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URBAN PLANNING AT THE MICRO SCALE CONSIDERING TRANSPORT ENERGY DEPENDENCE

PLANEJAMENTO DE MICROÁREAS URBANAS CONSIDERANDO A DEPENDÊNCIA DE ENERGIA POR TRANSPORTE

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DEDICATION

For my wife Nino and our children Anna and Noah.

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Foremost to God.

To my wife, Nino, for constant support and constant encouragement.

To my family and all the support and warmth provided throughout my doctorate.

To my wife’s family for their support and belief in me.

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RESUMO

SAUNDERS, M. J. **Planejamento de microáreas urbanas considerando a dependência de energia por transporte.** 2010. Tese de Doutorado – Departamento de Transportes, EESC, Universidade de São Paulo, São Carlos, 2010.

O alto consumo de energia nos transportes urbanos é diretamente influenciado pelo grau de dependência energética das formas urbanas e dos sistemas de transportes. Como o desenvolvimento de novas tecnologias veiculares e políticas de uso do solo ainda não foi capaz de produzir reduções significativas no grau de dependência energética dos transportes urbanos, defende-se aqui que uma legislação mais restritiva de uso do solo, combinada com novas ferramentas de Sistemas de Informações Geográficas, constitui-se em uma condição necessária para enfrentar a questão da dependência energética. O objetivo deste projeto é desenvolver uma estrutura conceitual em plataforma SIG, que possa ser usada como ferramenta de planejamento para o desenvolvimento urbano, capaz de reduzir drasticamente a dependência energética do transporte urbano. A ferramenta desenvolvida recebeu a designação Especificação de Energia para Transporte (ou TES, da sigla em inglês *Transport Energy Specification*), e destina-se a medir o nível de dependência do transporte urbano em relação a aspectos como o comportamento de viagens, escolha modal e aspectos espaciais dos elementos urbanos. A TES foi concebida para ser usada como elemento regulatório do uso do solo, sob o ponto de vista da eficiência energética, a partir da especificação de um valor máximo para o limite de dependência energética decorrente de modificações em áreas urbanas existentes ou em novos loteamentos. A implantação de uma estratégia de regulação de uso do solo baseada no conceito de "dependência energética" pode ser alcançada através de uma legislação de zoneamento e de incentivos, inclusive financeiros, para determinadas tipos de uso (residências, supermercados, creches, etc.). Estudos de caso com a ferramenta proposta para avaliação do grau de dependência energética foram conduzidos em cidades selecionadas na Alemanha, Nova Zelândia e Brasil, de forma a contemplar diferentes tipos de arranjos de vizinhança e de sistemas de transportes. Os resultados encontrados confirmaram os benefícios, já apontados por outros pesquisadores, de áreas com elevadas densidades e uso misto em zonas urbanas. Novas análises, estudos de caso e discussões com governos locais são necessários para fazer do TES parte de políticas futuras de desenvolvimento urbano.

Palavras-chave: planejamento de uso do solo, transporte sustentável, energia de transportes, planejamento urbano.

ABSTRACT

SAUNDERS, M. J. **Urban planning at the micro scale considering transport energy dependence.** 2010. Doctoral Thesis – Transport Department, University of São Paulo, São Carlos, 2010.

High urban transport energy consumption is directly influenced by the level of transport energy dependence of urban forms and transport systems. Despite the introduction of new land use policies and vehicle technologies, dramatic reductions in urban transport energy dependence are not yet being observed. It is proposed that stricter land use regulations coupled with new GIS tools are required that specifically tackle the energy dependence issue. The objective of this project is to design a GIS tool that could be used within an urban development framework to dramatically reduce urban transport energy dependence. A tool was developed and named the Transport Energy Specification (TES). The TES measures urban transport energy dependency from travel behaviour, mode use and spatial data inputs. The TES is designed to be used as an energy based land-use regulation inside an urban development framework by specifying a maximum allowable energy dependency limit for land use modifications in existing urban areas and new developments. Implementation of the "energy dependency" land use regulation will be achieved through zoning and providing financial or other incentives for the specific desired land use activities (residential, supermarkets, kindergartens etc.). Trials were performed in Germany, New Zealand and Brazil, allowing different urban neighbourhoods and transport systems to be measured with the TES energy dependency measurement tool. The measurements confirmed similar findings from previous researchers regarding the benefits of high density areas and mixed activities in urban areas. Further analysis, trials and workshops with local governments will set in motion the process of including the TES into future urban development policy.

Key-words: land use planning, sustainable transport, transport energy, urban planning

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1. Introduction

There is no doubt that transport energy makes up a large share of total world energy and despite efforts to increase the use of renewable energy in transport, transport energy is still, even in ethanol producing Brazil, currently largely supplied by petroleum based resources. The problem associated with high energy use from a transport energy security viewpoint is not so much related to the level of energy consumption but the level of transport energy dependence. An example from Kenworthy and Laube (1999, p. 24) illustrates this difference: when transport energy (oil) shortages occurred in the 1970s long queues and violence were observed at petrol stations in the USA whereas in the Netherlands highways were opened for people to roller-skate to work. The absence of transport energy in the Netherlands did not severely affect people from accessing their activities: work, recreation, shopping etc. The Netherlands has a very low dependence upon transport energy compared with many cities in the USA and the world.

1.1. Justification for research

> The coordination and the integration of transport policies with urban development policies that promote the utilisation of more efficient transport systems from the point of view of energy consumption, can and should be considered. Currently all energy and any form of energy should be used in the most rational way possible, strategies in this direction should be tested and prioritised (D’AGOSTO; BALASSIANO, 2001).

Transport energy shortages or even reductions have the ability to severely affect access to activities throughout the world, as noticed in the 1970s and 1980s fuel crises and the 2000 fuel strikes in the UK (POLAK; BELL; THORPE, 2003).

There is a big difference between a lack or reduction of transport energy making access to activities uncomfortable and making access nearly impossible. This difference lies largely in the use of land or the urban design of a city and to a lesser extent transport systems' efficiency and technology. It can be argued that technology is improving, transport systems and private vehicles are becoming less energy intensive and new energy sources are becoming available (DUDSON, 2000). However, heavy reliance on energy from any source, renewable or otherwise, brings risks to transport systems. By far the most secure way for city planners to provide low risk continuous access to urban activities is to create urban areas that are not dependent upon any form of transport energy for functionality.

Urban areas are currently heavily dependent upon transport energy because of their urban density and land use configuration characteristics. This may have occurred because traditional planning and policy measures are too soft to dramatically impact energy dependence. Therefore, to reduce future urban transport energy dependence, stricter policy measures and GIS tools are required that relate land use and transport system development to transport energy dependency.

Transport and land use policies found in both local and national government are commonly loosely written goals stating, for example, that energy efficiency will be pursued. The effectiveness of these loose policies therefore relies on the type and quality of methods and regulations used to achieve the stated goals. Where the goal is urban transport energy reduction, strict regulations are required that effectively control urban land use and transportation system development. Incorporating transport energy dependence into land use policy regulations is a new approach that should be beneficial because land use defines density and generates trips which are distributed among land use activities, defining the demand for transport energy.

1.2. Objectives

A new concept for an urban development framework that incorporates transport energy dependence is proposed. The urban development level proposed is the micro-scale level. It is proposed that the planning concept will be designed to direct micro-level (neighbourhood) development after determination of major transit routes. It is hoped that this could include directing development around rapid transit nodes using a Transit-Oriented Development (TOD) higher level planning document or for directing new energy efficient suburban development for peripheral city locations. The concept involves creation of a policy controlled regulation or specification for urban and transport system planning and development. This specification requires urban areas to meet a defined transport energy dependence limit. Development would then be constrained by this limit/specification. Transport energy dependence then needs to be quantifiably measurable to determine whether or not urban areas meet the defined specification.

In order to quantifiably measure transport energy dependence a new tool based on GIS was developed, the Transport Energy Specification (TES). The aim of developing the Transport

Energy Specification is to be able to measure energy dependence of different urban forms and transport systems at the neighbourhood level through incorporation of the following variables:

- Spatial separation of activities
- Energy consumption of available modes
- Accessibility of important neighbourhood activities

1.3. Scope

The scope of this work involves proposing an urban development framework and developing a GIS based tool to be used within the proposed framework. The tool will be tested with three case studies in remarkably different countries around the world, including both developed and developing countries. A relationship correlating the GIS tool energy dependence result to actual energy consumption will be investigated with recommendations made to further develop and calibrate this relationship for specific cities' contexts. The proposed urban development framework will reach the stage of professional analysis only; it is past the scope of this project to trial the GIS tool in urban policy. However, recommendations will be made for future use in policy.

1.4. Layout of text

The contents of this text are as follows. In the next section, following this introduction, a literature review is presented of research related to this project. The urban development framework and GIS based tool are then both presented in the section entitled Method. Case studies follow the method and the results are analysed and discussed. Finally conclusions are drawn as to the relevance of this thesis to urban planning and policy and recommendations are made to advance the work.

2. Literature review

2.1. Introduction

This literature review covers topics important to the research topic and objectives. First literature pertaining to sustainable transport is reviewed, followed by transport energy use and resources. A review of land use and transport policies is presented and the use of GIS tools pertaining to the research topic is explored. Gaps in the literature are identified and conclusions drawn as to the current state of urban planning as related to transport energy reduction with the use of GIS tools.

It is important to note that attention has been focused on reviewing a wide range of both past and recent literature. However, much of the relevant energy policy literature pertaining to urban and transport development in this review comes from the 1970s and 1980s as this was the period when energy concerns became forefront to society, due to the fuel crises experienced in this era.

2.2. Sustainable transport

Sustainable transport takes on many meanings; it covers safety, accessibility, environmental, social and economic factors of transport systems (JOUMARD; NICOLAS, 2010).

Sustainability is commonly defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). The OECD (1999) has further defined sustainability as applied to transport with its Environmentally Sustainable Transport (EST) definition of:

> Transport that does not endanger public health or ecosystems and meets mobility needs consistent with:
> - Use of renewable resources at below their rates of regeneration and
> - Use of non-renewable resources at below the rates of development of renewable substitutes.

The OECD definition of sustainable transport is consistent with the objectives of this project because it is focused on energy resource use. However, other facets of sustainable transport systems cannot be ignored.

In accessibility terms, urban neighbourhoods that are sustainable provide good access to employment, schools and amenities. These neighbourhoods are also typically more desirable and housing prices reflect this (CHIN; FOONG, 2006). Even in suburban areas, neighbourhood design and access to schools and amenities are often considered more important than openness and proximity to nature reserves for new home owners (VOGT; MARANS, 2004). Psychological attributes are also important to take into account when considering sustainability and accessibility. It was shown by Handy *et al.* (2005), for example, that some residents prefer a lifestyle involving longer trips and car use, however it is theorised that if these residents are placed in more compact settlements, they will automatically adopt a lower energy intensive travel pattern despite their desire for driving.

Another commonly assessed factor in determining sustainable transport is mode use. Mode choice and the availability of a variety of mode options are often considered an important aspect of urban transport sustainability. Mode choice is based on several factors, including personal factors such as income, environmental factors such as topography, and trip characteristics such as trip length and purpose. Mode choice and use are also linked to accessibility, as the accessibility created by the built environment and spatial separation of activities influences mode choice. Well designed neighbourhood areas, with activities within close range, can increase the attractiveness of walking and cycling modes (SOLTANI; ALLAN, 2006).

As a subset of mode use studies; the degree of public transport utilisation versus private transport is another way to gauge urban transport sustainability. Private transport offers social and economic benefits, however these are not easily quantifiable. Public transport, on the other hand, is uniformly sited as being more quantifiably sustainable than private modes from an energy and pollution standpoint (KENNEDY, 2002).

