THE PATH TO DELIVERING ENERGY RESILIENCE: MEASURING TRANSPORT CHOICE

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ABSTRACT

Accessibility modelling is an analytical method for understanding the ability of people to access services. It is increasingly being used by decision makers seeking a better way to measure the integration of land use and transport.

This paper presents an extension of the NZ Transport Agency accessibility modelling methodology developed by Abley Transportation Consultants. The extended methodology allows the calculation of the potential minimum energy consumption required by households within an urban form, and introduces a number of useful metrics. The minimum potential is a geographic and demographic, not behavioural, measure that assesses the inherent potential for residents to choose active modes. A low potential indicates the resident transport activity system can be serviced with a low energy input and hence the community has greater resilience to fuel price shocks and supply constraints. A high potential reflects the contrary. The potential is most usefully presented as a minimum percentage of household income spent on transport; including both private vehicle and public transport.

This paper introduces the enhanced accessibility methodology and presents a case study of Christchurch city. The case study results will interest those practitioners interested in the effects of community resilience when dealing with reduced oil consumption, and those seeking better ways to identify at risk communities and test various interventions.

INTRODUCTION

The transport energy consumption of households is strongly related to the design and layout of the urban form (Cao, Mokhtarian, & Handy, 2009; Frank, 2004). However, as contemporary urban forms have been designed under the assumption that transport energy is cheap and readily available, the disconnect between rising transport fuel prices and urban form will place pressure on travel behaviour to reduce energy consumption. This may affect access to goods and services, and may generate significant flow-on social and economic costs (Auckland City Council, 2008; Harward and Mussen, 2008).

Accessibility modelling is an analytical method for understanding the geographic ability of people to access goods, services and destinations. It is increasingly being used by decision makers to better understand the integration of land use and transport, and incorporate this into transport planning. In this paper the NZ Transport Agency accessibility modelling methodology developed by Abley Transportation Consultants is extended through the application of mode-ability and activity models which use New Zealand Household Travel Survey data. The extended methodology is based upon the concept of potential minimum energy consumption for private transport that is required by households within an urban form, and introduces a range of new metrics.

BACKGROUND

Transport Energy Consumption and the Urban Form

The transport energy consumption of an individual is a function of behaviour, technology, travel mode, distances to selected destinations and the frequency of travel. These are in turn dependent on individual preferences, economic decisions and factors of urban form. 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, higher network connectivity and varied land uses) tend to engage in a greater number of shorter trips, which are more easily made by active modes (Cao et al., 2009; Ewing and Cervero, 2010). As a result, they partake in approximately twice the number walking trips per week compared to residents of low walkable neighbourhoods (Sallis, Frank, Saelens, & Kraft, 2004). Studies investigating urban form links to obesity, such as that undertaken by Frank, Saelens, Powell and Chapman (2007), have shown that people who prefer walking as a transport mode will intentionally choose to live in walkable neighbourhoods. Despite this self-selection factor, residents of walkable urban forms still have the option of choosing to use private vehicles for all trips.

The difference between a walkable and non-walkable urban form within Christchurch (prior to the recent earthquakes), are shown in **Figure 1**. The diagram was produced in ArcGIS by creating a 1.2 km network service layer around a point in two suburbs and highlighting parks and commercial destinations. The analysis does not account for the amenity or safety of the network and facilities.

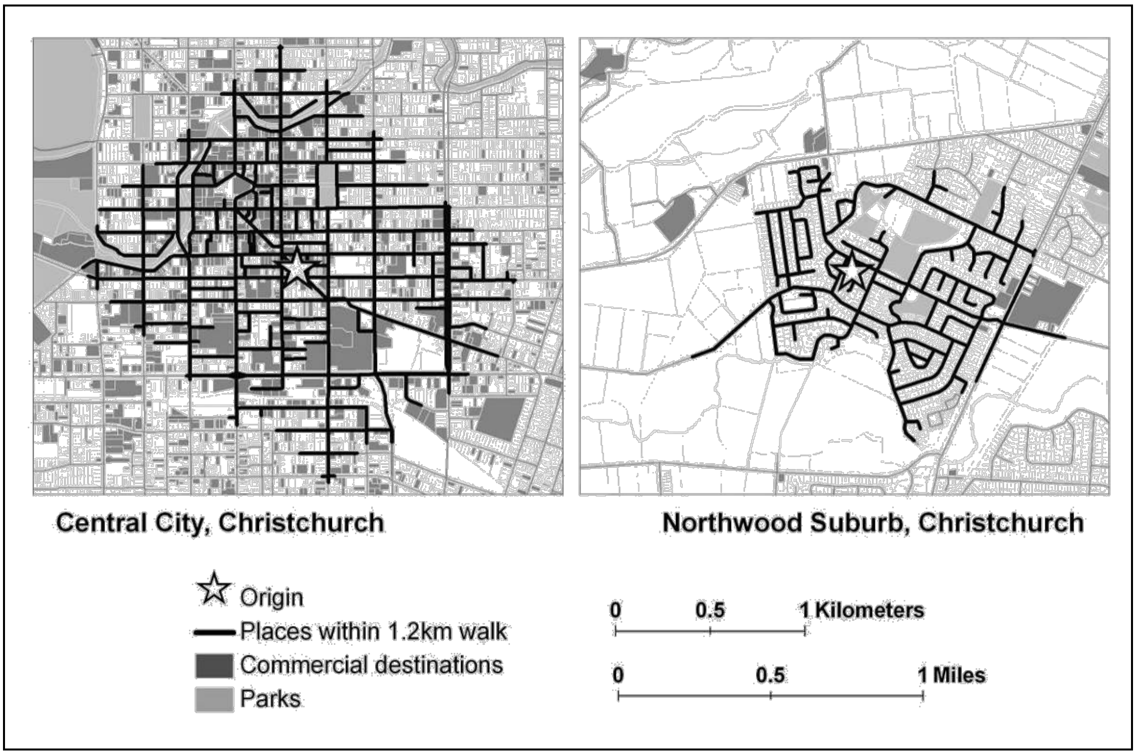

Figure 1: 15 minute (1.2km) walk along the road network in (a) the Christchurch central city and (b) Northwood suburb, Christchurch.

