Rendall, Mr. Stacy[1a] (Presenter)

Krumdieck, A/Prof. Susan[a], Page, Dr. Shannon[a] , Reitsma, Dr. Femke[b], Van Houten, Dr. Elijah[a]

[1]Corresponding author: AEMS Lab, Dept. Mechanical Engineering, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand. Tel.: +64 3 3642987; fax +64 3 364 2078; *email*: stacy.rendall@pg.canterbury.ac.nz

[a]Advanced Energy and Material Systems (AEMS) Lab, Department of Mechanical Engineering, University of Canterbury, Christchurch 8041

[b]Department of Geography, University of Canterbury, Christchurch 8041

Quantifying Transport Energy Resilience: Active Mode Accessibility

Intended category: Resilient Societies

Abstract

A reduction in the energy intensity of private transport is necessary to mitigate the uncertainties of future oil supplies, given the impending peak in world conventional oil production. 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 of *Active Mode Accessibility*, a method to characterise the underlying geographic form of an urban area and its transport networks. The active mode accessibility is defined as the proportion of activities that can be reached by active modes, given the population demographics of the study area. Greater active mode accessibility implies greater resilience to fuel price shocks and constraints. This paper introduces a spatial method for characterising the active mode accessibility within a selected study area, a GIS-based tool for applying the method, and presents two case studies. The active mode accessibility analysis is relevant to the redevelopment of existing areas and during the planning of new developments.

The central Christchurch case study gives an active mode accessibility of 100%, as there are a wide range of local facilities available for every activity. The Rolleston township case study gives a significantly lower active mode accessibility of 62%, due to a lack of local facilities.

The high facility density of central Christchurch for all activities results in a high level of resilience to both fuel price shocks and constraints. The complete lack of local pre-school and secondary education facilities was found to drastically reduce the resilience of Rolleston. As both study areas are expected to significantly increase in population in the near future, these findings are valuable for future planning within the context of fuel 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 will be 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 their transport behaviour to meet energy 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 some proportion of the resident activity transport system that can be met by active modes. *Active Mode Accessibility* is defined as the proportion of activities that can be reached by active modes, given the population demographics of the study area. Greater active mode accessibility implies greater resilience to fuel price 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. These are in turn dependent on individual behaviour and factors of the built environment. Although transport behaviour is complex and varied, certain links with urban form are apparent. For example, residents of highly walkable neighbourhoods (those that feature higher population density, network connectivity and land use mix) tend to engage in a greater number of shorter trips, which are more easily made 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, Frank, Saelens, & Kraft, 2004).

Figure 1 indicates the differences between walkable and non-walkable urban forms in Christchurch. The Central City has a transport network with higher connectivity (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).