The literature makes many direct and indirect links to energy from a sustainable transport perspective. Sustainable transport indicators involving energy include: mode energy intensity, pollution emissions (that are caused by energy consumption) and accessibility, which is influenced by spatial separation and urban design (ENTROP; BROUWERS, 2010). Literature describing energy use and resources pertaining to transport is investigated further in the following section.

2.3. Transport energy use and resources

A major concern of the continuation of transport systems is reliance on a finite resource. Eventually this will require that replacement resources are found, behaviour is modified and/or the transport system re-designed to allow human activities to continue in the same manner (SAUNDERS, 2005, p. 2). While some changes in energy consumption are possible through shifting to renewable resources, a long term sustainable solution requires a paradigm shift to more efficient use of the total physical transport system (BROWN; O'REGAN; MOLES, 2008). Otherwise efficiencies in fuel use and vehicle technologies may be offset by inefficient spatial growth and transport systems (HANKEY; MARSHALL, 2009).

It is possible to replace finite transport energy sources with renewable resources through either the use of renewable electrical sources or through bio-fuels. Electric trams and trolleys that make use of hydro, solar or wind power to replace fossil fuel buses are examples of renewable electrical sources replacing finite sources. However, substitution of transport energy to any great extent with electrical sources currently poses problems. The operational cost and new renewable electricity generation infrastructure required to replace equivalent fossil fuel consumption is at least an order of magnitude greater than using fossil fuels at their current costs (KRUMDIECK *et al.*, 2004). According to Padilha *et al.* (2009) it may be possible (in Brazil) to make use of unused hydro capacity for generating fuel for fuel cells, however the cost and availability of materials for the amount of fuel cells and supporting infrastructure required is not clear.

There are also many well known possibilities for renewable transport fuels such as biogas, bio-diesel and bio-ethanol. Possibilities for bio-fuel growth depend heavily on national government policy, incentives and industry partnerships (SATHAYE; ATKINSON; MEYERS, 1989). Many governments (including New Zealand, Canada and Brazil) have supported alternative fuel programs; however, by far the largest renewable fuel scheme in the world is the use of bio-ethanol observed in Brazil. Therefore in understanding the potential for renewable fuel it is interesting to look at the case of Brazil.

Brazil's ethanol program has become so successful that in addition to providing a share of the countries transport fuel (hydrous and anhydrous ethanol) for use in their own automobiles they now also export ethanol to other countries as a gasoline additive (FIGUEIRA, 2005). Despite a positive outlook for bio-ethanol, the energy balance of bio-ethanol is still debated today. In many countries, it is unclear if the amount of useful energy is greater than the energy input through fertilisers, machinery, processing etc. (GRAD, 2006). Brazil represents a possibly unrepeatable exceptional case where sugar cane crops receive required elevated sunshine hours compared with other countries further from the equator. In addition, sugar cane waste is used to create the electrical energy needed for the processing phase of the alcohol, further increasing production efficiency (D'AGOSTO, 2004). However, further expansion of the ethanol industry poses problems and may not result in economies of scale. It has been predicted that increased sugar-cane farm expansion for ethanol will need to occur in less populated regions of Brazil, further from major cities, therefore increasing production costs (MOTTA, 1987). These predictions have not yet been able to be validated as ethanol production tailed off at the end of the 1980s due to lower world oil costs. Only recently has production begun to increase again and therefore these predictions may be realised in the near future.

The potential for replacing very large proportions of petroleum products with renewable fuels is unclear. The actual replacement of Brazil's petroleum based products with ethanol, although substantial, is far from 100%. Despite favourable growing conditions and a proactive government, Brazil's bio-ethanol share of transport energy peaked at 28% in 1989 (ANDERSON, 1993) and in 2009 was sitting at only 18.8% (MME, 2010). This share is surprisingly low in part because ethanol can only replace gasoline consumption and a large share of Brazil's transport energy requirements are for diesel. To achieve 100% use of renewable resources would require a five fold increase in production (through both ethanol and bio diesel production) or the equivalent reduction in demand. Some level of demand reduction is possible through land use and transport policies, which are investigated in the following section.

2.4. Land use and transport policies

According to Grazi and van den Bergh (2008 p. 638) and confirmed during the literature review in this section, spatial planning as related to energy or environmental policy has received little attention compared with the importance of the topic. Relevant land use and transport policy literature for this project includes discussions or case studies of regulations or policies that have the ability to affect transport energy dependence or consumption. Of particular interest is transport energy consumption/dependence within urban or suburban areas. This is because this project focuses on these areas and a significant proportion of regional energy consumption occurs in the urban/suburban areas. When considering energy reduction, land use and transportation are significantly interrelated (SILVA; COSTA;

PAMPOLHA, 2001) and should be considered together (JOSEY, 1980). Transit Oriented Development (TOD) is one such concept that links land use to transport (DUDUTA *et al.*, 2010). However, urban transport energy can be affected by urban planners and decision makers through any such policies tied to land use and/or urban density, mode choice, Transit-Oriented Development (TOD), transport system operation and vehicle efficiency (LEFEVRE, 2009) as discussed in the following subsections.

2.4.1. Decision maker and planner's roles

This first subsection is devoted to the roles of the urban and transport planner, the decision maker and the policy developer, as these roles play an important part in the evolution of urban areas. It is the decision-maker who determines how much money should be spent on urban and transportation infrastructure and where this is to be allocated while the policy maker sets rules for use of infrastructure. Policy makers and urban planners work with decision makers in an effort to represent public desires. Decision makers are generally politicians and they direct the evolution of urban and transport systems by making decisions from information provided by the community and urban planners, of which some are engineers. The role of engineers in planning is to use modelling, knowledge and developed skills to aid decision makers and policy makers in understanding the transport system and urban environment. Engineers communicate this information to decision makers so that informed decisions can be made (ORTÚZAR; WILLUMSEN, 1994).

For urban and transport strategies, the process of arriving at decisions is as important as the decision itself. This is because the varying backgrounds of those involved in the decision making process can lead to multiple objectives. To bring academics, politicians, and civil servants together often requires application of multiple criteria decision making techniques. In the field of energy conservation, involving multiple parties in an initial brainstorming session followed by multiple criteria decision making allows a broad range of options to be equitably ranked and pursued (TZENG; SHIAU, 1987).

2.4.2. Urban growth restrictions

Many urban planners believe that low density growth at increasing distances from city centres is an unsustainable trend, causing increased vehicle kilometres that result in congestion, pollution and elevated energy consumption. It has been observed in several studies that urban density is a key factor related to per capita transport energy consumption (COSTA, 2003), (COSTA, 2001) (NEWMAN; KENWORTHY, 1989). Reducing minimum trip distances to activities through spatial planning makes reducing travel through transport policy much more effective (BOUSSAUW; NEUTENS; WITLOX, 2010). Therefore land use policies that encourage densification (through utility restrictions or tax incentives etc.) can affect energy consumption (COOPER *et al.*, 2002), (ROMANOS; HATMAKER; PRASTACOS, 1981). With the rise in popularity of the automobile, Dutch planners have applied this concept utilising various land use policies in an effort to contain automobile driven suburban expansion. However, controlling suburban development with traditional policy measures has proven difficult and not entirely successful (MAAT; HARTS, 2001).

In the field of transport and land use development, various tools have been and are still being developed to assist policy makers reduce urban transport energy reliance or consumption. The majority of these tools are evaluation tools that influence decision makers in the planning process, usually allowing different scenarios to be compared in a multi criteria analysis approach (LITMAN, 2006, and ARAMPATZIS *et al.*, 2004). A more direct approach is to control activity locations through regulations, as discussed in the following section.

2.4.3. Activity location regulations

Local authorities commonly influence, regulate or specify activity locations through zoning or other regulations. Residential, commercial and industrial activity locations are commonly controlled with zoning, whereas public services, such as: school's, library's and university's locations are usually determined after extensive research and in some cases public consultation.

Influencing land uses through a combination of zoning regulations and market forces has the possibility to reduce energy consumption. For example, taxation of land originally left vacant for speculation purposes can influence land owners to build or sell expensive lots, thus reducing vacant land contributing to urban sprawl. There are various GIS packages and methods that can be utilised to determine fair tax prices based upon the transport and infrastructure costs of vacant land (SILVA, 1993). However, these strategies often face strong opposition from land-owners and not all vacant land is held for speculative purposes. Some land-owners need time to first gather funds for development, in which case vacant land taxation is not entirely fair (JENKS; BURGESS, 2000).

Another measure is to rely solely on land use regulations as an alternative to market forces control, for example, to determine the location of commercial and retail areas. Such land use regulations, as described by Yang and Yang (2005, p. 1511), can be used to restrict activities in zones or areas that are already saturated, thus avoiding excessive competition. In addition to economic benefits, well planned and controlled activity locations can also reduce energy consumption, especially in the case of shopping trips (SARGIOUS; KUMAR, 1982). However, planning commercial activity locations remains difficult because uncertainties remain as to how consumer markets will develop (ARENTZE; BORGERS; TIMMERMANS, 2000).

An essential component of retail activity and urban environments is the supermarket, as it provides residents with access to food. The trend of smaller food stores being gradually replaced with fewer, bigger stores in the USA has resulted in increased supermarket travel distances. This has reduced supermarket accessibility for non-automobile owners and especially for the poor (EISENHAUER, 2001). Addressing this issue is not simple because local authorities do not have the power to force supermarkets to open in certain locations. According to Eisenhauer (2001, p. 131) alternative food access options for under-serviced urban areas involve local authorities making arrangements for farmers markets or providing public transport to the nearest supermarket.

Public services locations also affect transport energy consumption. Making a decision on the location and/or the size of a school has transportation impacts. Larger and more spatially separated schools can increase the demand for school buses or car modes over cycling and walking. When Germany enlarged its schools in the 1970s the resulting increase in school bus transport (and energy use) cost billions of marks per year (BOER, 2005, p. 11). Improving transport infrastructure around schools and creation of smaller neighbourhood schools can increase the amount of walking and cycling to schools and this significantly reduces transport energy costs, consumption and pollution emissions (EWING; FORINASH; SCHROEER, 2005).

In the USA, increases in school size have resulted in a decreasing number of schools and a corresponding increase in travel distances. According to Ewing, Forinash and Schroeer (2005, p. 4) this has contributed to the number of students walking or cycling to school falling from nearly 48% in 1969 to less than 15% in 2001. This data supports the argument for reducing school size. However, on the other hand, decreasing the size of schools can result in economic operational losses due to negative economies of scale. Research in South Holland suggests that for a school curriculum of 4 years, the minimum size should be 240 students with a maximum student travel time of 60 minutes by bus or bicycle (BOER; NEDERVEEN, 1990).

Various activity location issues have been reviewed in this section, the next section focuses on Transit-Oriented Development and its ability to affect energy dependency and consumption.

2.4.4. Transit-Oriented Development (TOD)

Transit-Oriented Development (TOD) has become increasingly popular in recent years because of its potential to positively influence urban form through promoting high-density development around transit nodes. A high-quality walking environment and mixed use development surrounding transit nodes provides the opportunity for increased public transit ridership, replacing automobile dependence and use (CERVERO, 2004). Therefore, TOD has the ability to reduce cities' energy consumption because replacing car trips with public transit trips reduces energy consumption due to the efficiencies of public transit over the automobile.

