RISK OF ENERGY CONSTRAINED ACTIVITY-TRANSPORT SYSTEMS (*RECATS*)

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Abstract: A long-term strategic planning tool called *RECATS*© is introduced. It explores the link between urban form and susceptibility to fuel shortages in order to quantify a risk factor at a queried year in the future for a given urban form and travel demand configuration. *RECATS* includes interactive models for global peak in oil production, development scenarios for alternative or bio-fuels, and fuel rationing or supply management. On the transport side, *RECATS* allows the user to specify the distance, mode, and frequency matrix which has been determined for a given urban form using standard transport modelling. *RECATS* was applied to a case study in which four different urban development forms for Christchurch, New Zealand were simulated. Results show that all urban forms would lose and/or change trips according to the land use-transport system configuration options, but the risk to activities would be very different for different future cities.

Key Words: *Transport Planning, Urban Planning, Energy.*

1. INTRODUCTION

Over the past several years, there have been concerns about the long-term fuel availability and the implications to movement of people and goods. International agency reports have shown that the generation of fossil fuel is declining, whereas alternative (coal, solar, wind, biofuel, etc) energy sources do not produce enough energy that could substitute economically and environmentally traditional fossil fuel (Deffeyes, 2001; BTRE, 2005). Furthermore, recent world wide disruptions to fuel supply due to natural disasters and labour unrest have demonstrated the vulnerability of existing transportation systems. According to Newman and Kenworthy (1999), the global peak in oil production will reverberate through our cities. The combination of declining in energy supply, fossil fuel reliance and suburban growth represents an unsustainable trend in transport, because oil fuels the vast majority of the world's mechanised transportation: automobiles, trucks, planes, trains, ships, farm equipment and the military. Oil is also one of the primary ingredients for many chemicals that are essential to modern life (Hirsch *et al*, 2005).

Although many have already realized the looming prospects of future fuel availability, planning and research initiatives have yet to incorporate energy shortage/crisis risks. On one hand, world-wide strategic and long-term planning actions have focused on developmental matters such as urban form, community well-being, environmental sustainability and economic development, but they have almost ignored energy availability issues (Lim, 1997; Chatterjee and Gordon, 2006). On the other hand, state-of-the-art transport models and methods rarely consider energy as an integral part of the transport and activity systems (Greiving and Wegener, 2001; Ortuzar and Willumsen, 1994). Existing models for transport energy demand have concentrated on mode change and the effect on energy consumption. Some new work relates energy to spatial patterns of urban settlement (Cooper *et al*, 2002), but risk-analysis or reliability assessment of transport systems disregards any potential shortage and/or price increase scenarios (Nicholson and Dantas, 2004).

In order to develop urban development strategies that may contribute in reducing exposure to energy availability risks in shortage/crisis events, this paper introduces a long-term strategic planning tool called *RECATS* (Risk of Energy Constrained Activity-Transport Systems). This tool is based upon the principle that urban form and transport system changes through planning actions may affect future travel behaviour and create communities that are less reliant on energy, because energy efficient mode choices as well as location/distribution of activities can be achieved throughout the urban area. Therefore, *RECATS* explores the link between urban form and susceptibility to fuel shortages in order to quantify a risk factor at a queried year in the future for a given urban form and travel demand configuration.

This paper is divided into four sections. After this introduction, section two presents *RECATS* modelling principles and structure. Section three describes a case study in which *RECATS* was applied to assess the energy risks of four different urban development forms for Christchurch, New Zealand. Finally, section four summarizes the findings, main limitations and future research prospects to this study.

2. RECATS MODELLING PRINCIPLES AND STRUCTURE

RECATS brings together probabilities of permanent fuel shortage or crisis and travel demand analysis in order to estimate a risk factor posed to a given urban form in the future. The term “risk” expresses the chances and the impact of disturbances on travel demand patterns and consequently on urban activities due to unavailability or limitations in the supply of fuel. Based on a comprehensive review of world-wide energy supply, Dantas *et al*. (2007) have created a model, which estimates the probabilities of permanent fuel shortages. *RECATS* incorporates the probabilities of oil shortage events at five year intervals of each level of oil reduction, as shown in Table 1.

Given an urban form and a future energy availability scenario, *RECATS* computes a risk factor through a step-by-step adjustment of the original travel demand pattern. Figure 1 represents these steps, which are:
- The travel pattern without the fuel shortage/crisis event is determined using available data expressing current/observed travel distances, mode choices and essentiality levels;
- Energy consumption is calculated;
- Considering the available energy due to future reduction levels, consumed and available energy are compared;
- If energy consumption is above the availability threshold, travel patterns are modified, then

energy consumption is recalculated. The travel patterns are modified until the energy consumption levels are lower than the available energy; and

- The risk is computed considering the original and modified travel patterns and the oil crisis/shortage probability.