The analysis shown in Figure 1 highlights that the Central City (a) has a transport network with higher connectivity, indicated by a greater effective distance coverable for the same walking time, and a much greater range and number of available destinations compared to Northwood (b). Studies show that the most influential factors relating to fuel consumption are destination proximity and the availability and practicality of alternative (non-car) modes (Kenworthy, 2003). Proximity and mode practicality are complex products of population density, network connectivity and land use mix (Bento, Cropper, Mobarak, & Vinha, 2003). Although Figure 1 shows a qualitative analysis of the potential fuel consumption differences between the two urban forms, through destination proximity analysis, it only indicates possible energy resilience for the particular origin examined.

Modelling Accessibility

Accessibility is a measure of transport potential; essentially it acknowledges the availability of opportunity within the transport network, and attempts to understand what people 'could' do. In comparison, traditional Transport Modelling, which focuses on automobile mobility, attempts to forecast what people 'would' do, and typically does not recognise other travel modes or take account of what people 'can not' do (Abley, 2010). Accessibility measurement accounts for people that are traditionally transport disadvantaged and provides a better accounting of the long term transport sustainability implications. Although there are currently no national frameworks for measuring accessibility in either Australia or New Zealand, both countries are very supportive of improving accessibility at the national level (Abley, 2010).

Activity Modelling

Application of activity based approaches in modelling urban travel demand is increasing within the field of transport research, and there is a growing body of literature detailing their use in practice (Algers, Eliasson, & Mattson, 2005; Iacono, Levinson, & El-Geneidy, 2008). Activity models are definitions of personal- or household-level patterns of activity; periodic trips are output for a given variable such as age, income, household composition or household status (Wang and Cheng, 2001; Lee, Washington, & Frank, 2009). The advantage of activity models over traditional approaches is their greater ability to account for behaviour changes, including responses to travel demand management (TDM) policies. The use of activity-based analysis is already widespread in time-use studies and travel surveys; for example, the New Zealand Household Travel Survey collects trip data in terms of the activity purpose of the trip (Ministry of Transport, 2008). Some studies have utilised age cohorts to define ‘common activities’ that are performed at a homogeneous rate within the cohort; for example, pre-school through to secondary school education is an activity attended five times per week by children aged 3 to 17 (Saunders, Kuhnimhof, Chlond, & Da Silva, 2008).

This research introduces the methodology for calculating the potential minimum energy consumption of households within an urban form. The minimum energy potential is a geographic and demographic, not behavioural, measure that assesses the inherent potential for residents to choose active modes. A low potential indicates the resident transport activity system can be serviced with a low energy input and hence the community has greater resilience to fuel price shocks and supply constraints. A high potential reflects the contrary. The potential is most usefully presented as a minimum percentage of household income spent on transport; including both private vehicle and public transport. The method is based upon accessibility analysis, extending the depth of the NZ Transport Agency (NZTA) model methodology that was developed by Abley Transportation Consultants.

METHOD

Accessibility Model

Commensurate with New Zealand’s policy support for improving accessibility, and the previous experience of Abley Transportation Consultants at developing measurement techniques, the New Zealand Transport Agency commissioned Abley Transportation Consultants to develop a methodology to assess the accessibility of a neighbourhood in May 2007. This methodology has been implemented within ArcGIS ModelBuilder, and calculates an accessibility score for access to eight core land use activities, along Walking, Cycling, Public Transport and Private Vehicle networks. Two types of Accessibility indicators are calculated at the household or meshblock level: a Threshold Indicator, which is a binary output answering a question such as ‘can a doctor be reached within 30 minutes of travel by public transport?’; and a Continuous Indicator, which maps the percentage of a population with access to a destination type. Both indicators utilise Deterrence Functions to determine the rate at which destinations further away are assigned less weight in determining the accessibility result. The methodology described above has since been applied to numerous case studies, including the Gisbourne District and Christchurch City.

Minimum Energy Potential

The minimum energy potential extends the Accessibility modelling method described above, by calculating ‘minimum energy’ modes for household-destination trips and applying annual frequencies for household-destination trips. The combination of these two functions forms a minimum energy activity system. It assumes, for each destination trip, that a household selects the mode with the lowest possible energy consumption (within the ability of its residents) and utilises the closest facilities available. The minimum energy activity system is an ‘energy-ideal’ theoretical behaviour construct; although this behaviour is unlikely to be met in reality, the presence or absence of ability to fit this behaviour is a powerful indicator of energy resilience. Although possible that individuals or households could willingly travel further by active modes or public transport than is defined by the model, this will only act to increase energy resilience. The minimum energy activity system is applied at the household level, and is defined by the age of the residents under the assumption that each household is typical within its census collection area.

Values used in the minimum energy activity system are derived from the responses of residents of Major Urban Areas within the New Zealand Household Travel Survey (NZHTS) dataset, and are categorised into New Zealand census age groupings. Mode ability is calculated as the 75th percentile travel time for each age group. For example, the calculated values for a 20-24 year old person are shown in **Table 1.** The mode used by a household in making a trip is selected by the model as the lowest energy mode determined through the application of a hierarchy, as outlined in **Table 2**.

