase active access;

- produce (by measuring the non-active travel thus required) a ‘minimum energy requirement’ for the study area, from which can be determined:
    - an ‘energy footprint’ figure for the area (if compared to current VKT); and
    - a peak oil based timeframe (the *resiliency timeframe*) within which adaptations alone will be sufficient to mitigate the effects of energy constraints; beyond which point activities will have to be forgone.

The analysis consists of two steps:

1. Measure the distance from each residence to the closest destination for every activity.
2. Select the minimum energy travel mode for each destination, as a function of age and distance.

The active mode accessibility is proportion of total trips met by active modes. Summing the distances travelled by energy consuming modes, and accounting for activity frequency, will produce a minimum energy requirement for the study area.

The method utilises a Minimal Energy Activity System, constant over all study areas, defined by:

- *Activity Frequency Model* – yearly trips to activities, by age group; and
- *Mode Model* – maximum travel distance by mode, by age group.

Data required to implement the method, for each study area:

- Census data of population age demography;
- spatial location of residences;
- spatial location of destinations, by activity classification; and
- transport networks.

3.2 Application

The method has been implemented in a computer model, programmed in the Python language and utilising the OGR Simple Feature Library to interface with geographic data (GDAL Development Team, 2009; Python Software Foundation, 2010).

Limitations of the model in its current stage of development:

- utilises Euclidean distance measurement, rather than network distances;
- simply finds the closest facility of each activity type - as future revisions will correct for this, results from the current model are indicative only;
- does not utilise public transport modes;
- does not consider employment; and
- does not account for the capacity of either modes or facilities.

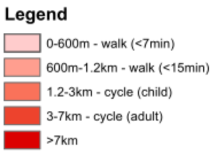
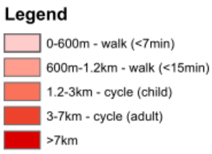
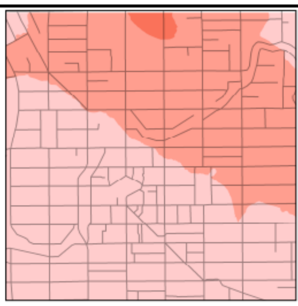
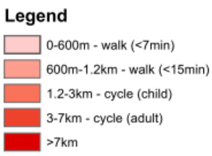
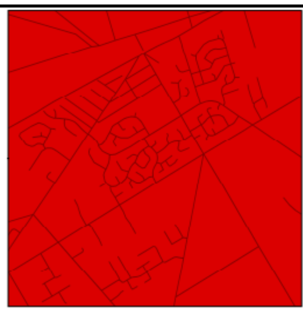
An intermediary output of the program is the distance-based spatial accessibility analysis for each activity type. The major outputs of the program are:

- Travel Mode to Closest Facility plots, indicating the minimum energy modes;
- Active Mode Accessibility (percentage of trips); and
- Minimum Energy Requirement (Vehicle Kilometres, or Litres of Fuel).

4. Results

Two case studies from the greater Christchurch area are compared; the central city (population 5700) and the satellite town of Rolleston (population 3800)[2], which lies approximately 20km from the central city. Destinations were incorporated from both the study area and surroundings, to avoid edge effects. Table 1, Figure 2 and Table 2 display the case study results.

Table 1. Study area comparison of destination counts and accessibility plots for selected activities

Comparator	Central City		Rolleston
Number of destinations analysed	Study area and surrounding Census Area Units: 1755		Study area and 5km radius: 103
Supermarket Accessibility			
Primary School Accessibility			
High School Accessibility			

[2] From 2006 Census Rolleston Area Unit; does not include the entire town.