Table 1 Event Probability Matrix*

		2005	2010	2015	2020	2025	2030
SCENARIOS	Peak Production	0%	37.8%	79.2%	94.9%	99.0%	100%
	7% Voluntary Reduction	0%	3.5%	52.4%	88.4%	98.1%	99.7%
	10% Ration Reduction	0%	0%	29.4%	78.1%	95.9%	99.4%
	15% Ration Regulated Reduction	0%	0%	1.5%	46.1%	86.0%	97.6%
	20% Ration Enforced Reduction	0%	0%	0%	7.3%	59.3%	90.7%

*Source: Dantas *et al*. (2007)

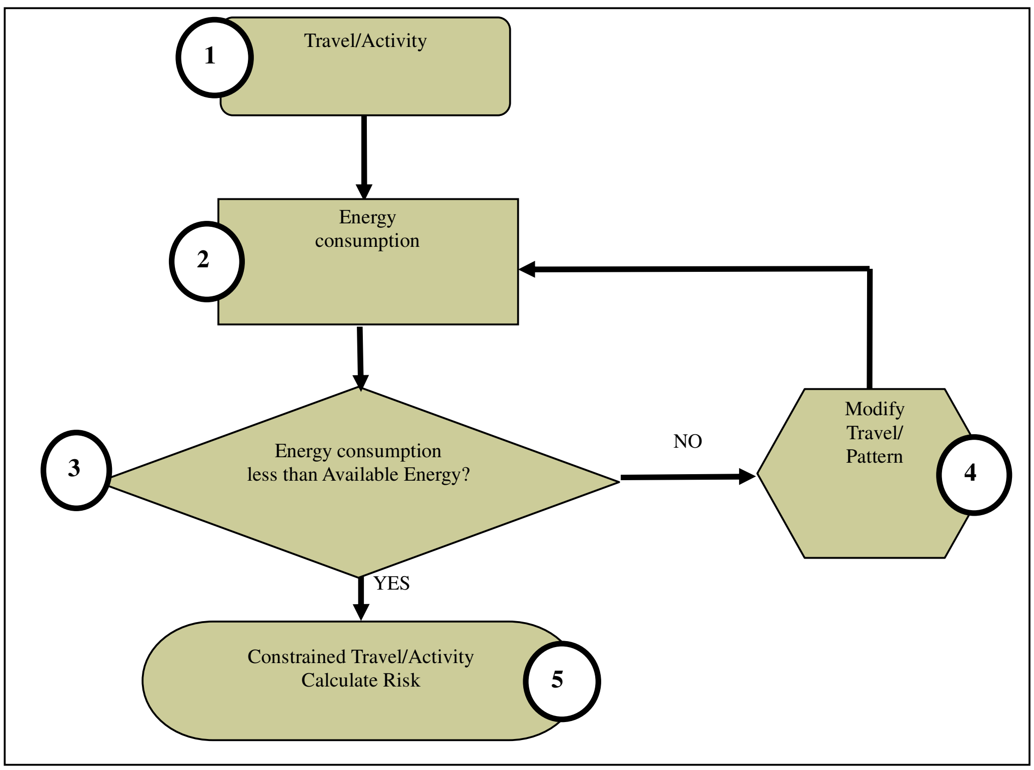


Figure 1 Schematic representation of the method steps

These steps are subsequently repeated for other urban form scenarios. The calculated risks are compared and assessed in retrospect to each scenario configuration. In order to adjust the travel demand patterns according to energy constraints of permanent fuel shortage event, *RECATS* incorporates the following assumptions:

- Urban communities would undergo significant transformation in order to cope with fuel availability constraints. Activities and travel behaviour would consequently change in their priorities and characteristics. Depending on the level of fuel availability, people would adjust their travel patterns, giving priority to specific activities in order to minimize disruption and

guarantee socio-economic, political and cultural continuity;
- People would adjust their travel demand according to degrees of Essentiality, which is individual metric used to decide whether trips represent an essential, necessary, or optional contribution to their wellbeing, socio-economic connection and happiness;
- According to the level of Essentiality of a trip, there would be two important types of changes in response to a fuel shortage/crisis:
  (*a*) Changing trip characteristics such as frequency, mode, distance, or destination are adjusted in order to preserve access to activities; and/or
  (*b*) Loss of accessibility to activities such as not making a trip that would have been made with unconstrained fuel.
- Losing accessibility would have a far higher impact. While changing behaviour may have associated costs and other effects, it would not be on the same scale as the impact of losing participation in activities;
- There would be three different levels of impact when accessibility to activities is compromised:
  (*i*) Low impact would occur if Optional trips were curtailed and/or if activities can be performed without traveling by using telecommunications (e.g. teleworking; teleshopping; etc).. It is assumed that elimination of these low essentiality trips would generate a low impact on wellbeing;
  (*ii*) Medium level impact would be felt if Necessary trips could not be made. If these trips could not be undertaken due to fuel constraints, then there would be a high impact on wellbeing of the household; and
  (*iii*) High level impact would occur if Essential trips were affected. The loss of these trips would cause extreme impact on the individual's wellbeing.

The following sub-sections present the mathematical description of *RECATS* and its functionalities.

2.1. Step 1 - Travel pattern without the energy shortage/crisis event

In this step, the characteristics of the urban form under analysis are converted into a travel pattern indicator (*T*) that expresses the level of activity without any disruption to energy supply, considering the Travel Demand (*TD*) for all modes and travel distance bins. Equations 1 and 2, respectively, represent *TD* and *T* for a given urban form. Figure 2 shows a schematic representation of the travel pattern indicator (*T*) as a Trip Length Distribution (*TLD*).

$$TD^{m,d} = MS^{m,d} * PO * \mu \tag{1}$$

$$T^{m,d,s} = TD^{m,d} * ES^{s} \tag{2}$$

where:
T = travel demand indicator per mode and distance bin and essentiality level;
TD = travel demand per mode and distance bin;
PO = Population in the study area;
μ=Average trips per person per day;
MS = Matrix of mode split per distance bin (or range of travel that is common to a group of trips);
ES = Vector of relative split of trips essentiality; and
$^{m,\,d,\,s}$ = refer to a particular mode, distance bin and essentiality level , respectively.