Table 1: Mode ability for 20-24 year old person

Mode	Mode ability [min] (20-24 yr old)
Walk	30
Bicycle	30
Public transport	40

Table 2: Mode selection hierarchy based upon travel time (T) to an activity

Energy rank (low to high)	Logical process	Selected mode
I	$T \leq Time_{Walk}$	Walk
II	$Time_{Walk} < T \leq Time_{Cycle}$	Cycle
III	$Time_{Cycle} < T \leq Time_{PublicTransport}$	Public Transport
IV	$Time_{PublicTransport} < T$	Private Vehicle

Activity frequencies are calculated assuming that the average activity frequency of respondents within the age group is typical. Activities are broadly defined as fitting into one of ten classifications, defined by the NZHTS with educational activities broken out by age group, as shown in **Table 3.** This table includes, as an example, the calculated (average) trip frequencies for a 20-24 year old person to each of the different activities.

Each NZHTS activity classification contains multiple distinct facility types; for example, 'Shopping' includes facilities such as supermarkets, book stores, chemists, clothing stores and so on. Consequently, a saturation value is used within the model that accounts for the effect of this classification. An ideal travel survey would capture travel information to every distinct type of activity, with the result that the model would only have to locate the closest single destination for each activity. The Saturation Value is defined as number of potential activity facilities that were forgone (within a radius of equal travel time) when selecting the actual destination for the activity; the Minimum Saturation Value is the 25th percentile of these values for travel to each activity. The values are calculated using the real facility locations and the NZHTS responses for travel to each activity; Minimum Saturation Values calculated for Christchurch are shown in Table 3.

Table 3: Model activity classifications, annual frequency and Saturation Values

Activity classification	Annual trip frequency (20-24 yr old)	Minimum Saturation Value
Preschool	0	3
Primary/Intermediate School	0	3
High School	0	2
Tertiary Education	57	3
Shopping	180	68

Activity classification	Annual trip frequency (20-24 yr old)	Minimum Saturation Value
Medical/Dental	8	10
Social Visits	240	9
Personal Business and Services	76	24
Recreation	65	1
Employment (jobs)	180	6,760

Applying the minimal energy activity system to an urban form generates a wide range of metrics, including: the specification of the minimum potential energy consumption; overall accessibility for all travel by active modes and public transport; inability to access destinations by active modes and public transport. Of these potential measures, three understandable and communicable metrics have been selected:

- **Active mode accessibility (AMA)**: the percentage of four key destinations that can be accessed entirely by active modes. The key destinations are defined to be Primary/Intermediate School, High School, Shopping and Employment.
- **Public transport mode accessibility (PTMA)**: the percentage of the same key four destinations that can be accessed if public transport is used as well as active modes.

Minimum travel spend as a percent of household income: the sum of fuel and fare costs, accounting for travel by public transport and private vehicle to all ten activities.

Both AMA and PTMA are calculated by the model once modes have been assigned to household-destination trips. AMA indicates the extent to which the resident transport activity system can be met by active modes. A high value implies the residents can engage in their activities with a low energy input, and hence the community has greater resilience to fuel price shocks and constraints. The spatial distribution of PTMA also indicates the energy resilience benefits of certain routes and the potential for public transport improvements.

Minimum travel spend as a percent of household income is a combination of the fuel cost and public transport fare cost for travel to all activities. This builds upon other intermediate outputs of the model, minimum VKT and number of trips by public transport (PT). Fuel cost can be approximated with the current fuel price by the formula shown in **Equation 1**, where $\eta_{avg.fleet}$ is the average light vehicle fleet fuel efficiency, 10L/100km in New Zealand (MoT, 2011), and the current price is NZ$2.068 /L (). Annual household PT cost can similarly be calculated by the formula shown in **Equation 2**; the product of the number of PT trips and the fare price, NZ$2.30/trip[1] (Environment Canterbury, 2011). The minimum percent of household income spent on transport is then calculated by the formula shown in **Equation 3**; household income is assumed to be the median within the households' census area.

Equation 1

$$Annual\_Fuel\_Cost_{HH} = VKT_{HH} \cdot \eta_{avg.fleet} \cdot price_L$$

Equation 2

$$Annual\_PT\_Cost_{HH} = Annual\_Trips_{HH} \cdot price_{trip}$$

[1] Assuming up to two trips per day on a concession card.

Equation 3

$$Min\_\%\_Income = 100.\frac{Annual\_PT\_Cost_{HH} + Annual\_Fuel\_Cost_{HH}}{Median\_Income_{HH}}$$

Shown spatially, minimum travel spend identifies the distribution of risk to fuel price rises within the urban form. In reality, the annual fuel spend of most households is likely to be higher than the minimum calculated by the model, indicating people currently choose to travel to facilities further than the model assumes, or travel using private motor vehicle in preference to other modes of transport. Of particular note are households where the minimum is not much less than the current transport spend; these households have limited ability to adapt to future energy price rises and consequently are at increased risk to transport energy price rises. As the model is sensitive to land uses and transport networks, the urban form and transport factors that cause certain areas to exhibit lower energy resilience can be determined, and suitable interventions can be highlighted

Data Requirements

The model requires:

- The New Zealand Household Travel Survey, from which activity frequencies, mode abilities and saturation values are derived.
- The New Zealand Census, which provides demography and income data. The data is available at two relevant levels, Area Unit, which is approximately the size of a suburb, and Meshblock, which is about four to ten times finer than an Area Unit. However, Area Unit data is preferred, as a significant number of data points are confidentialised at the Meshblock level.
- Destinations as GIS points, grouped by activity classification.
- Household locations.
- Transport networks for:
    - Walking
    - Cycling
    - Public Transport, including walking to/from stops
    - Private Motor Vehicle

The method can be applied to hypothetical data, to test transportation resilience for future land uses or development strategies. This allows accessibility and minimum energy use to be forecast, such that land uses and transport networks can be optimised to provide beneficial outcomes for all members of the community.

CASE STUDY

Study Area Overview

Christchurch is the largest city in New Zealand's South Island, with a population of nearly 350,000 people, 120,000 households and a land area of 450 km^2. This study is based upon Christchurch data prior to the significant earthquakes of September 4th, 2010, and February 22nd, 2011.