The success of TOD programs, however, depends on a wide range of factors and as in the San Francisco example, TOD has played only a modest role in directing metropolitan growth (CERVERO; LANDIS, 1997). Barriers to successful implementation are often market related or due to neighbourhood (public) opposition. In order to counter market related barriers and better direct urban development near transit nodes, a new zoning concept has emerged – TOD Overlay Zones, as described by Cervero (2004, p. 63). Special regulatory zones are overlaid on top of traditional zones near transit nodes that override normal zoning regulations, encouraging mixed land use and maximum (rather than minimum) parking limits etc. This is not provided as way to exclude market forces, but rather to contain market forces within limits that focus on maximising public transport accessibility and use around transit nodes. If such regulations prove successful TOD should gather further momentum, allowing for increased transit use and therefore contributing to reductions in city-wide energy consumption.

In this section Transit-Oriented Development was reviewed, the next section focuses on transport system policies and vehicle efficiency regulations that affect energy dependency and consumption.

2.4.5. Transport system and vehicle policies

Transport policies and vehicle regulations have the ability to affect energy use if a robust sustainable transport strategy is set at different levels of governance (PEI *et al.*, 2010). Transport policies can constrain travel demand and therefore energy consumption through reducing speed limits, influencing mode use and restricting parking through economic or regulatory measures. Vehicle import regulations and vehicle efficiency based tax incentives also have the ability to affect energy use. As noted by Buehler (2010, p. 2) on a study comparing German to American travel behaviour; even when American's are living in town's with population densities five time higher than German's they make a similar share of trips by car. This is due to differences making car travel slower, more expensive and less convenient in Germany.

Transport demand management or restraint options have been proven to reduce urban transport energy consumption and models exist in order to estimate the effect of demand management measures on energy consumption and pollution emissions (JOVIC; DJORIC, 2009). Demand management measures include long term or emergency policies to affect transport demand on environmental, congestion and/or energy consumption grounds. Emergency demand restraint measures may be effective in the short term; however travel pattern modification is more effective in the long term (KIHL; FLATHERS, 1983). Changing travel patterns requires land use, transport system or transport policy changes, such as road tolls, parking policies etc. Transport policies, such as: parking policies (reduced or more expensive city centre parking), inner city tolls (as in London), exclusive bus lanes and a variety of others contribute to improving the efficiency of an urban area. The end goal of transport demand management policies is to reduce urban trips by car to only essential trips and to divert the majority of residents to public transport systems (SALEH; NELSON; BELL, 1998). However, the extent to which transport energy can be reduced by these measures is likely to

be limited by the form of the built environment (CHIOU *et al.*, 2009).

Transport demand management options also include emergency measures such as fuel delivery management. Several techniques were proposed in the 1980s including scattered-refill scheduling where cars can only refill at a certain time of the day dependent upon the last digit of their licence plate. However, in severe circumstances many fuel delivery techniques proposed in the 1980s became ineffective due to the panic behaviour of drivers (HOBEIKA; YOUNG, 1983). A more effective measure may be automated fuel card control where fuel pumps are connected to a central computer system that controls and updates all fuel rations to real time fuel supply (SAUNDERS; SILVA, 2006).

Energy reduction can also be achieved through vehicle efficiency improvements and regulations. The private automobile is responsible for most of the energy consumed in urban areas. Improvements in automotive technology would therefore seem to have great potential in reducing energy consumption (KOHLER *et al.*, 2009). Hybrid vehicles have been now readily available on the market for some time, offering considerable efficiencies over similar sized conventional petrol or diesel vehicles. However, even with record hybrid vehicle sales in 2006, the USA still managed to set a new record in petrol consumption during this year (EIA, 2006). Yearly increases in distances travelled in urban areas have recently and historically offset gains in efficiency offered by technology improvements (SALEH; NELSON; BELL, 1998). It is therefore unclear to what extent energy consumption can be affected by vehicle efficiency improvements and regulations in the future.

This section and its subsections have discussed various policy and regulation options available for planners to reduce energy consumption or dependence. The next section reviews literature pertaining to the use of GIS as an aid to transport planners in transport energy and related fields.

2.5. GIS and energy modelling tools

Today, many transport and land use modelling tools are part of Geographic Information Systems, and energy models can exist in the form of sub models inside these systems. Energy models that were developed prior to the rise and use of computers in transport, during the 1970s, could theoretically be included into today's computer based models and databases. Some such models, developed as a result of the 1970s Arab oil embargo, may be interesting to reconsider because since the energy crises of the 1970s and 1980s, little further research has continued in this field. For example, a modelling approach developed by Romanos *et al.* (1977) optimises land use allocation and urban development for minimum energy consumption considering the existing and projected urban land use, transportation, economic and social constraints. This linear programming model approach offers optimal solutions for decision makers at specific future horizon years so they can backcast (create a strategy to move from the current situation to a desired future end state).

Geographic Information Systems (GIS) are becoming increasingly important in transport and urban planning. GIS tools offer planners the ability to more clearly understand urban activity and transport systems. For example, Moudon *et al.* (2002) recently applied GIS tools in a case study to identify areas that have a high potential for pedestrian demand.

GIS tools are also used by businesses. In the retail market, GIS tools are already widely used to determine ideal locations for shops. Mapping the best areas for retail locations, using GIS software, may help retailers to gain a competitive advantage. However, it is argued that GIS tools and GIS based modelling techniques need to become more specific for the task at hand. In addition, it may be difficult for the user to know which model is best suited for their analysis (BENOIT; CLARKE, 1997).

In the environmental area of transport and urban planning, GIS tools are becoming more important. Traditionally, the common practice for addressing environmental concerns is to perform an environmental impact assessment (EIA) for major projects. However, with the advance of GIS tools and modelling capability, incorporating environmental (energy, pollution, noise) modelling directly into the transport planning process is possible. This allows environmental analysis to be performed at a smaller scale (the network level) and in tandem with transport demand and road capacity analysis (BROWN; AFFUM, 2002).

The power of using GIS in policy is that it is possible to integrate various elements of transport, urban and environmental systems into one package. While there may be no new individual elements in GIS packages, the integration of many elements is itself a highly useful feature of GIS (ARAMPATZIS *et al.*, 2004) (SILVA, 1998). This integration allows, for example, independent air pollution models to be linked to transport demand and supply models in an easy to interpret format for decision makers (ARMSTRONG; KAHN, 2004). With the appropriate information that is readily provided by currently available and in use

GIS packages, decision makers now have improved resources to effectively direct long range urban and transport development (JOHNSTON; BARRA, 2000).

Many studies involving GIS in urban and transport planning have already been conducted. However, Allan and Soltani (2006, p.132) assert that “the influence of urban form on travel choices by considering micro-scale design attributes has not been widely investigated,” and “GIS tools can be used to quantify such attributes.” This leads us to believe that there are future uses of GIS left to explore, at least at the urban micro scale level.

An example of GIS tools being used at the micro-scale level is a recently created tool named “accession” (ACCESSION, 2007). This tool, primarily for use in England, aims to help: “local authorities and other agencies draw together transport, land use and socio-economic information to identify whether people can get to jobs, education, health and other key activities (ACCESSION, 2007)”. This accessibility tool is supported by the U.K. Department for Transport as a tool to assist in the preparation of a recently implemented urban planning requirement: development of Local Transport Plans (DEPARTMENT FOR TRANSPORT (U.K.), 2007). According to the New Zealand Ministry of Transport (2006), the U.K. is the world leader in neighbourhood accessibility planning and is therefore likely to possess the most advanced specialist GIS tools in this area of urban planning. However, even in the U.K., it is recognised that this area of urban planning is still in early stages of development and application (NEW ZEALAND MINISTRY OF TRANSPORT, 2006).

The ACCESSION software is a micro-scale tool, however it does not deal with energy. Transport energy models reviewed were not applicable at the micro-scale, and many tools were only loosely related to energy or considered energy in qualitative terms only. Models, tools and analysis techniques considered to be most closely related to the research in this thesis are presented here according to their resolution level:

a) ZONAL SCALE (several aggregated neighbourhoods):
   - TRansport and Environment Strategy Impact Simulator TRESIS (HENSHER; TON, 2002),
   - Accessibility analysis and resultant environmental impacts of transport infrastructure changes (VICENTE; MARTIN, 2006),
   - Transport policy analysis using a land-use transport interaction (LUTI) model that considers energy scarcity (increased energy cost) (SHEPHERD; PFAFFENBICHLER, 2006).

b) MICRO SCALE (individual neighbourhoods):
   - ACCESSION GIS software for accessibility planning in local transport plans, U.K. (ACCESSION, 2007),

The zonal level models included consideration of energy and environmental factors, but not at a neighbourhood level. They considered increased density within zones, but not neighbourhood accessibility. ACCESSION software considers neighbourhood level accessibility; however, energy factors are not included in the analysis. The ACCESSION software has been designed to deal only with the socio-economic problems of accessibility.

The tools/models presented here are all useful at their level of resolution, however there is a lack of availability of tools with micro-scale resolution that consider transport energy.

There exist many possibilities for the future use of GIS tools; however, GIS packages alone are not sufficient for the multi faceted task of urban planning. Planning and decision making require support systems to complement the information systems embedded in GIS packages (BARTON, PAROLIN; WEILEY, 2004). For example, spatial decision support systems (SDSS) use GIS as only one of the components in determining optimal service centre locations and planning support systems (PSS), that have recently evolved, require GIS tools to be integrated with traditional planning tools, environmental modelling and forecasting techniques (KLOSTERMAN, 1997).

2.6. Conclusions

This literature review has attempted to cover the main aspects relating to the project, which are: sustainable transport, transport energy, transport and land use planning and the use of GIS tools as related to these topics. While there is a lot of literature covering areas relevant to the project, there are also important gaps in the literature which leave an opening for further research.

The main aims of the project are to reduce energy dependence and consumption instead of increasing renewable or other energy supplies to meet future energy needs. This is because the literature points to the fact that oil production is peaking and while bio-fuels look to have a positive future as fuel additives; large scale or complete replacement of finite fuels at current consumption levels may not be feasible, physically and/or economically.

The literature also references studies relating to land use policies and methods to reduce travel demand and energy consumption. However, these methods have not to date been entirely successful and cities continue to produce ever increasing transport distances and dependence on private transport modes. A lot of the research and literature is devoted to understanding the urban environment and making policy or other recommendations. Much less literature is available on the actual creation or implementation of new GIS tools and frameworks for urban development. Whilst land use regulations can be found in local government, specialised transport energy regulations and tools that focus solely on achieving a defined level of urban transport energy dependence were not found in the literature and are therefore supposed to be non-existent in any city in the world. The inclusion of such "decision-maker independent" regulations may be the key to significantly reducing urban transport energy consumption and/or dependence in the future and is the focus of this research.

3. Method

3.1. Introduction

This project involves not only the creation of a new GIS based tool but also outlines the possible application into policy. The planning level of the tool is first described in relation to city and urban planning hierarchy. Policy considerations for local authorities are then presented followed by a detailed description of the GIS tool - the Transport Energy Specification (TES). Finally the methods applied to the case studies are outlined and resulting modifications to the TES explained.

3.2. TES and urban planning – where does it fit?

The TES urban development framework is a micro-level planning guideline or regulation, developed for directing energy efficient infrastructure and activity locations through zoning at the neighbourhood or small development level as illustrated in *Figure 3.1*. It is intended to be used to direct a variety of mixed use developments; however a large component of the neighbourhood or development being considered must involve residential land use, as the TES determines energy efficiency with relation to the household.