2.2. Step 2 - Energy Consumption

This step focuses on calculating the energy consumption using *TD* (from step 1), population and energy efficiency data observed in the study area. Equation 3 represents mathematically the energy consumption (E) calculation for a given urban form.

$$E = \sum_m \sum_d TD^{m,d} * EC^{m,d} DB^d \tag{3}$$

where:
$EC^{m,d}$ = Matrix of energy consumption per mode and distance bin; and
DB^d = Vector of distance bins (mid distance point).

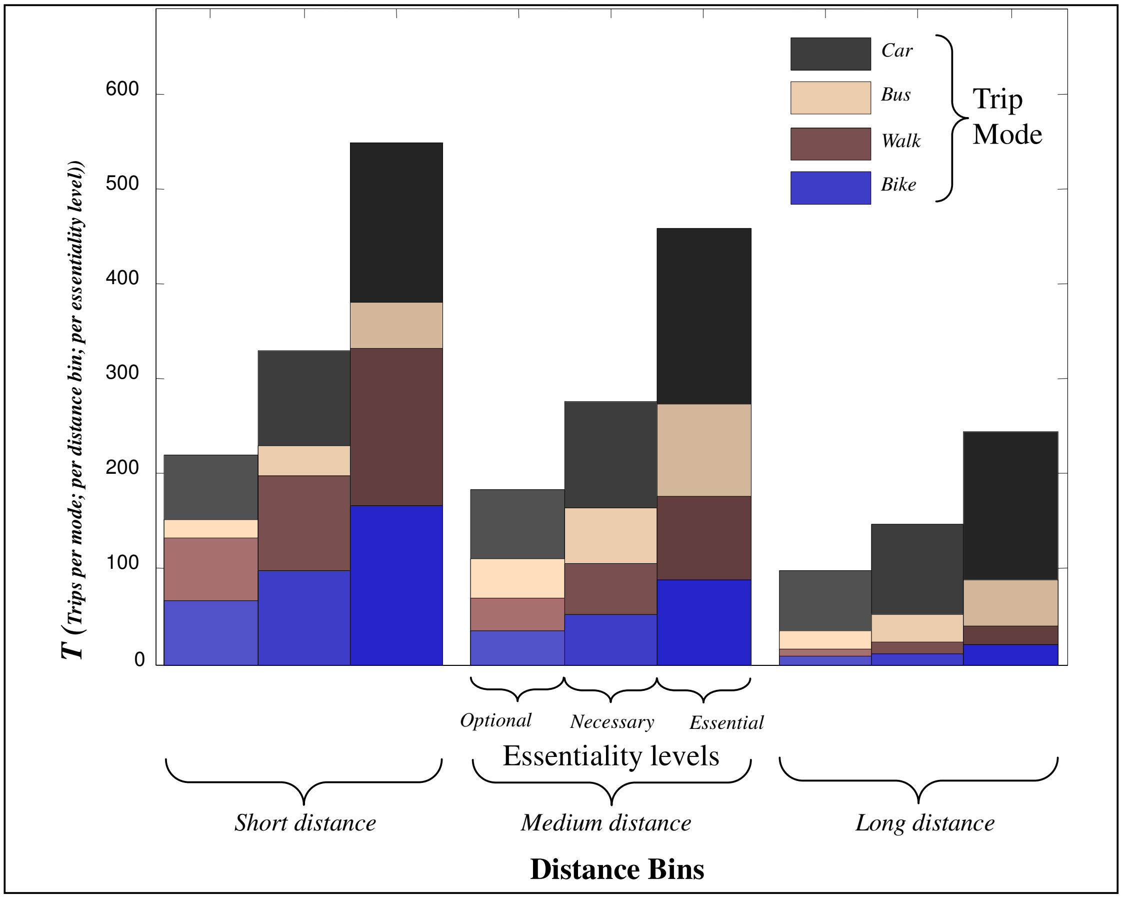


Figure 2 Schematic representation of the travel pattern indicator (T)

2.3. Step 3 – Comparison between Consumed and Available Energy

The energy consumption (E) computed in step 2 is compared against predicted available energy (AE) considering future supply disruption scenarios. AE is calculated using Equation 4.

$$AE_e = (100\% - \Phi_e) * E \tag{4}$$

where
AE_e =available energy in a supply disruption/shortage event e; and
Φ_e =energy reduction level.

Using Equation 5 the need or not for changes in energy consumption is verified.

$$ME_e = \begin{cases} 0; E \leq AE_e \\ 1; E > AE_e \end{cases} \tag{5}$$

where
ME_e = integer value indicating whether or not modification in travel demand pattern indicator

(T) and consequently energy consumption is required in a supply disruption/shortage event e.

2.4. Step 4 – Modification of travel patterns to cope with energy availability

The travel demand pattern indicator (T) is modified in this step until energy consumption is below (or equal) to the available energy. Adjustments in the travel demand patterns (e.g. up-take of ride-sharing or shifting to public transport or walking) are based upon the principle of preservation of Essential or Necessary trips. This is achieved by sequentially changing: the transport mode (car; bus; walking/cycling); travel distance (long, medium and short distance bins). Thus, the following four steps are taken to modify the original travel pattern T into a modified travel pattern Ψ:

- *Step 4.1- Compute trip combining considering AE_e*: Two trips are combined into one, effectively reducing the number of trips without losing any activity;
- *Step 4.2- Compute mode changes considering AE_e*: A single trip is shifted to lower energy consumption mode, keeping the purpose and distance bin the same;
- *Step 4.3- Compute bin shift considering AE_e*: A single trip is moved to a shorter distance bin than its original bin, whereas the mode and purpose are kept the same. This change represents that the trip is shifted to closer activity than originally observed; and
- *Step 4.4- Compute trip deletion considering AE_e*: A single trip in a given travel distance bin, travel purpose and mode choice is eliminated, considering that there is no energy available to perform it. Trip deletion can either be random, or prioritised, where the non-essential, long distance trips are removed first.