Key Activity Centres[2] are evenly located around the populated areas of the city, mostly within lower income areas, as shown in **Figure 2**. Population density is greatest in a ring around the central city, as shown in **Figure 3**. The central city and west towards the University are predominantly younger, while the fringes of the city are older. Urban Christchurch is

[2] Key activity centres: defined by Environment Canterbury (regional council) as key centres of business and service activity that are highly accessible and constitute nodes on strategic transport corridors (Environment Canterbury 2007).

predominantly flat, and the road network in the central city is laid out in a grid pattern. Christchurch has a comprehensive public transport network of busses, which pass through all the Key Activity Centres. A spatial analysis of the per capita distribution of employment and destinations is shown in Figure 4. Many of the areas with low income in Figure 2 and low population density in Figure 3 are those with a greater number of jobs and destinations per capita, indicating a high level of land use separation. The majority of areas to the south and east of the central city have both low numbers of jobs per capita and few destinations.

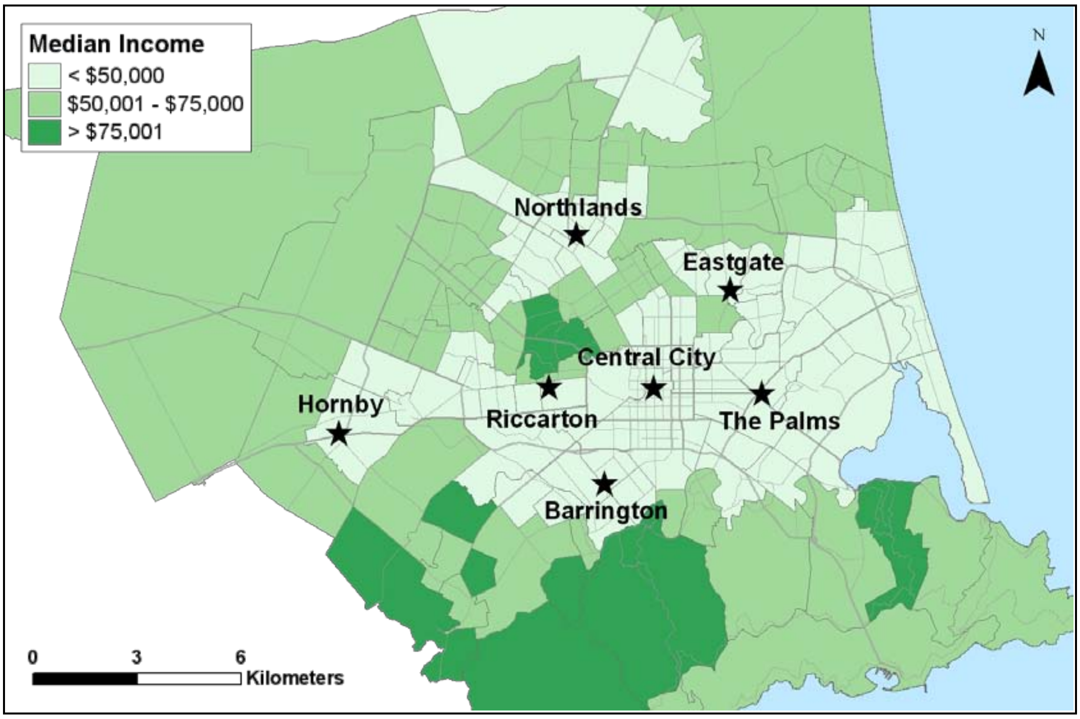

Figure 2 Key Activity Centres and median area income

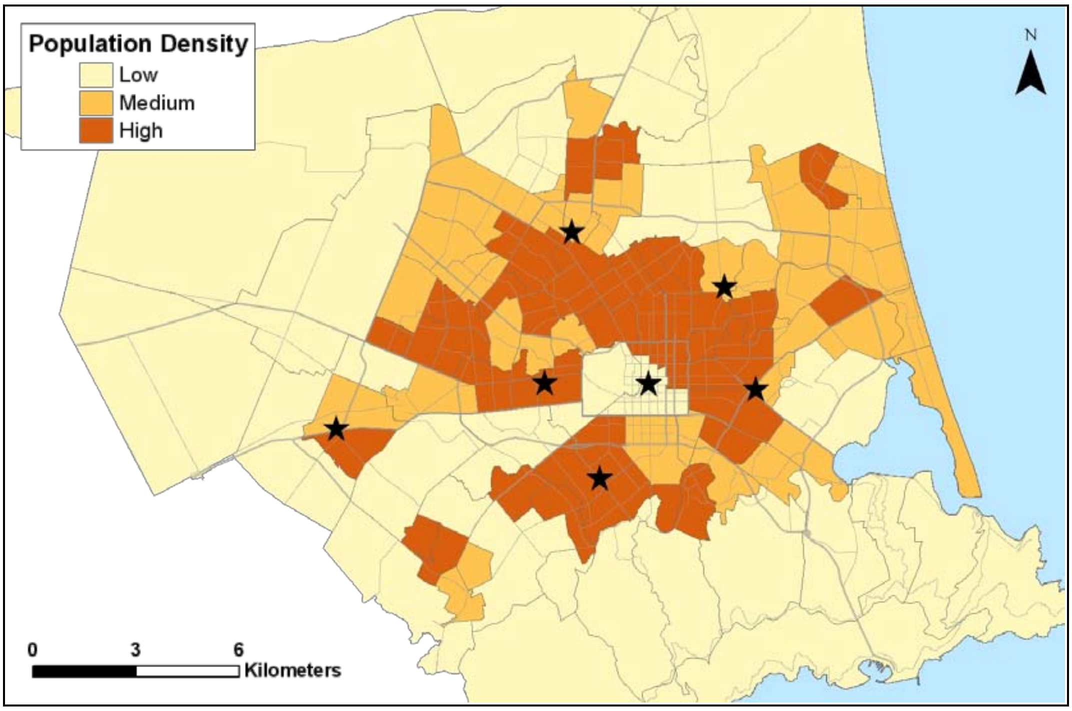

Figure 3: Key Activity Centres and population density

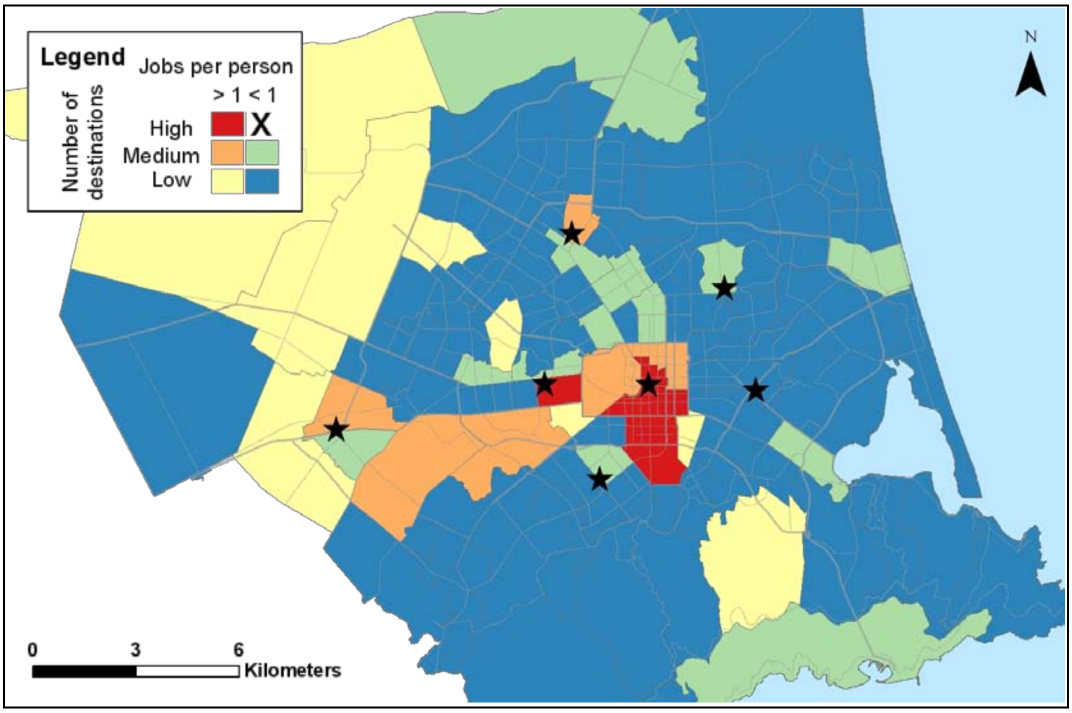