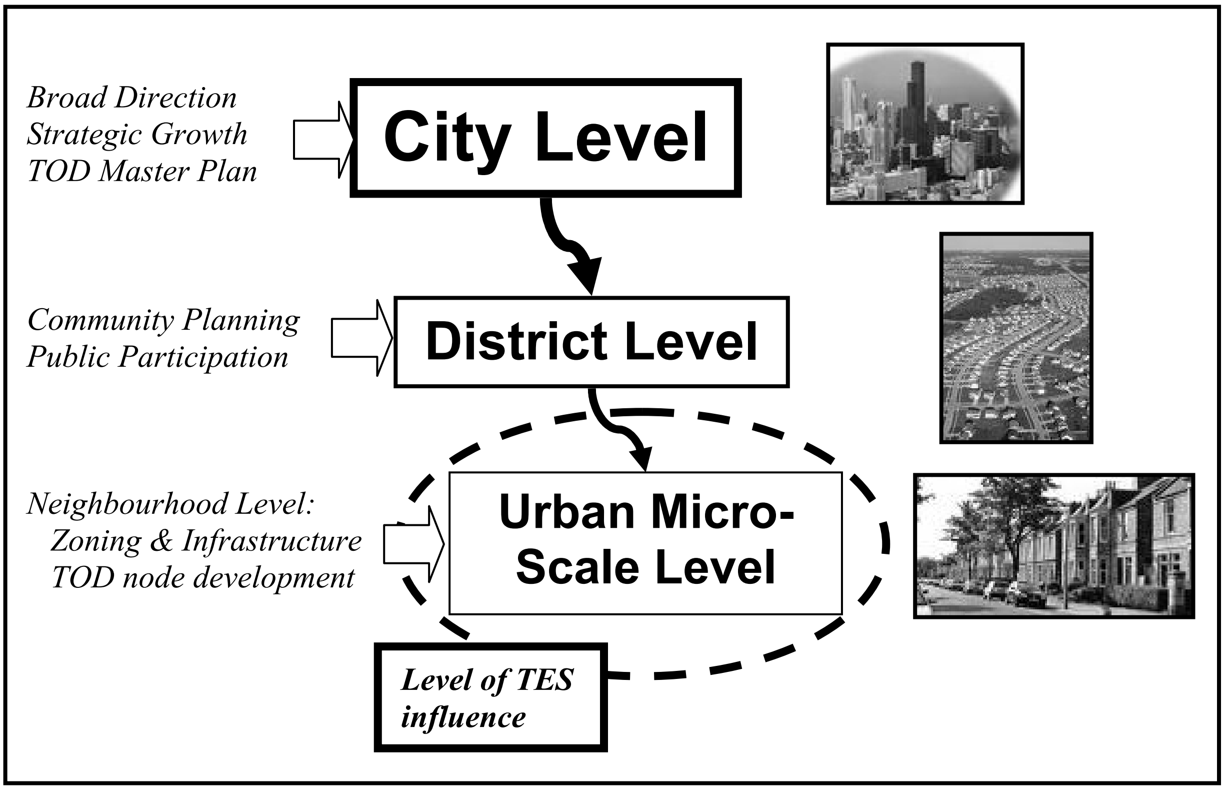


Figure 3.1 TES planning level hierarchy

Once a higher level document has been created specifying desired areas for urban densification or future growth, the TES regulation/guideline could be used to direct urban infrastructure and zoning to achieve energy efficient urban forms. In the special case of directing neighbourhood level Transit-Oriented Development (TOD), the TES could be applied as a TOD Zoning Overlay. An "Overlay" is intended as a measure to encourage an urban form that contains mixed land uses and infrastructure that results in increased cycling and walking to transit nodes. For more information on TOD Zoning Overlay's, refer to Cerevero's (2004, p. 63) book that describes this concept in detail.

In summary, the TES is designed to be used to direct energy efficient neighbourhood level development of the following:

- Previously identified "urban intensification" areas

- Previously identified future growth areas
- Urban areas surrounding Transit-Oriented Development (TOD) nodes

Note that in the case of the previously identified urban areas mentioned above, this refers to urban areas identified at the city or community level planning stages. TOD node locations would normally be determined by a city level strategic plan.

Now that the TES regulation/guideline has been defined in relation to an urban planning hierarchy, the development framework can be further explained, as is found in the following section.

3.3. Urban development framework

It is proposed that transport energy specifications or regulations could be included as part of cities' urban development requirements at the neighbourhood level. Development would then need to meet the pre-existing urban area specifications defined by the cities and also pass through the energy regulation component before new development or redevelopment of existing urban areas could commence, as illustrated in *Figure 3.2*.

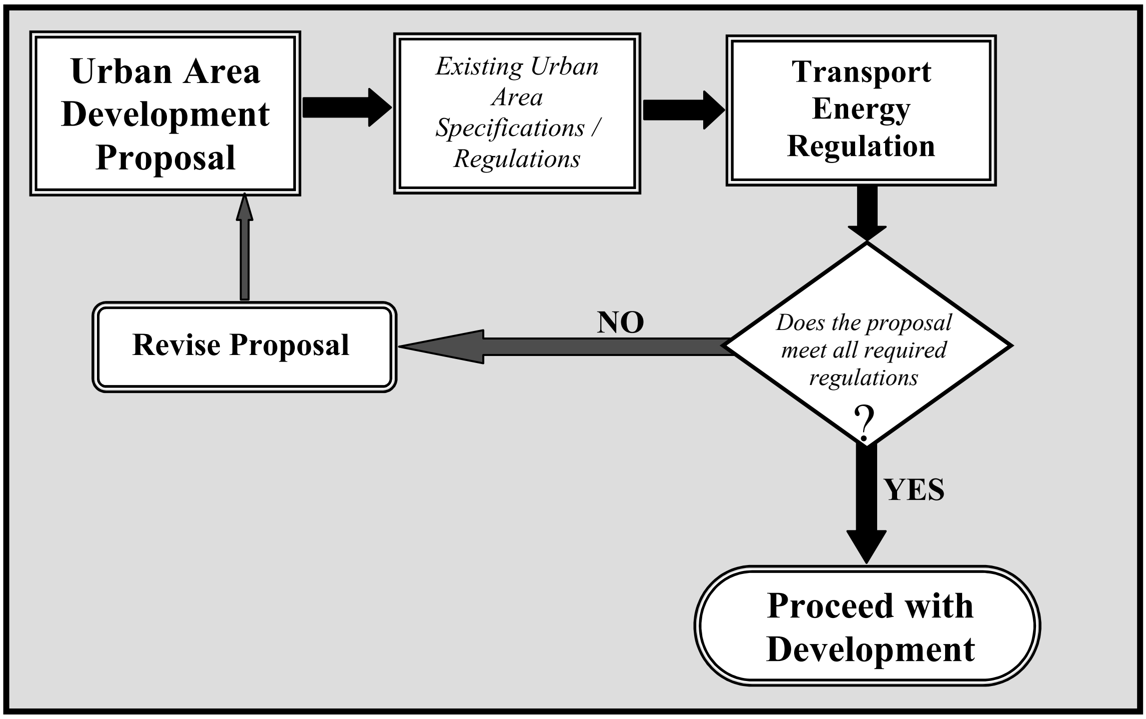


Figure 3.2 Possible role of transport energy regulations in land use planning

Transport energy regulations require:

a) defined quantifiable limits

b) relation to both transport energy and land use

Creating a regulation to control *actual* transport energy consumption (e.g. fuel rationing) may be difficult and overbearing. Also, in the case of regulations such as fuel rationing, there is no connection with land use. However, a regulation that sets out to control transport energy dependence (instead of consumption – see the following subsection: *Section 3.3.1*) could easily be related to land use. Such a regulation is not overbearing because it does not set to limit transport energy consumption, however as cities become less dependent on transport energy it is most likely they will also naturally consume less energy, as the consumption-dependence relationship in *Section 5.2* infers.

3.3.1. Energy dependence versus consumption

Energy dependence is concerned only with infrastructure and transport supply as opposed to consumption, which is related to infrastructure but also includes behavioural aspects. This is a crucial key-point to understanding the TES tool and this thesis. For example, a neighbourhood may have a local supermarket within 400 meters of all residents. This would mean that these residents are not dependent upon buses or cars to access this supermarket. However, this does not imply that no residents will drive to this supermarket or another supermarket outside the neighbourhood for reasons of comfort, preference, etc. Therefore energy dependence is only related to physical aspects of a neighbourhood, whereas consumption is also related to behaviour. The TES tool aims to provide information that could lead to the development/redevelopment of a low energy *dependent* neighbourhood, actual reduced consumption is not guaranteed to occur and may require policies directed at behavioural modification in addition to the built environment modifications arising from application of the TES. Formation of such policies is beyond the scope and aims of this thesis; however an attempt will be made to correlate energy dependence to actual energy consumption (see *Section 5.2*).

Behavioural aspects are considered to be important in the drive to reduce energy consumption, however infrastructure and transport supply is deemed to be more important, as was briefly touched upon in the introduction with the different fuel crisis effects on Dutch and American cities in the 1980s. Low energy dependent built environments allow for large behavioural changes to occur if required, such as in the event of an energy crisis. Behavioural modifications are limited by the built environment. It is therefore seen to be wiser to first focus on the built environment before looking at behaviour. Any reference to behaviour in the

TES is not a traditional reference to behaviour as transport planners would be accustomed to understand. Behaviour in the TES is hypothetical and allows for the evaluation of *options* available to residents due to the built environment, which consists of the spatial layout of activities, transport infrastructure and supply of transport services. This process determines a neighbourhood's transport energy *dependence* and not *consumption*. The next subsection addresses the issue of influencing urban activity locations.

3.3.2. Activity incentives

Regulating transport energy dependence through land use control is possible and would require effective zoning and encouragement of the identified desired activities through activity location incentives. It is not possible to force specific commercial activities, such as supermarkets, to open shop in specific locations. However, once the ideal location(s) have been identified by the TES, local authorities could feasibly provide incentives (fiscal or other) for these activities to consider the desired location(s).

3.4. GIS tool: the Transport Energy Specification

The Transport Energy Specification measures energy dependence of different urban forms and transport systems at the neighbourhood level. In calculating energy dependence, the TES incorporates spatial separation of activities, accessibility and energy consumption of available modes.

The Transport Energy Specification applies weighted accessibility factors to an urban population accessing urban activities. Minimum transport energy required to access urban activities within a study area is calculated using this tool as illustrated in *Figure 3.3*. This minimum energy is defined as the transport energy *dependence* of the specific urban/suburban neighbourhood. For the purposes of the TES calculation, neighbourhood size is between 200 and 5000 residents (refer to *Section 5.4*). Areas containing more than 5000 residents should be subdivided. Smaller areas are preferable because they provide insight into micro-level energy dependency and allow comparison of neighbouring areas.

Energy consumption is measured in both quantity and type of transport energy (e.g. petroleum, electricity). Walking and cycling are both assumed to consume zero energy. As the TES deals only with energy, external studies are needed to incorporate/compare transport costs with the transport energy benefits/impacts produced by the TES.