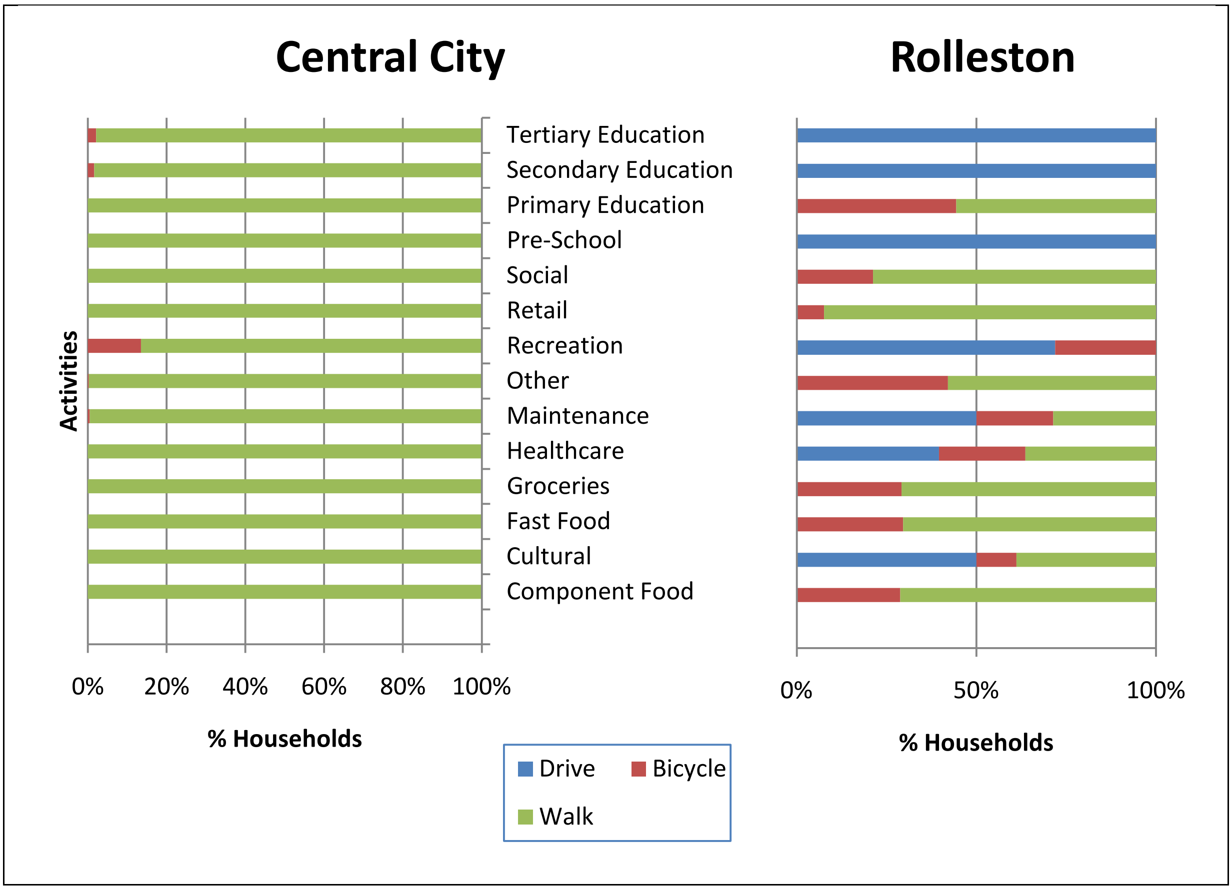


Figure 2. Travel mode to closest facility for each study area

Table 2. Active Mode Accessibility and Minimum Energy Requirement results

Comparator	Central City	Rolleston
Active Mode Accessibility	100%	62%
Minimum Energy Requirement[3]	0 L/Person/Year	47 L/Person/Year

5. Discussion

At this stage of model development, the results are comparative rather than absolute. Rolleston, having fewer local facilities, and lacking facilities for pre-school and secondary education activities, has a much lower Active Mode Accessibility than the Central City, and consequently a higher Minimum Energy Requirement. The sample accessibility plots indicate that it is not the distribution of facilities within Rolleston that contribute to its low Active Mode Accessibility score, but the complete lack of local facilities for certain activities.