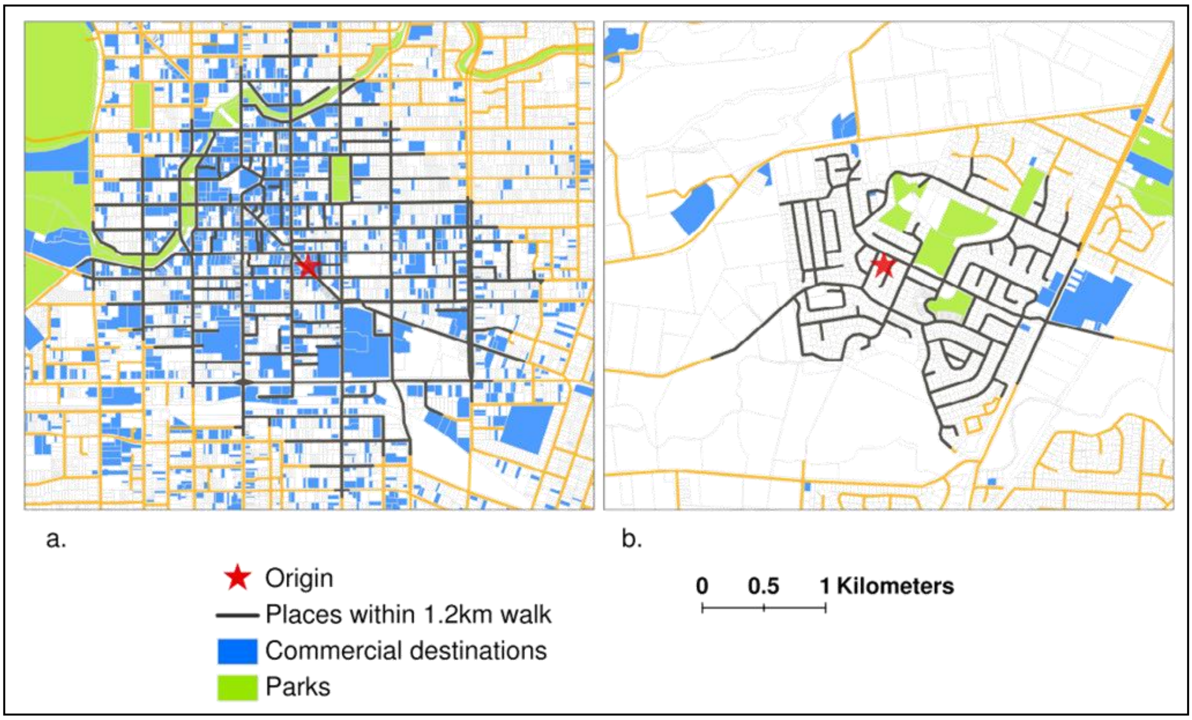


Figure 1. 15 minute (1.2 km) walk along the road network in a) the Christchurch Central City and b) Northwood suburb, Christchurch.

2.2 Transport adaptation and resilience

To reduce the effects of both high fuel prices and potential fuel shortfalls, private transport users may adapt their transport behaviour to reduce energy consumption (Krumdieck, et al., 2010). There are five methods of transport adaptation: 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 an activity that can no longer be accessed by car, 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. Furthermore, adaptation is limited by the nature and geography 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***, allows residents greater adaptability; alternative modes are more viable, due to shorter distances and higher density, and there are a large number and wide range of destinations 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). However, 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. 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). During both historic fuel disruptions a large number of trips were forgone, including those for leisure, business and shopping activities. This indicates a lack of transport resilience; a result of urban forms which did not allow residents to adapt.

2.3 Current tools

There have been a number of recent developments with relevance to transport resilience:

- The URBANSim Project, which integrates land-use and transport planning (Borning, Waddell, & Forster, 2006).
- The use of accessibility modelling in planning. Accessibility assesses whether an activity or facility can be reached within a certain distance, time or financial criterion. Recent studies include: 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 (Mavoa, 2007; Pitot, Yigitcanlar, Sipe, & Evans, 2005; Vandenbulcke, Steenberghen, & Thomas, 2009).

Furthermore, a number of recent Australian studies have investigated the spatial distribution of financial fuel price vulnerability within selected cities. The study measured vulnerability as a function of socio-economic status, car dependence and vehicle use (Dodson & Sipe, 2005); a second study then included the effects of mortgage in the vulnerability assessment (Dodson & Sipe, 2006). A more recent study considered the factors of vehicle kilometres travelled (VKT), vehicle fuel economy, fuel use, modal split and income to assess vulnerability (Fishman & Brennan, 2009).

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. In this paper we propose an *Active Mode Accessibility* characterisation of the underlying geographic form and transport networks of an urban area. The active mode accessibility is defined as the proportion of activities that can be reached by active modes, given the population demographics of the study area. Greater active mode accessibility implies greater resilience to fuel price shocks and constraints.

3 Method

3.1 Theory

Active Mode Accessibility is a behaviour-independent property of the built urban form. It is a function of population demography, 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 a *Minimum Energy Requirement* for the study area, by measuring the non-active travel required. The minimum energy requirement provides:
    - 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 active mode accessibility analysis consists of two steps; measuring the distance from each residence to the closest destination for every activity; then selecting the minimum energy travel mode for each destination, as a function of age and distance.