Figure 4: Comparison of employment density and number of destinations by Census Area Unit. Note: there are no areas with a high number of destinations and less than one job per person.

Case Study Results

Active mode accessibility (AMA)

Most households in central Christchurch have the ability to access all of their four key destinations by walking and cycling, as shown in **Figure 5**, in which each household is represented by a point. Households in and near the city centre have high AMA, as there are a large number of destinations, while accessibility drops markedly at the fringes. Numbers of households within each accessibility category are shown in **Table 4**.

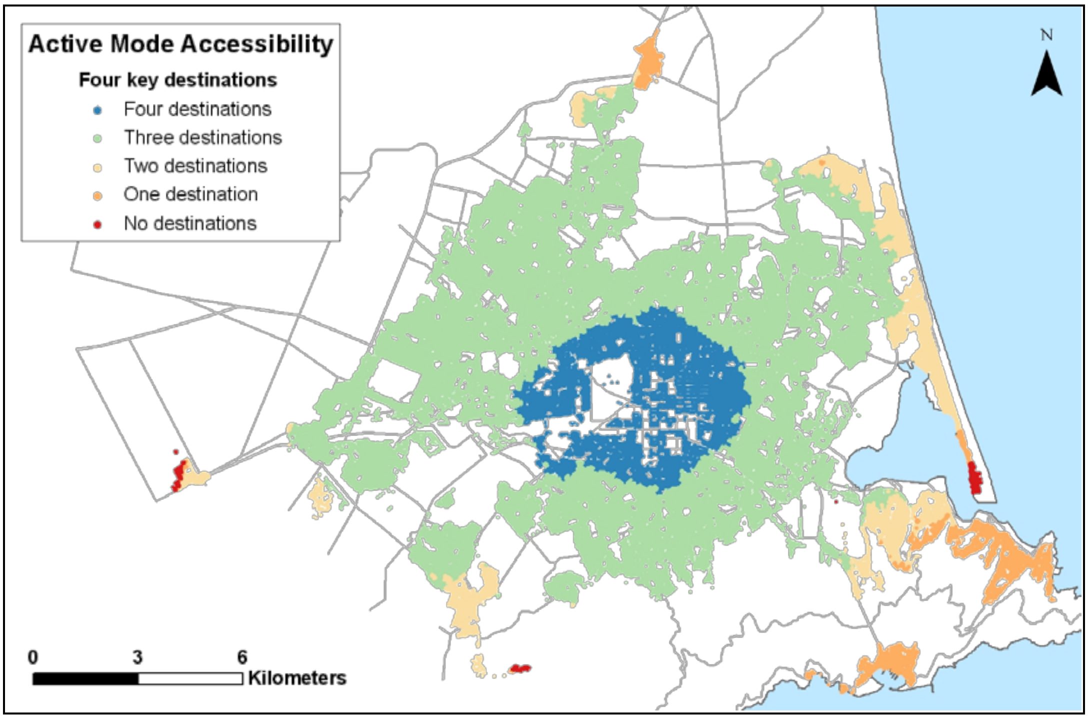

Figure 5: Spatial distribution of accessibility by active modes of four key activities; Primary/Intermediate School, Secondary School, Shopping and Employment

Table 4: AMA results

Number of key destinations accessible	Number of households	Percent of households
Four	19,495	16%
Three	85,492	71%
Two	10,119	8%
One	4,560	4%
Zero	391	< 1%
	120,057	*100%*

Public transport mode accessibility (PTMA)

To understand the contribution of public transport to potential accessibility, the additional accessibility provided by public transport is shown in **Figure 6** and **Table 5**. 17% of all households receive an improvement to their accessibility through the addition of public transport. Most notably, households around the centre of the city, on or near bus routes, gain access to employment.