Ψ is subsequently used to estimate the modified energy consumption (ξ) as previously defined in step 2 and equation 3. Travel patterns are modified until energy consumption (ξ) converges to meet the energy availability criteria (i.e. ME_e=0).

2.5. Step 5 – Computing the risks of energy supply disruption / shortage

Using the results from previous steps, the risk (R_e) to travel/activities due to an energy supply disruption/shortage event e is calculated. Equation 6 presents the mathematical formulation to compute R_e. It is the probability of an event e multiplied by an impact factor, which expresses the disparities between the participation based on travel pattern before and after disruption/shortage.

$$R_e = P_e * \left(\frac{\sum_m \sum_d \sum_s T^{m,d,s} * IW^s}{\sum_m \sum_d \sum_s \Psi^{m,d,s} * IW^s} - 1 \right) \tag{6}$$

where

P_e = Probability of occurrence of an energy event e; and

IW^s = Vector of Impact Weight for each change/loss in travel patterns at the essentiality level s.

Equation 6 shows that if the same level of travel/activity is carried out after the oil crisis/shortage, i.e. the weighted sum of T and Ψ are the same, the estimated risk is zero. Figure 3 represents graphically the relationship between probability and impact affecting risk levels, i.e. the higher the probability and impact are, the higher the risk is.

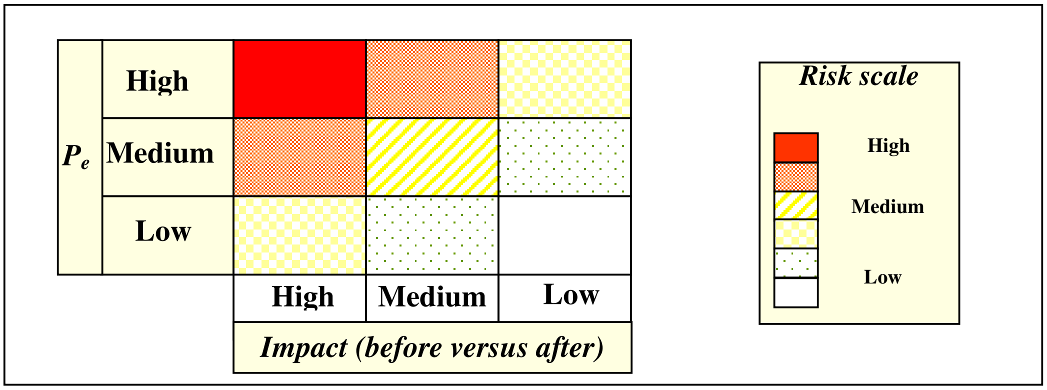


Figure 3 Risk levels as a function of probability and impact

The repetition of these steps for other scenarios will produce risk indicators that should be comparatively assessed in order to identify the urban forms, transportation-activity system configurations and mitigation options that may minimize the impacts of potential fuel shortage/crisis. At the two extremes, the highest risk would be posed if zero trips (Ψ=0) were performed after the fuel shortage/crisis. On the other hand, the lowest risk would be occur if no changes in the travel pattern (Ψ=T) were observed even after shortage/crisis. In practice, risks will be similar in magnitude and will depend on the urban area characteristics (e.g. population, travel demand characteristics, etc).

2.6. RECATS functionalities

RECATS has six main input areas as shown in the upper-left side of Figure 4. They are:

- Mode and Distance Split: This input area defines the percentage of daily trips expressing the travel pattern (vector *T*), which is in accordance with the given urban form to be analysed;

- Energy Constraint: For a given forecast year (e.g. 2030), the percentage reduction from non-disrupted (unconstrained) consumption is defined in the Reduction Event (e.g. 5%) drop-down option. Using these input data *RECATS* returns the estimate probability (e.g. 99.9%) of the energy disruption/shortage event occurring. The event probability is shown graphically in the upper-right corner of Figure 4.

- Relative split of trips essentiality: This input area further divides the travel pattern (vector *T*) according to essentiality (*ES*); the resulting travel behaviour (unconstrained) is shown in the lower left trip length distribution graph of Figure 4;

- Mitigation Options: This comprises four options that rule how the travel pattern indicator (*T*) is modified (Ψ) in order to cope with the energy constraint. These options relate to allowing individuals to change the trip destinations, or mode choice, or combining (or chaining or increase in vehicle occupancy), or deletion of trips according to their level of essentiality (*ES*);

- Urban Forms: This allows *RECATS*' users to switch between pre-defined urban forms and data/results associated with each one of them; and

- Fleet Efficiency: This allows the consideration of different consumption rates (litres/100km) per distance bin for different travel modes (car and bus).

Using these input data, *RECATS* is run (Calculate button) and after multiple iterations are made, results of the risk and impact levels for each urban form are presented on the screen (Analysis Output). The modified travel pattern indicator (Ψ) is also shown graphically (Travel Behaviour After Fuel Constraint) in the lower-right side of Figure 4.