Active mode accessibility is the proportion of total activities that can be met by active modes. Summing the number of trips, and distances, travelled by energy consuming modes will then 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 for each 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).

Model characteristics (at current stage of development):

- utilises Euclidean distance measurement;
- uses the closest facility of each activity type;
- considers private vehicle and active modes only;
- considers all destination types except employment; and
- assumes facilities and modes are not capacity constrained.

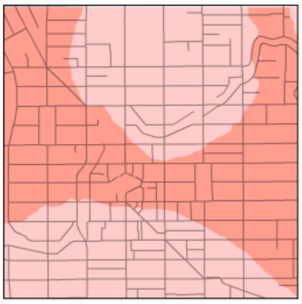
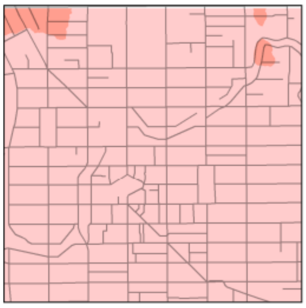
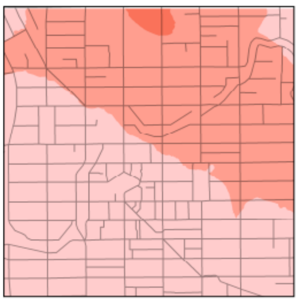
The major outputs of the program are:

- distance-based spatial accessibility analysis for each activity type;
- minimum energy travel mode to closest facility plots;
- active mode accessibility (percentage of activities); and
- minimum energy requirement (minimum Vehicle Kilometres, or Litres of Fuel, per capita).

4. Results

Two case studies from the greater Christchurch area are compared; the Central City (study area population 5700) and the satellite town of Rolleston (study area population 3800), which lies approximately 20km from central Christchurch. 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.

	Central City		**Rolleston**
Number of destinations analysed	Study area and surrounding Census Area Units: 1755 destinations (0.3 destinations per capita)		Study area and 5km radius: 103 destinations (0.03 destinations per capita)
Supermarket Accessibility			
Primary School Accessibility			
High School Accessibility			