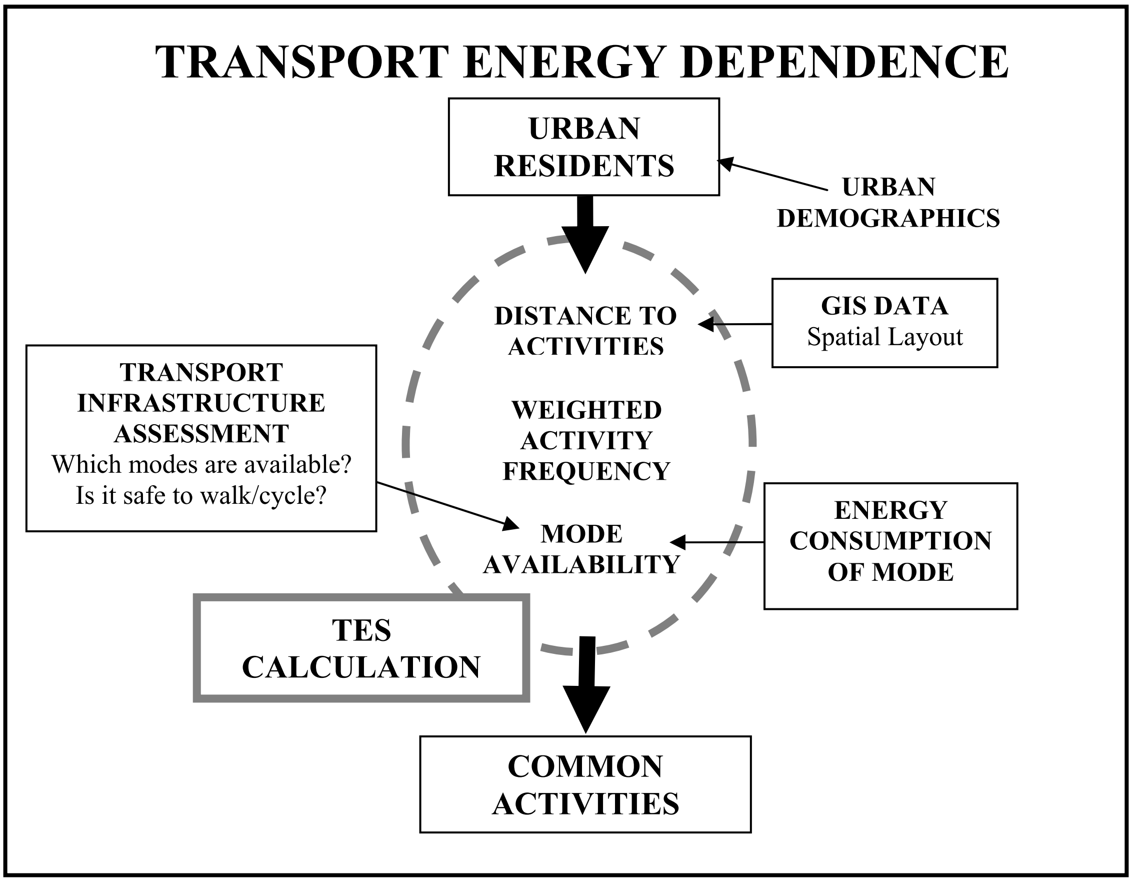


Figure 3.3 The TES method and calculation for urban trips

Data is collected that describes the demographics of the study area, the transport system and surrounding activities (supermarkets, work locations, universities, schools etc). These are then added to a GIS database.

The final step in the Transport Energy Specification process is the actual calculation. Using GIS software and arithmetic, the transport energy dependence of each resident (ER_i) is calculated and summed to give the overall transport energy dependence (E_{TOTAL}) for all residents per week for the study area. The average energy dependence per person is simply the total divided by the number of residents ($E_{PerPerson}$). Equations (1), (2) and (3) are used for this purpose.

$$ER_i = \sum_{k=1}^{p} \left(\sum_{j=1}^{m} TL_j F_j \right) EC_k \qquad (1)$$

Where:

TL_j = Distance (km) from i^{th} resident's house to their j^{th} activity(s) (j = 1 to m)

F_j = The weighted activity frequency (#/week) of the i^{th} resident performing the j^{th} activity

EC_k = The energy consumption (MJ/p.km) of mode k (k = 1 to p) according to *Table 3.2*

$$E_{TOTAL} = \sum_{i=1}^{n} ER_i \qquad (2)$$

$$E_{PerPerson} = \frac{\sum_{i=1}^{n} ER_i}{n} \qquad (3)$$

Using the above equations and GIS data for trip length; energy dependence will be given in mega joules per week (MJ/week – *Equation 2*) or mega joules per person per week (MJ/person/week – *Equation 3*) for all residents in the study area. The mode energy consumption data is collected from local authorities or using general mode use data typical of the country or region. A summarised version of mode use by country is contained in Kenworthy's (2003) paper.

Urban activities selected for use in the TES are only activities that are significantly affected by urban form and that can be spatially influenced by land use planning. Accessibility factors and GIS computation for the TES are explained further in the following sub sections.

3.4.1. Accessibility factors

Accessibility factors for the TES include simulating access to common urban neighbourhood activities using the available lowest energy intensive modes. Common activities selected for use in the TES and their respective age groups and weighted activity frequencies will need to be determined by local governments through understanding of their specific urban context. It is envisaged that the weighted activity frequencies could be defined by first setting the annualised home based work activity value, of which a common weekly value results in a weighting of 4.5 times per week (5 day working week, 47 weeks per year). Other urban activities and their weighted activity frequencies could be standardised against the work value using observed trip generation rates commonly found in government travel survey data (LTSA, 2006), (DEPARTMENT FOR TRANSPORT, 2004), (DPI, 2002). However, weighted activity frequencies need not represent data entirely from travel surveys of observed behaviour; they may also represent desired activity frequencies. For example, if observed travel behaviour to “open space” reserves is notably low due to a lack of reserves within the vicinity of a particular neighbourhood, the weighted activity frequency for open space reserves could be increased above the observed behaviour. This would result in a higher importance (weighting) for this activity and the resulting energy dependence calculation would become more sensitive to this activity (see *Section 5.4*). Ultimately, in this case, recommendations for providing "open space" reserves would receive increased attention.

The examples given in *Table 3.1* are loosely based on various observed travel behaviour surveys; however this is not too important, as discussed in the previous paragraph. Each activity frequency is represented as a fraction of the standardised work-based activity, e.g. if *n* equals 78% for kindergartens, the frequency in Table 1 of (n x 4.5) will result in the example weighted frequency of 3.5 x/week. This means observed or desired weighted frequency for the kindergarten activity is 78 % of the work activity value. Cities applying this tool will need to justify and define their specific data. For the purpose of demonstrating the application of this tool, the example values in *Table 3.1* (however inaccurate) were used in all of the case studies. The age groups and relative frequencies used in a TES provide an indication of the relative importance of each urban activity with relation to energy dependence. For example, the spatial separation of work locations (18 to 65 age group, frequency of 4.5 x/week) contribute to urban transport energy dependence more so than spatial separation of kindergartens (3 to 5 age group, frequency of 3.5 x/week).

Table 3.1 Common activities, age groups and weighted activity frequencies for the TES

Common Activities (Example)	Age (years)	Example (years)	Freq. (x/week)	Example (x/week)
Kindergarten	a to b	3-5	n x 4.5	3.5
Primary School	b to c	6-10	o x 4.5	3.5
Intermediate & Secondary School	c to d	11-17	p x 4.5	3.5
Tertiary School	d to e	18-65	q x 4.5	4
Work (full and part time)	f to g	18-65	**4.5**	4.5
Supermarket	h to i	18 and over	r x 4.5	2
Retail Services + Other Recreation	j to k	18 and over	s x 4.5	3
Recreation "Open Space" Reserve	l to m	6 and over	t x 4.5	1

The standardisation of these activities, frequencies and age groups allows urban areas within a city to be equally evaluated based upon approximations of travel behaviour but independent of actual observed travel behaviour; this also saves time and money. Developers in Neighbourhood A, for example, would be subject to the same TES regulation as any other neighbourhood in that city even if travel behaviour is observed to be different due to the neighbourhood income, psychology of residents or other factors.

Mode availability for the TES is also standardised, based upon *comfortable* walking and cycling distances. In defining comfortable distances, observed distances for cycling and walking were roughly represented. Establishing a standard comfortable walking and cycling distance is difficult and research varies in its findings of both observed and recommended comfortable distances for these modes. Currently applied walking distances by trip purposes have little empirical verification (MOUDON *et al.*, 2002). Observed distances tend to be much less than what is considered to be comfortable. Also, observed distances may be under-reported for short trips and the distance travelled for each activity purpose is not always clear in travel surveys (DEPARTMENT FOR TRANSPORT, 2004). Mode availability, according to *comfortable* guidelines for minimalist transport energy use is presented in *Table 3.2*. The distances may be modified by local authorities with adequate justification, however the order of preference for "options" may not be modified as this is how dependence on transport energy is calculated (as opposed to consumption).

Table 3.2 Determination of mode availability for the TES

Age Group	1st Option Walk	2nd Option Cycle	3rd Option Public Transport	4th Option Car
3-5	< 600 m [a]	N/A	< 300 + 300 m [a,b]	Final Option
6-10	< 800 m	N/A	< 400 + 400 m [b]	Final Option
11-17	< 800 m	< 2.5km [c]	< 400 + 400 m [b]	Final Option
18-65	< 800 m	< 2.5km [c]	< 400 + 400 m [b]	Final Option
65+	< 800 m	N/A	< 400 + 400 m [b]	Final Option

a Children 3-5 years are accompanied by parent.
b For tram/bus users; the stops must be within 300 or 400m of the origin and destination.
c For cyclists, it must be safe to cycle.

The distances given in *Table 3.2* are one-way distances; however for activities of short duration, such as shopping, the distances are treated as return distances. This is because a journey to work of 800 meters in the morning and then returning in the evening (1600 meters total) is perceived to be much different to a 1600 meter return trip to the supermarket. The exclusion of the cycle mode for children under 10 years and adults over 65 years does not imply that these age groups cannot use this mode, just that this mode should not be assumed to be completely viable due to education and/or physical limitations by members of these age groups.

In addition to the above accessibility inputs, external journeys for work and shopping are also standardised and included into the model. City's will need to define their own values, however, as a default, ten percent of all working age residents are directed to the city centre for work, with an additional 5% being sent to another major employment attractor (if existing). For shopping trips, 10% are sent to the closest major shopping area (which could be the city centre as well); a further 5% are sent to the next closest major shopping area/centre (if existing).

The inputs in tables 3.1 and 3.2 and the described external journeys are provided and recommended as a starting point for assessments, city planners may wish to modify these tables and inputs to their specific local conditions where they have supporting data. However the trip data is not recommended to based upon actual trip behaviour and should be designed around possibilities for residents that allow the minimum transport energy dependence for residents as opposed to determining actual energy consumption, which could be later linked to the TES using a modified origin-destination survey as discussed in Sections 4.4.4 and 5.2.1. The GIS component of the TES is explained further in the following section.

3.4.2. GIS computation

The Transport Energy Specification (TES) requires many origin to destination distances to be calculated along road, bus, walk and cycle networks. The TES requires shortest paths to be calculated along the networks; therefore GIS software with this capability is preferable. The following GIS description of the TES uses examples from TransCAD software (commonly used GIS transport modelling software); however other simpler software programs should perform equally well.

The GIS process for the TES involves five steps:

1. Importing Map Data
2. Adding Land Use Data
3. Creating the Network

4. Generating Shortest Path Data
5. Simulating Modifications to the Urban Area

Once a study area has been defined (a proposed or existing neighbourhood, TOD node or urban area of 200 to 5000 residents), data is imported into the GIS software. Map data (to scale) that includes all road, bus, walk and cycle networks is required. This data can be imported into many GIS software packages from a variety of file types.

After importing the required (to scale) map data, the collected land use data is added to the map using GIS software as shown in *Figure 3.4*. More detail is included in Annex A.