[3] Vehicle fleet efficiency approximately 10 L/100km (Ministry of Transport, 2010)

5.1 Future model development

Model capabilities currently under development:

- Travel distances calculated along the transport network.
- Inclusion of real data, derived from the Household Travel survey, within the Activity frequency and mode models, which are currently only hypothetical.
- Specifying and implementing activity classification corrections, which will account for multiple destinations being classed within the same activity. For example, currently only the closest retail destination is located, even though the retail classification contains more than 12 distinct destination types.
- Including Public Transport as a mode, and employment as an activity.
- Education facility capacity.

However, the above modifications are likely to further reduce the Active Mode Accessibility of Rolleston, as:

- Network distances to destinations will be greater, and activity classification corrections will result in increased distances to access all relevant facilities within the activity, both tending to shift trips into higher energy modes;
- The inclusion of employment will result in a significant increase in the number of household trips, most of which will be to destinations outside the local area.

6. Conclusions

Urban transportation systems, the combination of destinations and transport networks within an urban environment, form a vital part of functioning urban environments. However, the resiliency of users within these systems to fuel price shocks and constraints has been previously unknown, but historically poor; as indicated by the high numbers of forgone trips during previous oil crises. This novel method goes some way towards providing an understanding of, and empirically measuring, transportation resilience. The Active Mode Accessibility calculation introduced in this paper contributes an important new understanding to future transport and land-use planning.

The results of two case studies investigated within this paper indicate some of the valuable outputs of this tool in understanding the factors that contribute to both transport resilience and vulnerability. Broad suggestions for improving transport resilience, particularly for Rolleston, can currently be drawn from the results, even though the model is still under development. Currently, the lack of local pre-school and secondary education facilities drastically reduce the resilience of Rolleston, while the high destination density of the central city indicates that the residents of the central city area are extremely resilient to both fuel price shocks and constraints.

Acknowledgements

Central City origins data was acquired from Boffa Miskell environmental planning and design consultancy, on behalf of the Christchurch City Council. Destinations data was derived from the Zenbu *Everything from Zenbu.co.nz* dataset, and transport network data is from the NZ Open GPS Maps *Improved Road* Centrelines dataset, both available from http://koordinates.com/.

6. References

Auckland City Council (2008). Economic analysis for Auckland, July 2008. Retrieved 27 August, 2008, from author: http://www.aucklandcity.govt.nz/auckland/Economy/analysis/default.asp

Bento, A. M., Cropper, M. L., Mobarak, A. M., & Vinha, K. (2003). *The Impact of Urban Spatial Structure on Travel Demand in the United States*. Washington: The World Bank.

Borning, A., Waddell, P., & Forster, R. (2006). *UrbanSim: Using Simulation to Inform Public Deliberation and Decision-Making*. Seattle: University of Washington.

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2009). The relationship between the built environment and nonwork travel: A case study of Northern California. *Transportation Research Part A: Policy and Practice, 43*(5), 548-559.

Chatterjee, K., & Lyons, G. (Eds.). (2002). *Transport lessons from the fuel tax protests of 2000*. Aldershot: Ashgate.

Connor, S. (2009, 3 August 2009). Warning: Oil supplies are running out fast. *The Independent* Retrieved 28 August, 2009, from http://www.independent.co.uk/news/science/warning-oil-supplies-are-running-out-fast-1766585.html

Dodson, J., & Sipe, N. (2005). Oil Vulnerability in the Australian City. Brisbane: Griffith University.

Dodson, J., & Sipe, N. (2006). Shocking the Suburbs: Urban Location, Housing Debt and Oil Vulnerability in the Australian City. Brisbane: Griffith University.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment -- A Meta-Analysis. *Journal of the American Planning Association, 76*(3), 265 - 294.