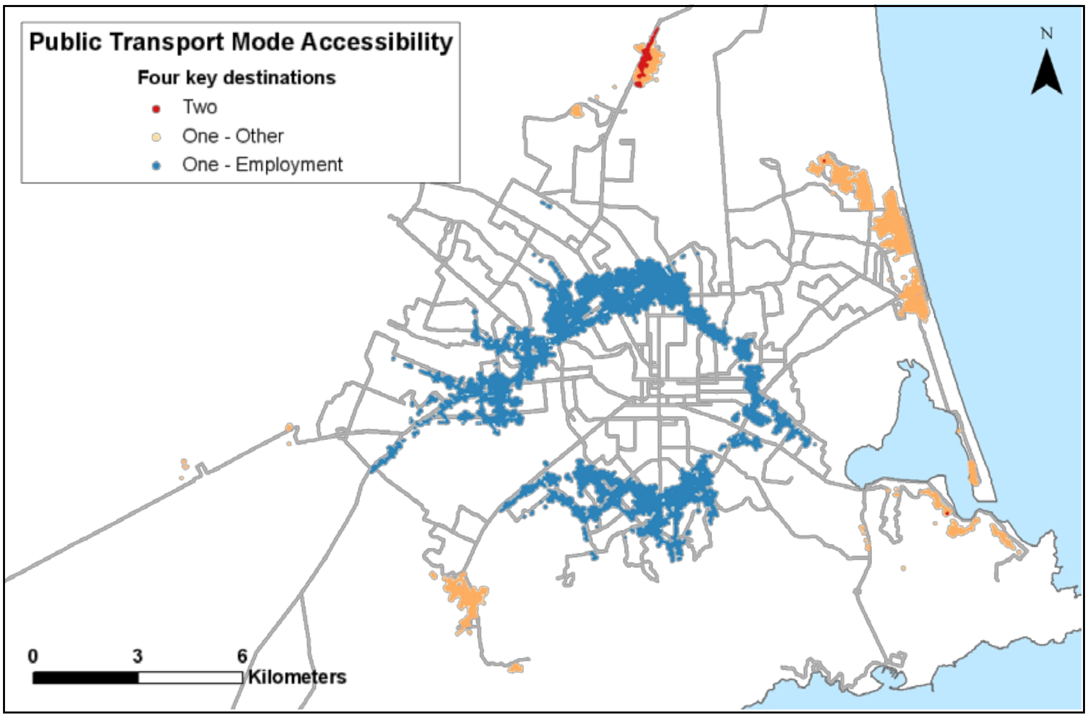

Figure 6: PTMA: additional destinations that can be reached when both Public Transport and Active Modes are used, overlaid on bus routes

Table 5: PTMA results

Number of additional key destinations accessible	Number of households	Percent of all households
Two	177	<1%
One – other	4,366	4%
One – Employment	15,289	13%
	19,832	*17%*

Minimum travel spend as a percent of household income

Household annual minimum travel spends to all activities are calculated from the product of minimum VKT, average fuel efficiency and the current fuel price, the number of bus trips and price, as shown in Equations 1, 2 and 3. The spatial distribution of this value is shown in **Figure 7**, while the number of households within each category are displayed in **Table 6**. As with the results shown in previous figures, households further from their destinations and transport routes are less resilient, and have to spend a greater proportion of their income on transport energy.