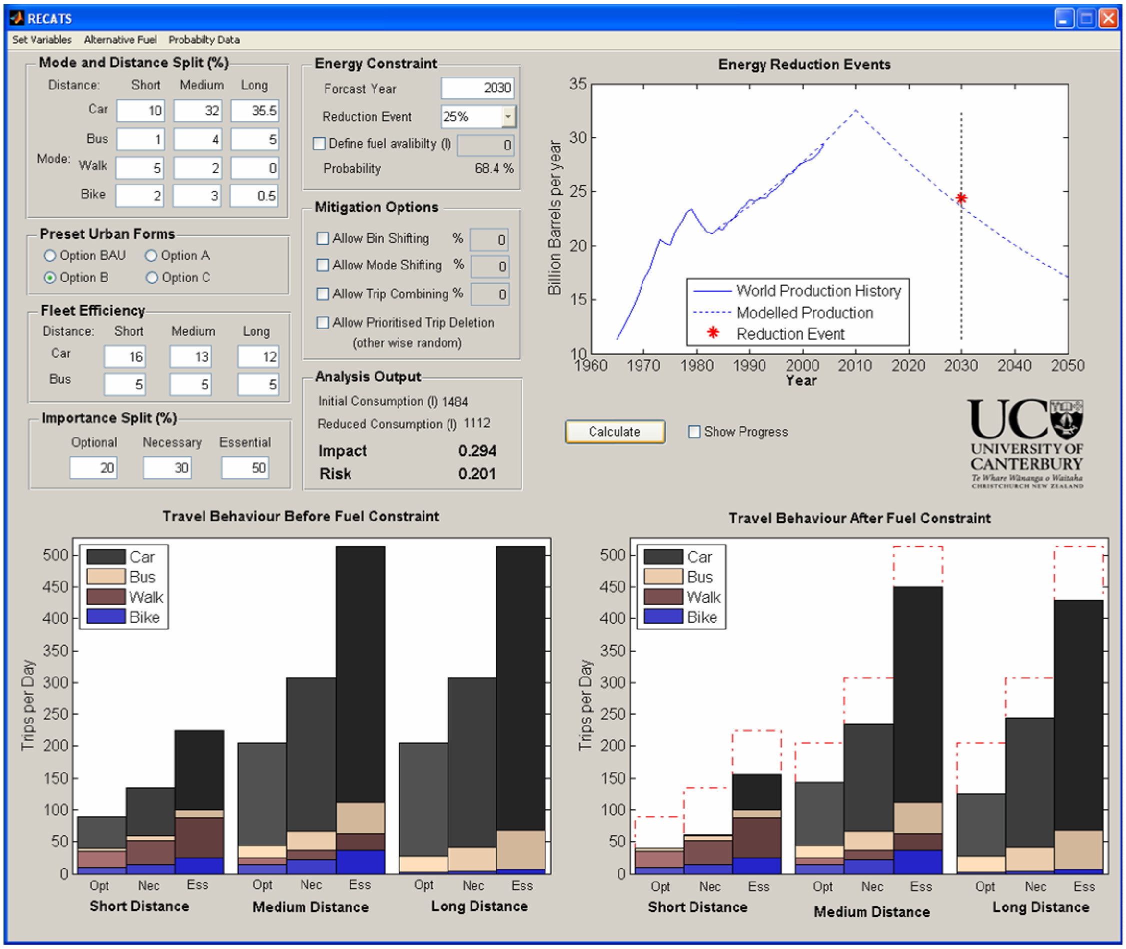


Figure 4 *RECATS* main window interface.

3. CASE STUDY

This case study aimed to demonstrate how *RECATS* was applied in the context of the consultation process of the Urban Development Strategy (UDS) of the Greater Christchurch, New Zealand. The following sub-sections present the context of the UDS and its urban form options; the characterisation of the urban forms and travel demand patterns; energy supply scenarios; case study assumptions; and results.

3.1. Greater Christchurch Urban Development Strategy – Urban Development options

The Greater Christchurch Urban area has experienced significant changes over recent years and predicted growth will require immediate planning interventions to cope with future community needs and expectations. For example, there has been a considerable fluctuation in population growth, which is due to natural increase and internal and external migration. In a 10 year period (1991-2001), the estimated census population changed from 289,071, to 316,227 (CCC, 2003). Over 400 people make the city their home every month. The population in 2041 is estimated to reach 500,000 people (UDSF, 2004). Also, Buchanan (2004) has identified various changes in population and employment densities as well as significant development tendencies observed in the north part of the city. Population profile changes associated with other development tendencies are likely to eventually create extra demands in terms of basic services and utilities (housing, water, waste treatment, health, education, transport, etc.).

A UDS forum has been constituted to discuss, elaborate, assess and communicate a series of planning actions to manage the predicted growth of the Greater Christchurch area. The forum, established in 2005, is part of a multi-organisational participatory planning effort, which comprises representatives from the Christchurch City Council (including the former Banks Peninsula District Council) Selwyn and Waimakariri District Councils, Environment Canterbury (the Regional Council), Transit New Zealand and a cross-section of local leaders drawn from community, business and government organisations (UDSF, 2006).