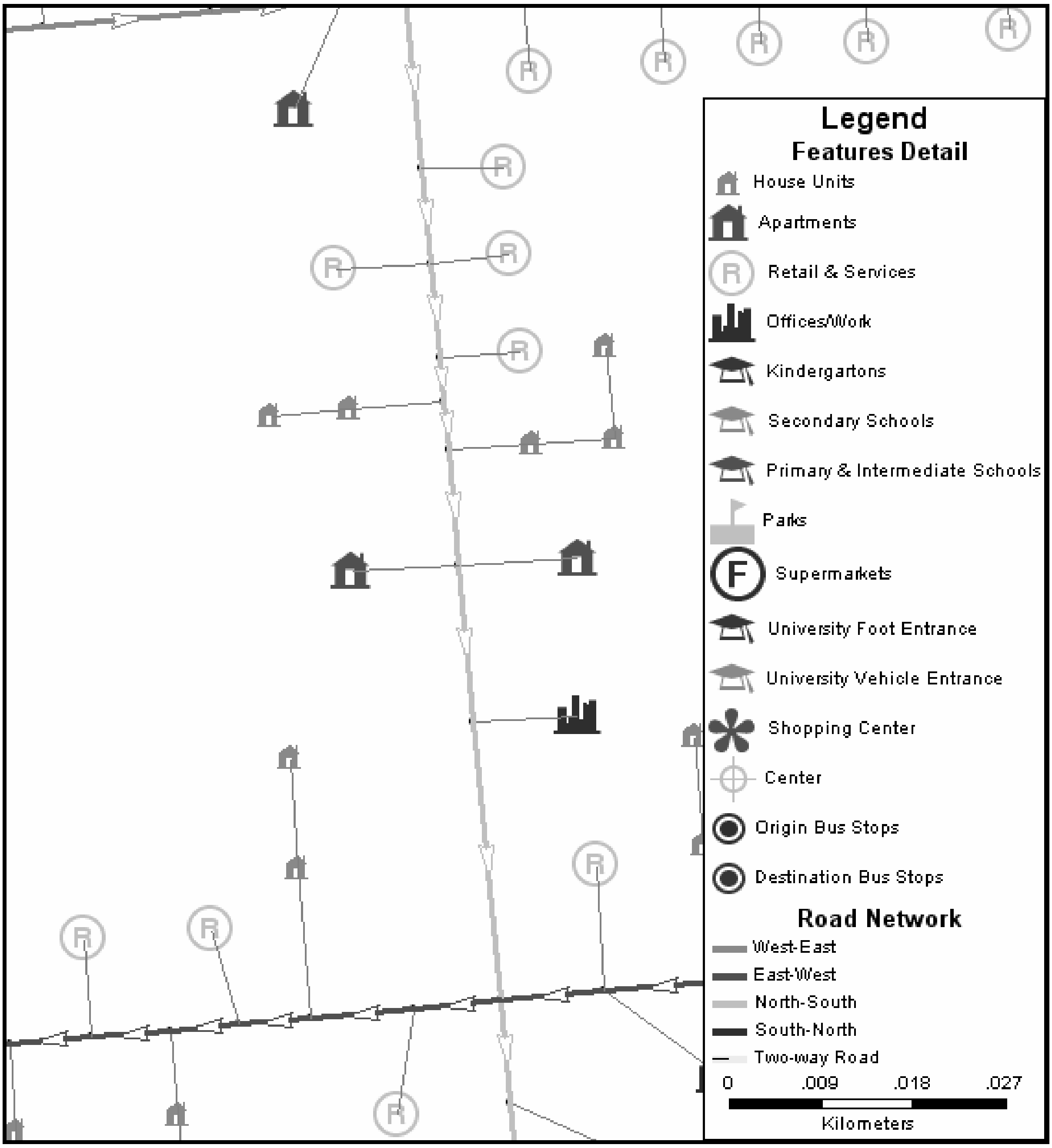


Figure 3.4 Land use data added with the use of GIS software

After importing and modifying the map data, a network is required. In the case of one-way roads, link directions are assigned to the relevant links. When creating networks that have one-way road sections but two-way walking or cycling sections on the same link, two networks are required; one for pedestrians and cyclists and another for vehicles.

The most important output data required from the GIS software are the shortest path distances for the various urban activities as detailed in the TES method. This data is obtained by performing a "Multiple Shortest Path" calculation with the GIS software as shown in *Figure 3.5*. The calculation is performed on all networks (i.e. pedestrian and vehicle networks) and for all activities.

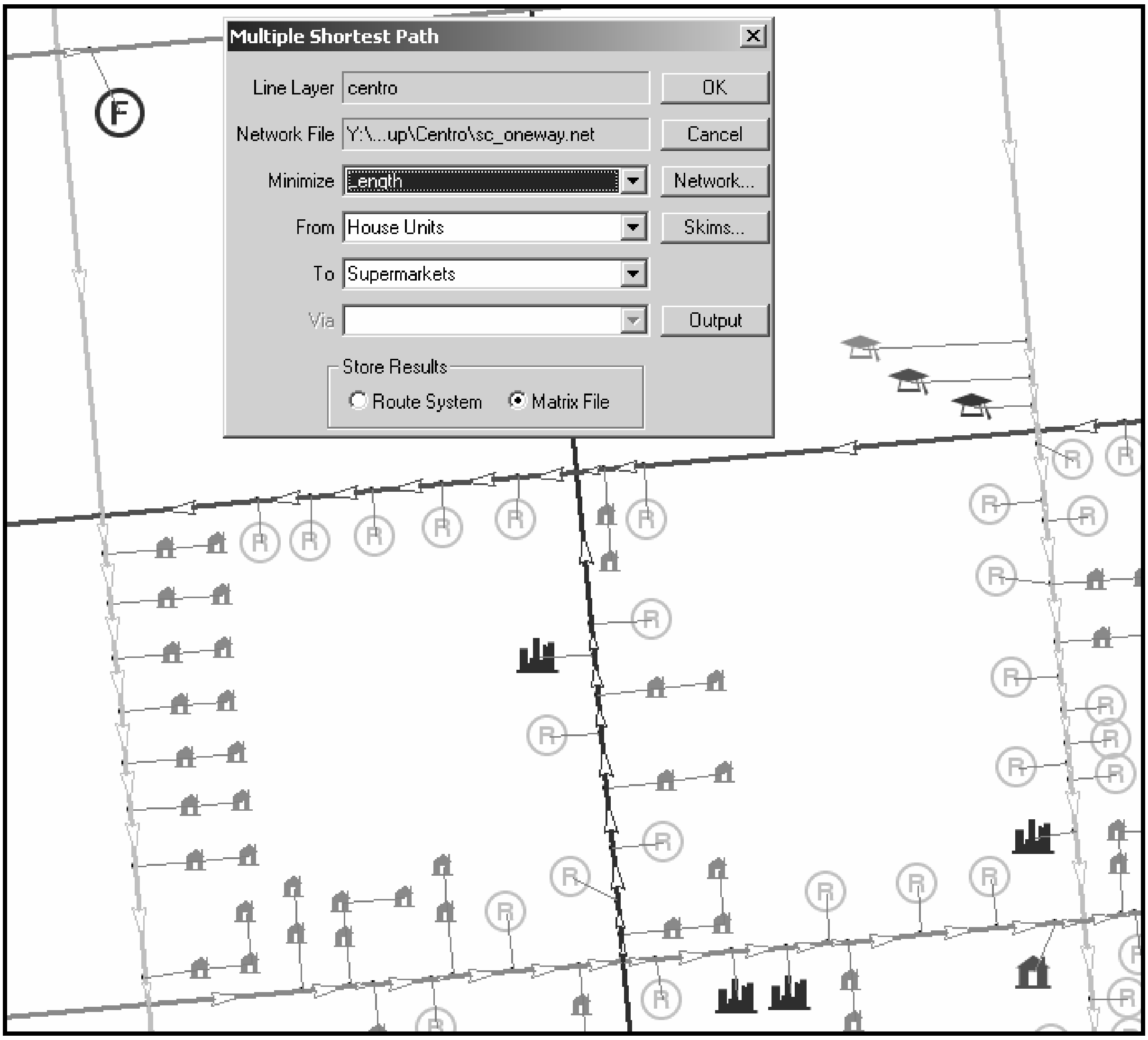


Figure 3.5 Multiple shortest path calculation example from houses to supermarkets

The output files in TransCAD are matrix files, which are then exported to *txt* file formats and imported to electronic spreadsheets. The equations provided in the TES method are then applied to the shortest path distance data to produce energy dependence data.

Modifications can be simulated for urban areas by simply adding to or changing the land use data directly within the GIS software as shown in *Figure 3.6*.

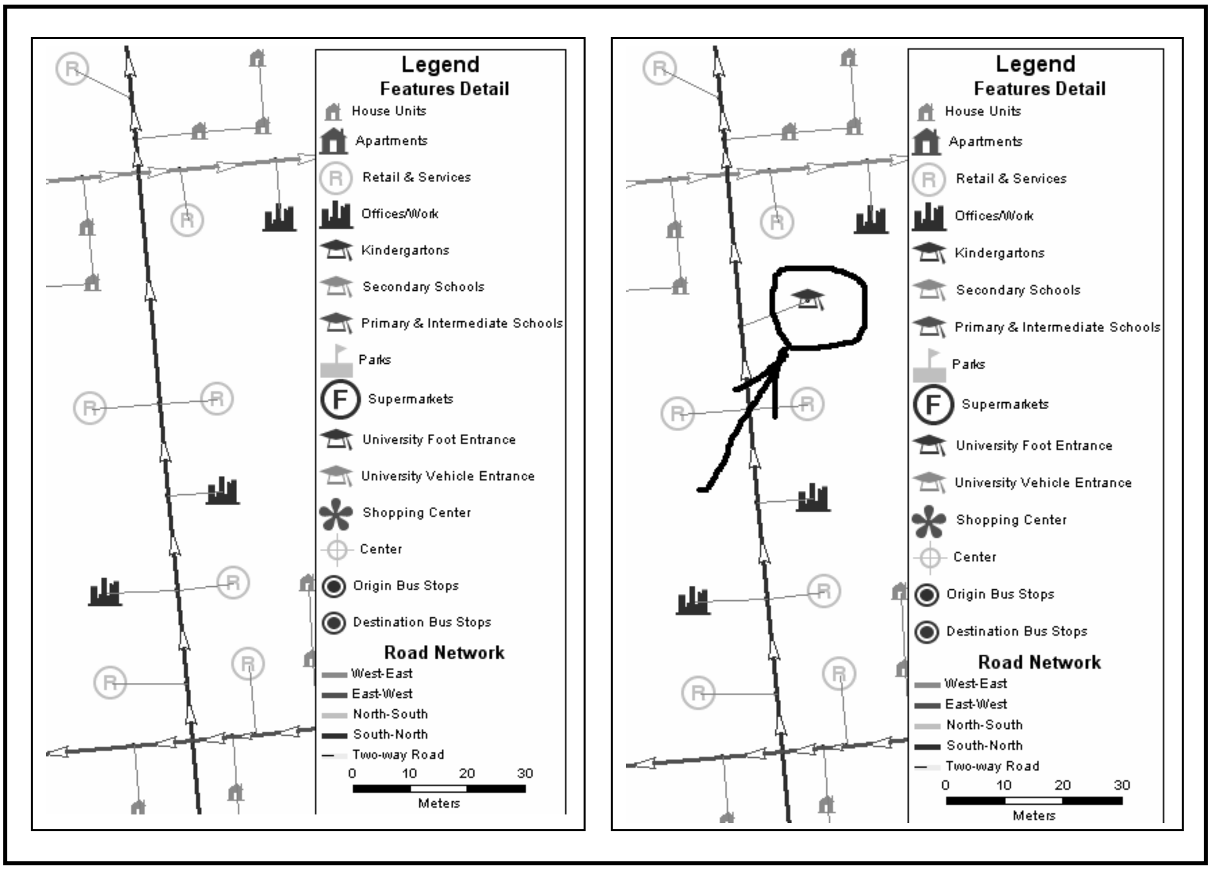


Figure 3.6 Simulating modifications to an urban area; in this case addition of a kindergarten

The energy dependency calculation of the modified urban area is achieved by performing a new shortest path calculation and applying this new data to the TES equations.