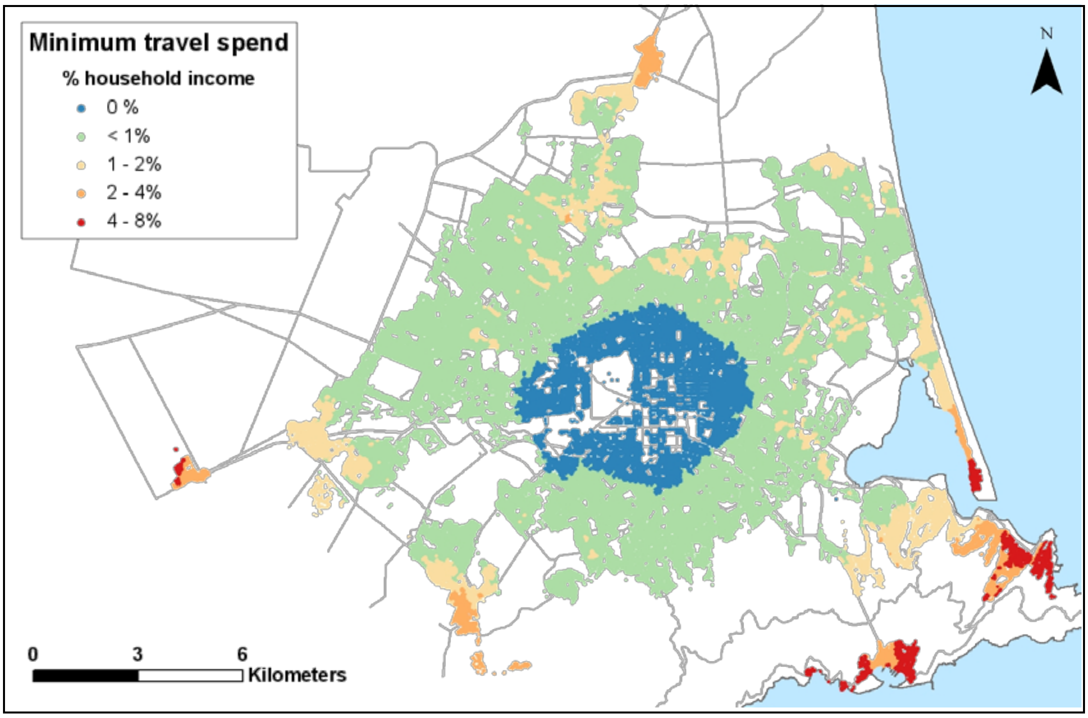

Figure 7: Minimum travel spend as a percent of household income

Table 6: Minimum travel spend as a percent of household income results

Minimum travel spend as a percent of household income	Number of households	Percent of households
0	19,040	16%
< 1%	83,504	69%
1 – 2%	12,106	10%
2 – 4%	3,485	3%
4 – 8%	1,922	2%
	120,057	**100%**

DISCUSSION

Macro-Level Resilience Analysis

The majority of the households in urban Christchurch exhibit a high level of energy resilience; 85% of households have the potential to meet all of their travel while spending less than 1% of their income on travel (by both public transport and private vehicle). The highest minimum travel spend required in the study area was 8% of household income. The least resilient households are those on the urban fringes, as they tend to be in lower density areas that are not near destinations nor well served by public transport. Some of these areas are also lower income. The model can also be used to investigate city-wide public transport improvements, which will be discussed in the presentation.

Micro-Level Resilience Intervention Analysis

Three households, each typical within its area, were selected for resilience analysis and to highlight potential interventions. The households, in Fendalton, Hallswell and Southshore, are shown in context of the rest of the city in **Figure 8**, and general information about each is shown in **Table 7**.

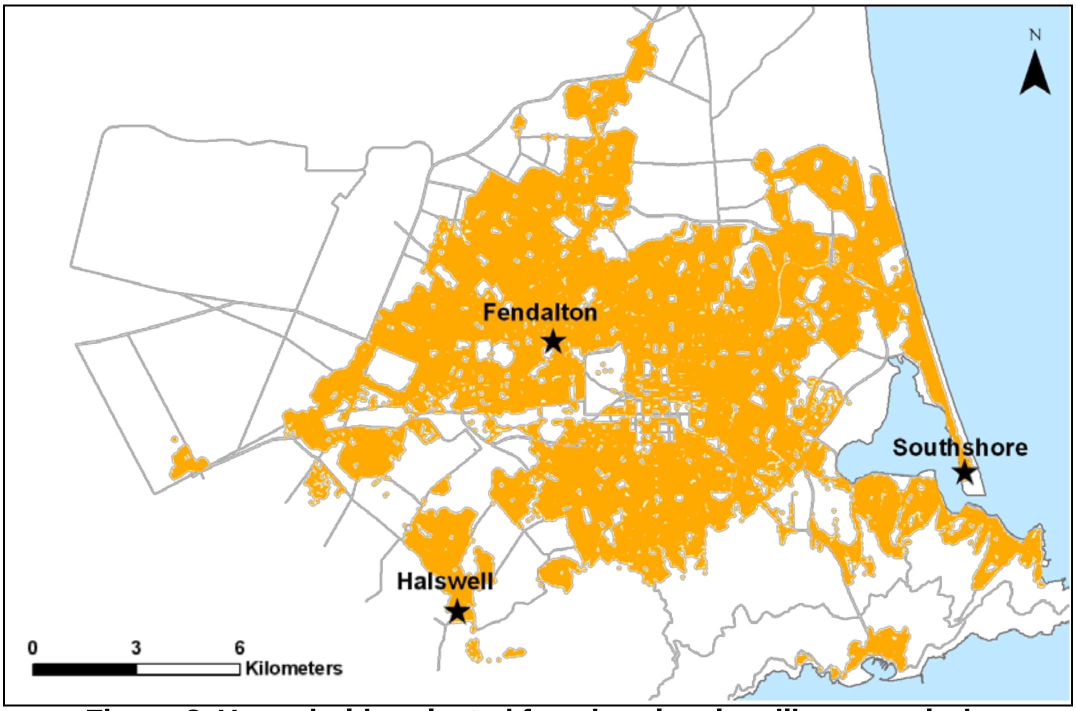

Figure 8: Households selected for micro-level resilience analysis

Table 7: Properties of each of the households

	Fendalton	Hallswell	Southshore
Income ($) - *census area median*	97,000	62,000	49,000
Distance to some destinations (km)	1	1.5	6
Distance to closest major shopping centre (km)	1.5	7	11
Distance to central city (km)	4	10	13
Bus routes < 500m	3	2	1

Fendalton

This household exhibits a large amount of transport choice, as well as a high income which reduces the relative financial effects of increasing fuel prices. The proximity of destinations and employment make it possible that all trips can be met by active modes; consequently, this household is already resilient. Education and Travel Demand Management schemes may assist the household in adapting.

Hallswell

Many trips can be met by active modes and public transport, although the AMA is only two as neither Employment nor Shopping can be fully satisfied by active modes. The current public transport system does not increase accessibility to any of the four key destinations. Improvements to the public transport system, such as express routes directly to the central city or creating suburban hubs from which higher frequency services operate, may increase resilience. Interestingly, as this area is targeted as a future growth node, new shopping (and potential employment) facilities to support the growing population will likely provide many resilience benefits to the existing population.

Southshore

Due to the isolation of Southshore, and poor transport connectivity to the rest of the city, it forms a worst-case energy resilience scenario. The household has an AMA of zero, as none of the key destinations can be accessed by active modes, although the addition of public transport allows them to reach Primary/Intermediate school. Overall, the household has limited choice for most of the travel they undertake. Simply due to the location, there are few viable resilience interventions; improving active mode links with the nearest shops, about 6km away, may be beneficial but this distance is beyond the active mode ability of the residents (as calculated from the Household Travel Survey). Travel on Demand public transport services may be viable, particularly if they link in to other services at a local hub.