As an initial step to develop the UDS, the forum has examined four options of urban forms and their related characteristics, needs and envisaged challenges. The urban forms are very distinct in the way future development is spatially distributed throughout the metropolitan area. Their main characteristics are:
- Option Business as Usual (BAU): Non-interventionist in which land use comprises 79% new subdivisions (Spread across districts in towns and rural subdivisions), 21% urban renewal (Christchurch inner suburbs) and Mixture of housing types;
- Option A: Concentration in which growth is limited in district townships and high densities at some high amenity sites
- Option B - Consolidation of existing built areas or expansion into immediately adjacent areas;
- Option C - Dispersal or low-density land use that comprises separation of homes, jobs, and services; absence of strong urban activity centres and growth occurring adjacent to but outside the city centre with a general outward migration of people.

The following sub-sections present the characterization of the travel demand patterns; energy supply scenarios; case study assumptions; and results.

3.1 Travel demand patterns

Considering the UDS context, the travel patterns for each urban form option were defined based upon information gathered from the various UDS documentation, international scientific and technical literature and travel demand modeling previously conducted by the Christchurch City Council.

Initially, travel distances were divided into three main distance bins. This was based on a combined assessment of all transport modes and their respective travel distances (UDSF, 2004; UDSF, 2006). For example, the Christchurch Transport Model (CTS) estimates that average vehicle travel distance will be 7.4 km in 2021, but it also acknowledges that most trips are short distances. Therefore, values shown in Table 2 represent a general combination of all trips by all modes and purposes.

Table 2 2021 Estimated Travel Distance Bins.

	Distance bin		
	d=1	*d*=2	*d*=3
Distance (km)	0-1.5	1.5-6	6>
Average distance per bin	0.75	3.5	9.5

Based on Buchanan (2004), Transfund (2000) and Denne *et al* (2005), the relative split of essentiality levels were given as: 20% Optional (s=1); 30% Necessary (s=2); and 50% Essential (s=3).

Using the definition of the distance bins (Table 2), the mode split (vector *MS*) is divided into 4 main transport modes, namely: car (*MS* 1), public transport (*MS* 2) and other non-energy consuming modes walking (*MS* 3) and cycling (*MS* 4). Table 3 summarizes the mode split for each option, with the total adding up to 100 (CCC, 2003).

For example, in Option A, car mode (*MS* 1) comprises 75% (17+36.5+21.5%) of the total number of trips, whereas public transport (*MS* 2) and other modes (*MS* 3 and 4) cover, respectively, 13, 8 and 4% of the total number of trips.

Table 3 2041 mode split for each development option and distance bin.

		Option BAU			Option A			Option B			Option C		
		d=1	*D*= 2	*D*=3	*d*=1	*d*= 2	*d*=3	*d*=1	*d*= 2	*d*=3	*d*=1	*d*= 2	*d*=3
MS	**1 (car)**	12.	36.0	37.0	17.0	36.5	21.5	10.0	32.0	35.5	10.0	30.0	51.0
	2 (bus)	0.0	1.5	2.5	2.0	8.0	3.0	1.0	4.0	5.0	0.0	1.0	2.0
	3 (walk)	5.0	0.5	0.0	7.0	1.0	0.0	5.0	2.0	0.0	0.0	0.5	0.0
	4 (bike)	2.0	3.0	0.5	2.0	2.0	0.0	2.0	3.0	0.5	2.0	3.0	0.5

Using Equation 1, travel demand (*TD*) was calculated. Table 4 presents the results considering the mode slip (Table 4), 500’000 inhabitants in the study area and 5 trips per person per day. These results were subsequently used to calculate the travel demand indicators ($T^{m,\ d,\ s}$) and Trip Length Distribution (*TLD*).

Table 4 2041 Estimated Daily Travel Demand (thousand trips) per mode, distance bin and urban form

		BAU Option			Option A			Option B			Option C		
		d=1	*d*=2	*d*=3	*d*=1	*d*=2	*d*=3	*d*=1	*d*=2	*d*=3	*d*=1	*d*=2	*d*=3
	1 (car)	300.0	900.0	925.0	425.0	912.5	537.5	250.0	800.0	887.5	250.0	750.0	1275.0
M	2 (bus)	0.0	37.5	62.5	50.0	200.0	75.0	25.0	100.0	125.0	0.0	25.0	50.0
S	3 (walk)	125	12.5	0.0	175	25.0	0.0	125.0	50.0	0.0	0.0	12.5	0.0
	4 (bike)	50.0	75.0	12.5	50.0	50.0	0.0	50.0	75.0	12.5	50.0	75.0	12.5

Also impact weigh vector (IW^s) was defined for this case study. Trips losses are computed as follows:
- Loss in optional trips (s=1) have a impact weight of 2;
- Loss in necessary trips (s=2) have a impact weight of 3; and
- Loss in essential trips (s= 3) have a impact weight of 4.

3.2 Energy Consumption

Considering the travel demand patterns and an average petrol consumption rate (10 litres per 100 km), the energy consumption for each urban form for vehicle travel was calculated using equation 3. Results are shown in Table 5.

Table 5 Energy consumption for each urban form option (million litres/day)

	Option BAU	**Option A**	**Option B**	**Option C**
E	1.536	1.151	1.483	1.852

3.3 Future development scenarios using RECATS

In order to perform the simulations, major assumptions were made. They are:
- Relative split of trips essentiality would not change after the fuel shortage/crisis event;
- No special provision of fuel would be made to public transport;
- Loss of trips is prioritized on the basis of essentiality levels and impacts weights;
- Distance bins would not change after the fuel shortage/crisis event;
- Location of activities would not change after the fuel shortage/crisis event;
- Changes in travel mode and travel distance would not result in impact;
- No mitigation options would be applied after the fuel shortage/crisis event; and
- Vehicle efficiency and occupancy would not change after the fuel shortage/crisis event.