3.5. Case study method and resulting TES modifications

The method presented in this section is the most up to date form of the Transport Energy Specification. The TES was updated to its current form due to recommendations made by a professional review of the method following completion of the first case studies. The review was undertaken by transport professionals from the Energy Efficiency Conservation Authority (EECA) of New Zealand.

The differences in the TES method applied to the first case studies (all case studies except São Carlos, Brazil) included:

a) One way walking distance of 400 m (200 m to bus/tram stops) instead of 800 m (400 m to bus/tram stops).
b) One way cycling distance of 1 km instead of 2.5 km
c) Retail shopping trips not included
d) External trips for work and retail shopping not included
e) Slight variation in the trip frequencies of activities

The identical TES version was applied to all three case studies and the results are presented in the following section. Note that the São Carlos, Brazil trial was performed with both the older and the updated TES method.

4. Case studies

4.1. Overview

The TES is designed to evaluate different built environments at the neighbourhood level, without inclusion of socio-economic factors. For this reason it is interesting to perform TES trials on contrasting neighbourhood areas, which could probably all be found within one country or even one city. However, it is interesting to trial the TES on built environments that use different transport energy sources and have existing preconceptions of being sustainable or otherwise in a transport sense. Therefore, three case studies were performed on very different neighbourhood regions of three countries. Karlsruhe, Germany was selected for the initial study because of its well known reputation and appearance as a sustainable transport city. Suburban areas in New Zealand were selected to contrast the Karlsruhe case study with areas that are assumed to be much more transport energy dependent, similar to American suburban style sprawl. An urban area in Brazil was selected for the third study to include results from a country using a large quantity of bio-fuels. The TES managed to incorporate the different transport energy types found in the three transport systems, including bio-ethanol, electricity, liquid petroleum gas (LPG), diesel and petrol. Comparison of the three trials is represented in *Table 4.1*.

Table 4.1 TES summary for neighbourhoods in Germany, New Zealand and Brazil

TES Summary Karlsruhe, Germany					
Car		**Electric Tram**		**Total**	
MJ/Trip	3.27	MJ/Trip	1.48	MJ/Week	2184
L/Trip	0.096	L/Trip	N/A	%Energy Petrol	95.9%
MJ/Person/Week	0.93	MJ/Person/Week	0.040	%Electricity	4.1%
L/Person/Week	0.027	L/Person/Week	N/A		
Cars/1000 people	605			MJ/Trip	0.15
Area					
Total Area (hectares)	9.84			**MJ/Person/Week**	**0.97**
Density (ppl/hect)	228.6				
TES Summary Tauranga, New Zealand					
Car		**Bus (LPG & Diesel)**		**Total**	
MJ/Trip	12.31	MJ/Trip	8.73	MJ/Week	447596
L/Trip	0.36	LDE/Trip	0.39	%Energy Petrol	66%
MJ/Person/Week	26.44	MJ/Person/Week	13.34	%Energy Diesel	20%
L/Person/Week	0.77	LDE/Person/Week	0.59	%Energy LPG	13%
Cars/1000 people	375			MJ/Trip	6.71
Area					
Total Area (hectares)	772			**MJ/Person/Week**	**39.79**
Density (ppl/hect)	14.6				
TES Summary São Carlos, Brazil					
Car		**Bus (Diesel)**		**Total**	
MJ/Trip	4.61	MJ/Trip	0.46	MJ/Week	12302
L/Trip	0.15	L/Trip	0.01	%Energy Petrol	68.3%
MJ/Person/Week	6.97	MJ/Person/Week	0.28	%Energy Diesel	3.9%
L/Person/Week	0.23	L/Person/Week	0.01	%Energy Alcohol	27.8%
Cars/1000 people	345			MJ/Trip	1.21
Area					
Total Area (hectares)	17			**MJ/Person/Week**	**7.25**
Density (ppl/hect)	101.6				

Energy units are in mega joules for all modes; however these have also been expressed in litres per week for liquid fuel. In the case of New Zealand buses, liquid petroleum gas (LPG) and diesel are jointly represented as litres of diesel equivalent (LDE). A similar method is applied to Brazilian cars that use both alcohol and petrol. It is also important to note that the New Zealand summary is an average result of three neighbouring suburban areas that ranged between 37 and 43 MJ/Person/Week; individual neighbourhood results are presented in

Section 4.3. The other summary results are of individual neighbourhood areas in Karlsruhe and São Carlos. Both of the neighbourhood study areas in São Carlos and Karlsruhe are inner city regions. The city populations are approximately: 100,000 in Tauranga, 210,000 in São Carlos, and 285,000 in Karlsruhe.

The results in *Table 4.1* compare the transport energy dependency of the three case studies following the TES method. As expected, the low density suburban areas in New Zealand produced by far the highest transport energy dependence result. This result being 40 times more than the inner city study area in Karlsruhe and 5 times more than the São Carlos study area. The two inner city study areas produced considerably lower energy dependence results than the suburban study area, however the difference between the São Carlos and Karlsruhe results are also significant. The São Carlos neighbourhood was 7 times more transport energy dependent than the Karlsruhe neighbourhood. This difference was due to many factors, such as Karlsruhe being a slightly bigger city, which may have contributed to its neighbourhood density being greater. Another major factor was the inability to cycle in the São Carlos urban study area due to busy roads, difficult topography and lack of cycle lanes. The one-way grid system of roads also increased São Carlos' energy dependence. Finally, the increased spatial separation of supermarkets in the São Carlos study area compared with the Karlsruhe study area further increased the energy dependence gap.

After professional evaluation from the Energy Efficiency Conservation Authority (EECA) of New Zealand, the TES method was modified to the form presented in this thesis. The current updated TES method was re-applied only to the São Carlos neighbourhood (due to impossibilities of redoing the other neighbourhoods) and modifications to the urban area were simulated, these results are discussed in detail in *Section 4.4*. The following sections describe results from the individual case studies.

4.2. Germany

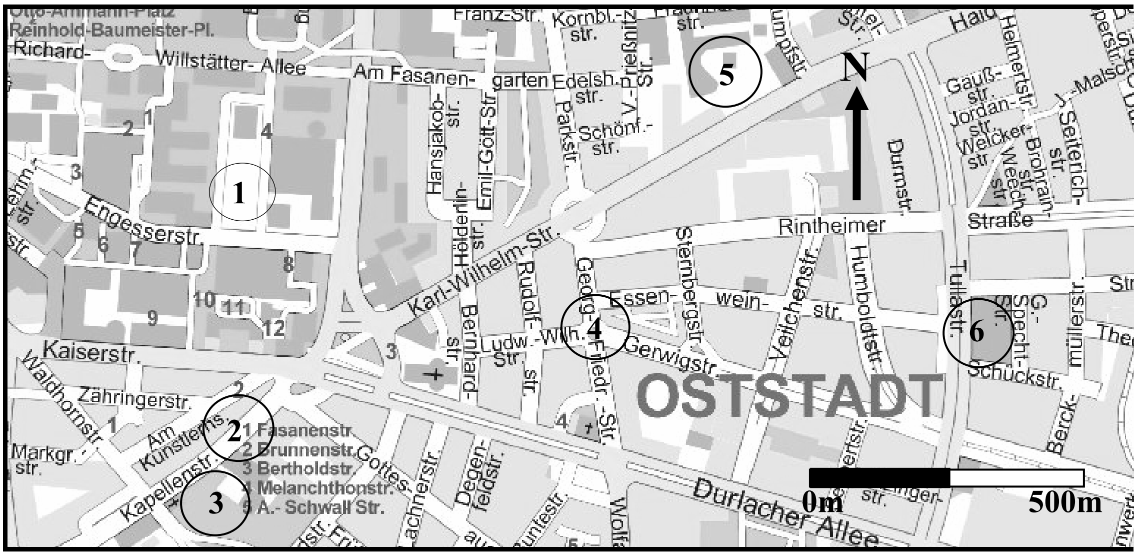
A case study was performed on a neighbourhood in Karlsruhe, a city with ample safe active transport (walking and cycling) and a high performance public transport system. Such a city was selected to be used as a base "best case" scenario in order to compare all future urban regions to this case study.

Karlsruhe (population approx. 285,000) is located in the South West of Germany and close to the French border. Karlsruhe is famous in transport circles for pioneering the concept of using rail tracks for the combined use of passenger trams and regional and freight trains. The city layout also provides for easy walking and cycling. In addition, neighbourhoods contain a variety of activities (medical services, restaurants, schools etc.) within the residential areas as shown in *Figure 4.1*, ensuring that many activities are within walking or cycling distance of residents.

Figure 4.1 Typical residential building in Karlsruhe with activities (book/wine stores) on the first floor

The case study focuses on a typical small urban neighbourhood in the Oststadt district of Karlsruhe containing approximately 2250 residents. The region is contained by three streets forming a triangle. The three streets forming the study region triangle are: Karl-Wilhelm St, Georg-Friedr. St., and Durlacher Allee. The Durlacher Allee side of the triangle is approximately 500 m in length. Karlsruhe University is located to the immediate Northwest of the study region as shown in *Figure 4.2*.

From observation of the paths and roads within and surrounding the study region, it was determined that cycling and walking are both safe. Many cyclists and pedestrians were also observed accessing their activities during the study region assessment. Cycle storage facilities were present at all major activity centres (schools, shops etc.) and it was also observed to be possible to store cycles close to smaller activity centres (securing to lampposts etc.). Many tram routes pass close to the study region, with many residents being located within 200 m of a tram stop. The tram routes and stops are shown in *Figure 4.2*, surrounding activities are also highlighted.



Key: 1 = University, 2 = Primary School (6-9yrs), 3 = Recreation Reserve, 4 = Supermarkets, 5 = Industry, 6 = School (6-17yrs), • = Tram Stops

Figure 4.2 Oststadt study region showing surrounding activities and tram stops

Demographic and employment data was provided by Karlsruhe University for the study region. There are approximately 2250 people within the study region, 1225 male and 1025 female, 16% of the adult population are students and 16% are unemployed. The closest available employment is located at the University and a nearby industry sector (Numbers 1 and 5 in *Figure 4.2*). These two locations provide over 4000 jobs. Following the TES method, workers travel to the closest available work sites; therefore all workers will travel to these two locations.

A visual inspection of the location of residences within the study region was performed. It was assumed all residents were evenly distributed amongst the available housing in the study region. The housing and activity locations were then plotted onto a map to allow trip distances to be calculated using the different modes according to the mode rules specified in the TES. The following Western European energy consumption data (KENWORTHY, 2003) was used for the available modes:

1. Walk and Cycle 0 MJ/km
2. Tram 0.72 MJ/p.km
3. Car 3.3 MJ/km or 9.65 Litres/100 km

Energy calculations were performed for all residents following the TES method, the results of these calculations are presented in *Table 4.2*.