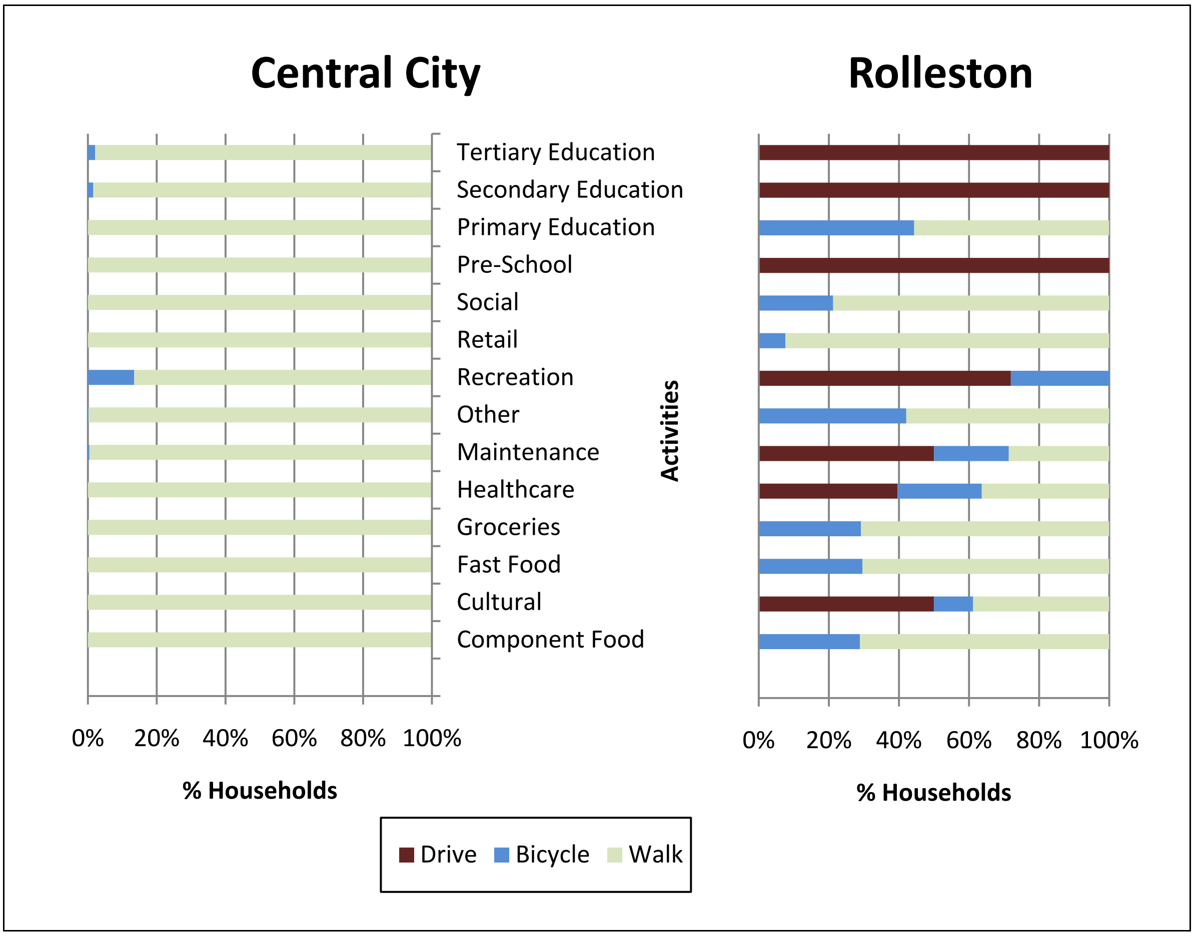


Figure 2. Minimum energy travel mode to closest facility for each study area.

Table 2. Active Mode Accessibility and Minimum Energy Requirement results.

	Central City	**Rolleston**
Active Mode Accessibility	100%	62%
Minimum Energy Requirement Vehicle fleet efficiency approximately 10 L/100km (Ministry of Transport, 2010)	0 L/Person/Year	545 L/Person/Year

5. Discussion

The active mode accessibility method has shown a significant quantitative difference in the resilience of the two urban forms. The results show that 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. In consequence, Rolleston also has a higher minimum energy requirement. The 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. These findings are of particular interest, given that both study areas are expected to experience high levels of population growth in the near future, the Central City to 30,000 people by 2026 and Rolleston to around 20,000 residents by 2045 (Christchurch City Council, 2006; Selwyn District Council, 2009). Future model runs will assess the resilience implications of both the proposed redevelopment of the Central City and the expansion of Rolleston.

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 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 facility types.
- Including public transport as a mode, employment as an activity and the capacity of education facilities in the analysis.

The above modifications are likely to have little effect upon the active mode accessibility of the Central City as it is highly connected, destination dense, and contains a large number of employment opportunities. However, addition of these factors will further reduce the active mode accessibility of Rolleston, as:

- 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;
- Network distances to destinations will be greater, and activity classification corrections will result in increased distances to access all relevant facilities, both tending to shift trips into higher energy modes.

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, although previously unquantified, historically appears low; as indicated by the high numbers of forgone trips during previous oil crises. This novel method provides an understanding of, and empirically measures, 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 the 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 can currently be drawn from the results even though the model is still under development; particularly the necessity for local pre-school and secondary education facilities in Rolleston. As both study areas are expected to significantly increase in population in the near future, these findings are valuable for future planning within the context of fuel 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.

Christchurch City Council (2006). *Central City Revitalisation Strategy: Stage 2*. from http://resources.ccc.govt.nz/files/CCRPStage2-projectcentralcity.pdf.

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.

Selwyn District Council (2009). *Rolleston Structure Plan*. from http://www.selwyn.govt.nz/__data/assets/pdf_file/0015/14361/Final-Rolleston-Structure-Plan-230909.pdf.

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.