Based on these assumptions, four scenarios of future development were simulated using *RECATS*. For each scenario, an energy reduction event occurring in 2041 was defined according to estimated probabilities (Table 1)**.** Table 6 and Figure 5 present the results of the scenario simulations. For example, Scenario 1 refers to a low energy reduction event (7%), which has a 100% probability of occurrence until 2041. Scenario 1 results show that Option C would pose the highest risk to urban activities, while Option A would have the lowest risk level.

RECATS was also used to calculate changes in travel patterns due to oil unavailability. For each scenario, significant changes in the travel demand patterns are observed in modified Trip Length Distributions (*TLD*). Table 7 shows the modified travel demand profiles for scenario 4 (20% energy reduction and 99.9% probability). It is observed that a significant portion of optional trips would be lost in all urban form options. Once again, Option C would experience the highest number of lost trips (90%). All these optional trips would be lost in the mode car, mostly due to energy efficiency levels of public transport travel.

Despite significant changes in travel patterns, Options A and B would generate the lowest levels of impacts to the community. There would be the need to eliminate a considerable amount of Long distance-Optional Trips, but there would also be the substitution of a many car trips to energy efficient modes due to the particular land use patterns and the transportation system characteristics of Options A and B. These options would produce slightly different performances if considered the difference in terms of the number of eliminated trips (18 thousand), which is considerable and directly related to motorized travel Option A would allow for the extensive use of walking and cycling, whereas Option B would still depend a great deal on car and bus modes.

These risks and impact results have been presented to the USD forum, which has decided to explore Options A and B in detail, in order to also assess other indicators of community well-being (health, education, environment, economic performance, etc.

Table 6 Risks of future development scenarios

			Risk (*1000)			
#Scenario	**Energy Reduction**	**Estimated Probability (%)**	**Option BAU**	**Option A**	**Option B**	**Option C**
1	**Low (7%)**	100	24	18	23	28
2	**Medium (10%)**	100	34	25	33	41
3	**Medium-High (15%)**	100	59	56	57	63
4	**High (20%)**	99.9	117	105	110	126

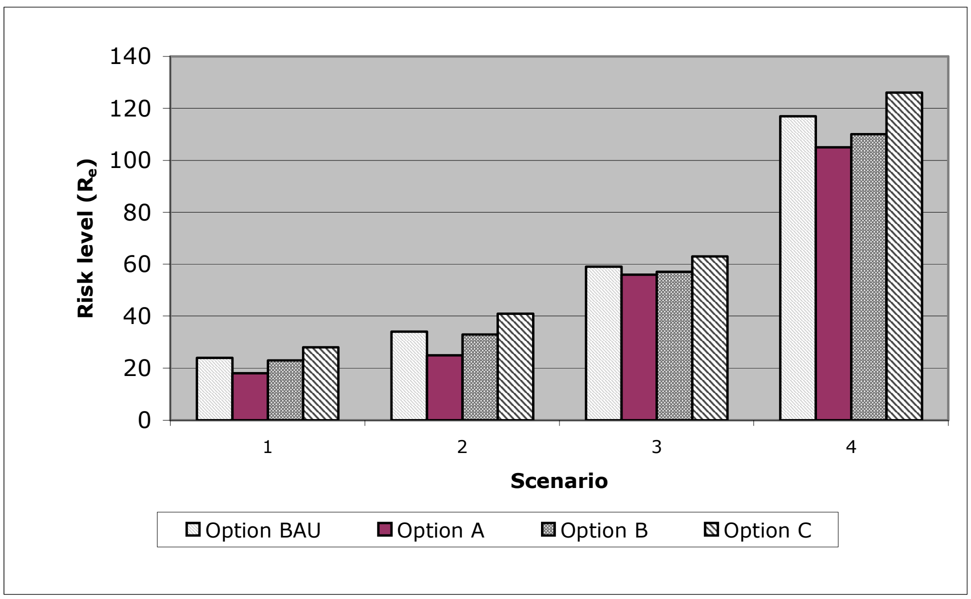
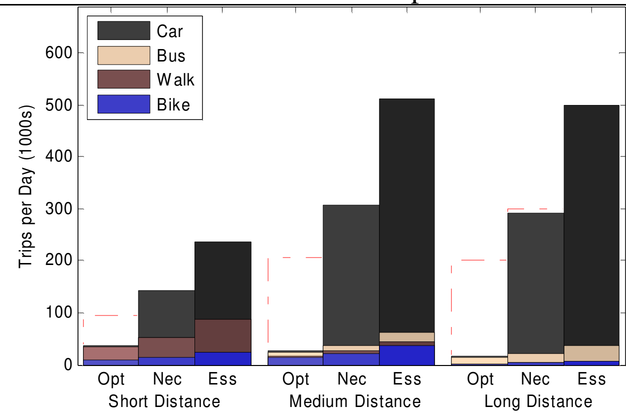


Figure 6: Risks results for energy reduction scenarios

Table 7 Scenario 4 Modified *TLD* for each urban form option

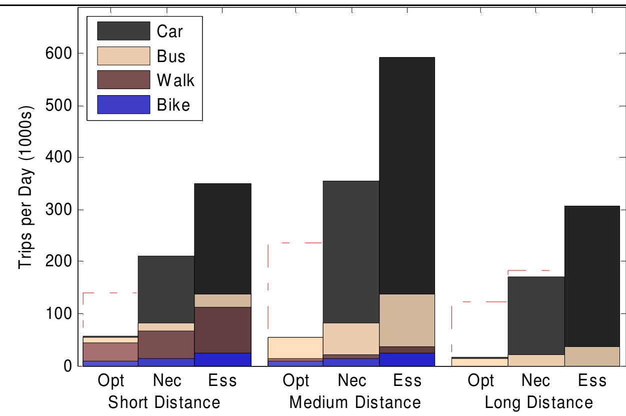
Option Business as Usual:

- Optional Trips must be reduced by 84%;
- Necessary trips must be reduced by 1%; and
- 17% reduction in car travel; and
- Loss of 430 thousand trips.