Further Applications

The outputs of the model can be more generally applied to improving energy resilience outcomes within communities, for example:

- Enhancing the Benefit Cost analysis of proposed walking, cycling and public transport projects. The model inherently considers these modes as a linked system.
- Test the transport resilience impacts of variations in the composition of the private vehicle fleet, to investigate the potential for alternative fuels and increasing vehicle efficiency.
- Optimising the mix of land uses and residential density in mixed use developments.
- Combine with other metrics, such as the Deprivation Index or VAMPIRE score, to analyse areas likely to suffer from transport disadvantage.
- Assess accessibility changes over time due to forecast demographic changes.

Future development of the model will shift travel impedance analysis from a time basis to a cost basis. This will allow the inclusion of proxy measurements for the attractiveness and amenity of active mode and public transport routes, which will further assist in the Benefit Cost analysis of proposed projects.

CONCLUSIONS

Urban form, transportation networks and travel behaviour are determinants of transport energy demand. The household-level resiliency of transport activity systems to fuel price shocks and supply constraints has not previously been quantified, but has historically been considered low for contemporary western urban forms.

This paper introduces the *minimum energy potential* as an extension to the NZ Transport Agency accessibility modelling methodology developed by Abley Transportation Consultants. It is a measure of household-level energy (fuel) price resilience assessed at the city scale that can be implemented using GIS and Census data. The minimum potential for a household is a function of the age demography of the resident population, the proximity of destinations and the viability of active modes and public transport. The minimum potential contributes both an important new understanding to future transport and land-use planning, and a quantifiable measure of transport energy resilience.

Results of the case study investigated in this paper indicate that many of the residents of urban Christchurch exhibit a high level of energy resilience; 85% of households have the potential to meet all of their travel while spending 1% or less of their income. This is due to the high connectivity of transport networks and proximity of destinations for most households. Residents of the urban fringes tend to exhibit lower resilience as they have to travel further to reach their destinations, and have no option within the model other than to divert a greater portion of their income to meeting transport energy needs[3]. The model can be used at a range of levels to identify potential resilience interventions, as well as test proposed future land uses, demographic forecasts or specific developments.

REFERENCES

ABLEY, S. 2010. Measuring Accessibility and Providing Transport Choice. *Australian Institute of Traffic Planning and Management National Conference.* Brisbane.

ALGERS, S., ELIASSON, J. & MATTSSON, L.-G. 2005. Is it time to use activity-based urban transport models? A discussion of planning needs and modelling possibilities. *Annals of Regional Science,* 39**,** 767-789.

AUCKLAND CITY COUNCIL. 2008. *Economic Analysis for Auckland, July 2008* [Online]. author. [Accessed 27 August 2008].

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.

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**,** 548-559.

ENVIRONMENT CANTERBURY 2007. Regional Policy Statement, Proposed Change No.1, Chapter 12A, Development of Greater Christchurch; and section 32 Report [Online]. http://ecan.govt.nz/publications/Plans/RPSProposedChangeNo1FINAL2Notified28July2007.pdf [Accessed 9th April 2011]

ENVIRONMENT CANTERBURY 2011. Metro – Fares. http://www.metroinfo.org.nz/fares.html [Accessed 14th July 2011]

EWING, R. & CERVERO, R. 2010. Travel and the Built Environment -- A Meta-Analysis. *Journal of the American Planning Association,* 76**,** 265 - 294.

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**,** 146-153.

FRANK, L. D., SAELENS, B. E., POWELL, K. E., & CHAPMAN, J. E. 2007. Stepping towards causation: Do built environments or neighbourhood and travel preferences explain physical activity, driving and obesity? *Social Science & Medicine*, 65, 1898-1914.

HARWARD, E. & MUSSEN, D. 2008. *Fill up now before the fuel price shock hits* [Online]. Sunday Star Times. Available: http://www.stuff.co.nz/4576379a6442.html [Accessed 27 August 2008].

IACONO, M., LEVINSON, D. & EL-GENEIDY, A. 2008. Models of Transportation and Land Use Change: A Guide to the Territory. *Journal of Planning Literature,* 22**,** 323-340.

KENWORTHY, J. R. Year. Transport Energy Use and Greenhouse Gases in Urban Passenger Transport Systems: A Study of 84 Global Cities. *In:* The International Third Conference of the Regional Government Network for Sustainable Development, 2003 Fremantle, Western Australia.

LEE, Y., WASHINGTON, S. & FRANK, L. D. 2009. Examination of relationships between urban form, household activities, and time allocation in the Atlanta Metropolitan Region. *Transportation Research Part A: Policy and Practice,* 43**,** 360-373.

MINISTRY OF TRANSPORT 2008. *Detailed Travel Survey Information* [Online]. [Accessed 12th November 2010].

MINISTRY OF TRANSPORT 2011. *The New Zealand Vehicle Fleet: Annual Fleet Statistics 2010* [Online]. http://www.transport.govt.nz/research/Documents/The-NZ-Vehicle-Fleet-2010-Mar2011(2).pdf [Accessed 8th April 2011]

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**,** 249-268.

[3] These residents may have made a conscious decision that the 'costs' of increased travel times and expenses are worth the lifestyle benefits of living in their chosen location.

SAUNDERS, M. J., KUHNIMHOF, T., CHLOND, B. & DA SILVA, A. N. R. 2008. Incorporating transport energy into urban planning. *Transportation Research Part A: Policy and Practice,* 42**,** 874-882.

WANG, D. & CHENG, T. 2001. A spatio-temporal data model for activity-based transport demand modelling. *International Journal of Geographical Information Science,* 15**,** 561 - 585.