Fishman, E., & Brennan, T. (2009). *Oil Vulnerability in Melbourne*. Melbourne: Institute for Sensible Transport.

Frank, L. D. (2004). Economic determinants of urban form: Resulting trade-offs between active and sedentary forms of travel. *American Journal of Preventive Medicine, 27*(3, Supplement 1), 146-153.

Frank, L. D., Chapman, J., Bradley, M., & Lawton, K. (2005). *Travel Behaviour, Emissions & Land Use Correlation Analysis in the Central Puget Sound*. Seattle: Washington State Department of Transportation.

GDAL Development Team (2009). OGR Simple Feature Library (Part of GDAL - Geospatial Data Abstraction Library), Version 1.6.1. Open Source Geospatial Foundation: http://gdal.osgeo.org/.

Gordon, I. (2008). Density and the built environment. *Energy Policy, 36*(12), 4652-4656.

Gusdorf, F., & Hallegatte, S. (2007). Compact or spread-out cities: Urban planning, taxation, and the vulnerability to transportation shocks. *Energy Policy, 35*(10), 4826-4838.

Harward, E., & Mussen, D. (2008). Fill up now before fuel price shock hits. Retrieved 27 August, from Sunday Star Times: http://www.stuff.co.nz/4576379a6442.html

IEA, & OECD (2009). World energy outlook Retrieved 30th June, 2010, from http://lysander.sourceoecd.org.ezproxy.canterbury.ac.nz/vl=13088122/cl=24/nw=1/rpsv/cw/vhosts/oecdthemes/99980053/v2009n18/contp1-1.htm

Kenworthy, J. R. (2003). *Transport Energy Use and Greenhouse Gases in Urban Passenger Transport Systems: A Study of 84 Global Cities.* Paper presented at the The International Third Conference of the Regional Government Network for

Sustainable Development, Fremantle, Western Australia.

Krumdieck, S., & Dantas, A. (2008). *The Visioning Project: Part of the Transition Engineering Process*: AEMS Lab.

Krumdieck, S., Page, S., & Dantas, A. (2010). Urban form and long-term fuel supply decline: A method to investigate the peak oil risks to essential activities. *Transportation Research Part A: Policy and Practice, 44*(5), 306-322.

Mavoa, S. (2007). *Estimating the Social Impact of Reduced CO_2 Emissions from Household Travel Using GIS Modelling*. Paper presented at the 30th Australasian Transport Research Forum

Ministry of Transport (2010). *The New Zealand Vehicle Fleet: Annual Fleet Statistics 2009*.

Peskin, R. L. (1980). *Policy Implications of Urban Traveler Response to Recent Gasoline Shortages*. Paper presented at the National Energy Users' Conference for Transportation.

Pitot, M., Yigitcanlar, T., Sipe, N., & Evans, R. (2005). *Land Use & Public Transport Accessibility Index (LUPTAI) Tool - The development and pilot application of LUPTAI for the Gold Coast*. Paper presented at the 29th Australasian Transport Research Forum.

Python Software Foundation (2010). Python Programming Language, Version 2.6.4. Python Software Foundation: http://www.python.org/.

Sallis, J. F., Frank, L. D., Saelens, B. E., & Kraft, M. K. (2004). Active transportation and physical activity: opportunities for collaboration on transportation and public health research. *Transportation Research Part A: Policy and Practice, 38*(4), 249-268.

Sharpe, R. (1978). The Effect of Urban Form on Transport Energy Patterns. *Urban Ecology, 3*, 125-135.

Transportation Research Board (1980). *Considerations in Transportation Energy Contingency Planning*. Washington, D.C.: National Academy of Sciences.

Vandenbulcke, G., Steenberghen, T., & Thomas, I. (2009). Mapping accessibility in Belgium: a tool for land-use and transport planning? *Journal of Transport Geography, 17*(1), 39-53.