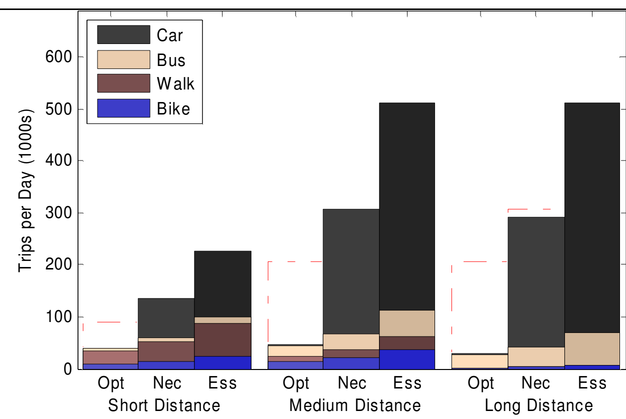
Option A:

- Optional Trips must be reduced by 74%;
- Necessary trips must be reduced by 1.9%;
- 15% reduction in car travel; and
- Loss of 381 thousand trips.



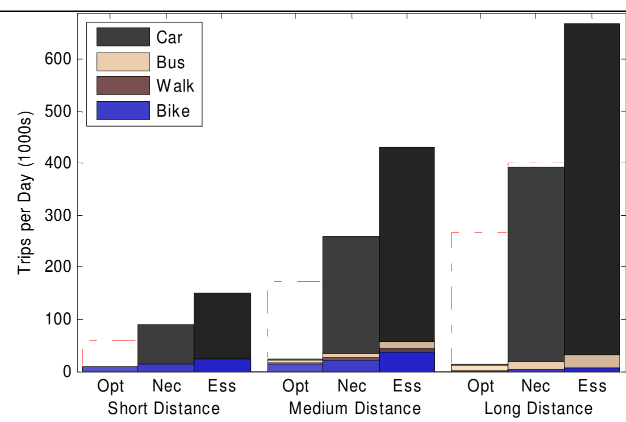
Option B:

- Optional Trips must be reduced by 72%; and
- Necessary trips must be reduced by 2%;
- 16% reduction in car travel; and
- Loss of 401 thousand trips.



Option C:

- Optional Trips must be reduced by 90%;
- Necessary trips must be reduced by 1%;
- 18% reduction in car travel; and
- Loss of 460 thousand trips.



4. CONCLUSIONS

The most important contribution of this research is the concept that energy shortage risks can be quantified, assessed and considered as part of urban and transportation planning decisions. *RECATS* is presented as a planning instrument that can be used to engage all involved parties in understanding how urban development options are likely to produce different outputs in terms of exposure to a permanent fuel shortage event. This is possible because *RECATS* combines a simple user-interface allowing quick modifications to urban form options and graphical outputs in terms of the impacts in travel demand patterns.

Also, *RECATS* is based on a new concept of transportation modelling in which travel demand patterns and changes are subject to availability of energy. The proposed an model tracks travel behaviour change and takes account of the impact associated with these changes. When energy becomes constrained, people will act to preserve their participation in activities by changing mode, efficiency or destination. These changes represent an impact which may incur costs or disruption. If fuel shortages are large enough, people will preserve their necessary and essential trips at the expense of their optional trips. Eliminating these optional trips may not degrade the household's wellbeing, but it will have some impact on general economic activities and on social connections. When the participation in necessary activities becomes curtailed, then the impact may include loss of community participation and may limit educational and economic opportunities. The highest impacts, including risks to health and inability to participate in work or shopping activities, are indicated for fuel shortages that require elimination of essential trips.

As a demonstration of RECATS potential, we applied it to a case study involving the long range growth planning for the Greater Christchurch Urban Area. Scenarios for four different growth patterns to 2041 have been modeled by the regional planners; a business as usual, concentrated CBD, consolidated centers, and dispersed urban sprawl. The travel demand patterns and mode adaptability models were developed for each growth pattern in 2041 assuming no fuel constraints. Then four different fuel shortage events, 7%, 10%, 15%, and 20% energy reductions, were imposed on the development patterns and the impacts calculated. The results of the case study were quite clear. The people living in low-density sprawled urban forms with very few work or resource destinations accessible by public transport, biking or walking, are at a higher risk than people living in concentrated activity areas with closer access to production and work activities.

The main limitation of our study is that very limited data on travel behaviour in energy or oil shortage/crisis is available. This limits the extent to which land use and travel demand modelling can be applied to forecast changes in behaviour and activities in shortage/crisis event. We envisage that further research should focus in developing new methods to obtain data/information about travel behaviour under energy constraints. Also, *RECATS* could be applied to assess the effects of mitigation options that may contribute to reduce energy risks and assist the development of urban transport policies.

ACKNOWLEDGEMENTS

This research project was supported by a research grant from Land Transport New Zealand. The authors wish to acknowledge the support and advice of the Christchurch City Council personnel and all transport engineering practitioners that participated in the end-users workshops.

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