Table 4.2 Energy and trip data for the study area separated into "common activities"

Age Group	**No.**	**Main Activity (5x/week) - School/University/Work**										
		Walk		**Cycle**		**Tram (0.72 MJ/pkm)**			**Car (3.3 MJ/km)**			
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
0 to 2	29	0		0		0			0			
3 to 5	27	18	200	0		0		0	9	360	106.9	3.12
6 to 9	35	0		0		12	1030	89.0	23	640	485.8	14.2
10 to 17	71	0		71	820	0		0	0		0	0
18 to 64:												
-workers	973	348	85	625	450	0		0	0		0	0
-students	546	286	350	260	500	0		0	0		0	0
-unemployed	290											
65 and over	279											
Total	2250	652	187.8	956	490.5	12	1030	89.0	32	561.3	592.7	17.33
		Food Shopping (2x/week)										
		Walk		**Cycle**		**Tram (0.72 MJ/pkm)**			**Car (3.3 MJ/km)**			
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
0 to 17	162	0		0		0			0			
18 to 64	1809	1809	300	0		0			0			
65 and over	279	264	180	0		0			15	350	69.3	2.03
Total	2250	2073	284.7	0	0	0	0		15	350	69.3	2.03
		Recreation (1x/week)										
		Walk		**Cycle**		**Tram (0.72 MJ/pkm)**			**Car (3.3 MJ/km)**			
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
0 to 9	91	2	390	0		0			89	600	352.44	10.3
10 to 17	71	2	390	69	600	0			0			
18 to 64	1809	40	390	1680	600	0			89	N/A[b]	0	0
65 and over	279	6	390	0		0			273	600	1081.1	31.6
Total	2250	50	390	1749	600	0	0		451	600	1433.5	41.9
		Weekly Totals										
		Walk (50.8%)		**Cycle (44.5%)**		**Tram (0.4%)**			**Car (4.4%)**			
		Trips	Dist.	Trips	Dist.	Trips	Dist.	Energy	Trips	Dist.	Energy	Petrol
Trips/Week	14686	7456	243.0	6529	519.8	60	1030	89.0	641	578.6	2095.5	61.28

a "Dist." = Average one way distance (m) to activity.
b In the case of children travelling by car, parents accompany them using zero energy.
c "Energy" units are MJ/Week; "Petrol" units are Litres/week of petroleum.

According to the specification guidelines, 95.3% of trips can comfortably be performed by active transport (cycling or walking). The high possibility for cycling and walking results in an overall low transport energy requirement. Of the motorised transport (cars and trams), about 10% of these trips could be completed by tram following the TES mode rules. Several factors contribute to this low mode share, such as no tram routes connecting the study region to the recreation reserve or the supermarket and tram stops not being within 200 metres of all residents and the value used here of 200 metres. If this 200 metre mode-distance was doubled (as it is in the current TES version) so that residents were allowed to access tram stops 400 metres from an origin, the tram share would most likely markedly increase.

The summarised TES for the study region is presented in *Table 4.3*, which shows that there is an average transport energy *dependence* of 0.97 MJ per person per week. This is equivalent to the energy required to power a 60 W light bulb for about four and a half hours. However, estimated observed energy use in German urban areas, typical of the Oststadt neighbourhood, is closer to 310 MJ/Person/Week (MOP, 2006). This infers that there is a large possibility for behavioural change in German urban areas. However, while German residents choose to use transport energy, they are not entirely dependent upon high energy use to access their activities, at least not in the study area of Oststadt.

Table 4.3 The Transport Energy Specification summary for the Karlsruhe study area

TES Summary Karlsruhe, Germany					
Car		**Electric Tram**		**Total**	
MJ/Trip[a]	3.27	MJ/Trip	1.48	MJ/Week	2184
L/Trip	0.096	L/Trip	N/A	%Energy Petrol	95.9%
MJ/Person/Week	0.93	MJ/Person/Week	0.040	%Electricity	4.1%
L/Person/Week	0.027	L/Person/Week	N/A		
Cars/1000 people	605			MJ/Trip	0.15
Area					
Total Area (hectares)	9.84			**MJ/Person/Week**	**0.97**
Density (ppl/hect)	228.6				

The TES specifies a minimal transport energy dependence for the urban layout of the study area. High population density (229 people per hectare) and a large share of jobs being located within or close to the study area contribute to this very low TES transport energy dependence value. The contrasting New Zealand case study is presented in the following section.

4.3. New Zealand

The New Zealand trial assessment was performed in three suburbs of Tauranga City, a medium sized city of approximately 100,000 residents but with one of the fastest population growth rates in the country. Three areas (Greerton, Merivale and Gate Pa) were selected for the study with a combined estimated population of 11,250 residents, according to 2001 census data (CENSUS, 2006). The three areas are adjacent to each other and are located south of Tauranga City Centre as shown in *Figure 4.3*.

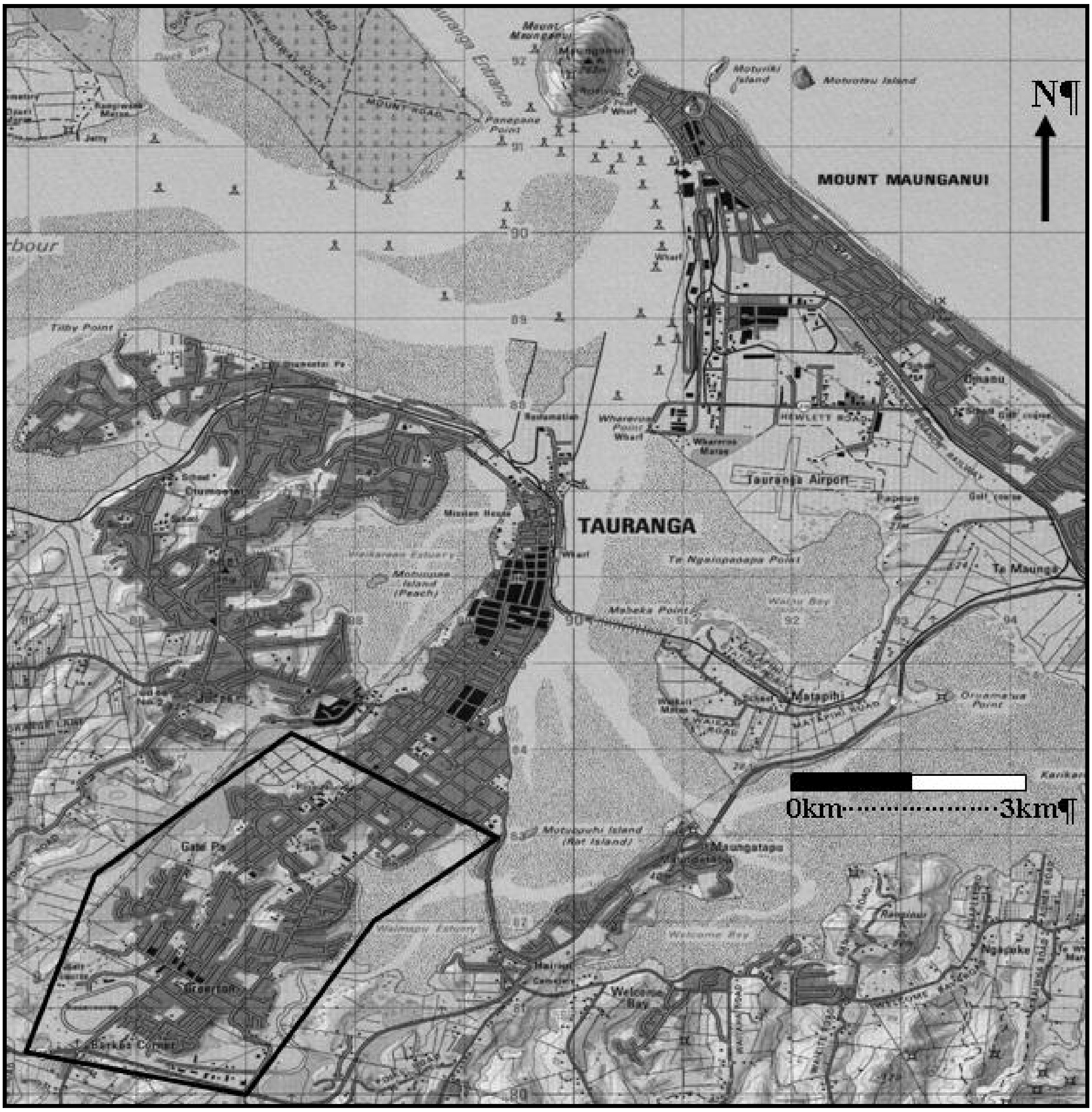


Figure 4.3 Tauranga City Map with Study Areas Outlined

There are three bus routes that serve the study areas and various parks, schools, supermarkets, and workplaces available to the residents.

From observation of the paths and roads within and surrounding the study areas, it was determined that walking was safe but only limited cycling was safe as shown in *Table 4.4*. Cyclists and pedestrians were observed accessing their activities during the assessment.

Table 4.4 Roads unsafe for cycling

Index	Roadname	Unsafe Reason
1	Matthew St	Narrow with parking on both sides of the road
2	Seventeenth Ave (West)	Narrow with parking on both sides
3	Seventeenth Ave (Central)	Parking on both sides
4	Seventeenth Ave (East)	Parking on both sides
5	Nineteenth Ave	Narrow with parking on both sides
7	Brook St	Industrial, very busy
8	Page St	Industrial
9	Courtney Rd, Twenty-second	Narrow, industrial, very busy
10	Chadwick Rd (South)	Industrial
11	Alach St, Sherson St	Industrial
12	Chadwick Rd (North)	Narrow and very busy
13	Maleme St	Industrial, very busy
14	SH 29	Very busy SH
15	Chadwick Rd, Oropi Rd	Very narrow and busy

The 2001 census data used for this report shows that 12% of the adult (18 to 65 years old) Tauranga population are students and 10% are unemployed. Employment is found to be distributed throughout the study areas, with major employers being the hospital and some industrial work sites. These locations provide over 2000 jobs. Following the TES method (original version), workers travel to the closest available work sites. Because there is enough employment inside the study areas, no-one is required to travel outside the study areas for work.

A visual and aerial inspection of the location of residences within the study areas was performed. It was assumed all residents were evenly distributed amongst the available housing in the study areas. Cars were distributed to houses that could not feasibly walk, cycle or use the bus for all required activities. For the study areas, (375 cars/1000 people) there were enough cars to allow all residents requiring a car to use this mode (CENSUS, 2006). The housing and activity locations were then plotted onto a map to allow trip distances to be calculated using the available modes according to the TES method. The following energy consumption data (KENWORTHY, 2003), (EECA, 1999) were used for the available modes:

1.	Walk and Cycle	0 MJ/km
2.	Bus	1.66 MJ/p.km or 4.5 LDE/p.100 km
3.	Car	3.3 MJ/km or 9.65 Litres/100 km

Note: LDE = Liters of diesel equivalent - combined diesel and liquid petroleum gas (LPG)

Energy calculations were performed for all residents following the TES method. The results of these calculations over the combined three study areas are presented in *Table 4.5* and *Table 4.6*. The individual area's results are presented later in this section.

Note: The following New Zealand data was calculated by a third party (Opus International Consultants). Due to software difficulties further explained in Chapter 6, there may be some small discrepancies where the individual trip numbers do not add up the total number of trips estimated from the census data.

Table 4.5 Trip data for walking and cycling separated into "common activities"

Age Group	**No.**	**Main Activity (5x/week) - School/University/Work**			
		Walk		**Cycle**	
		Trips	Dist.	Trips	Dist.
0 to 2	520	0		0	
3 to 5	560	31	151	0	
6 to 10	880	196	257	0	
11 to 17	1190	89	108	221	741
18 to 64					
- workers	4340	1276	250	1528	750
- students	1350	0	0	0	0
- unemployed	650				
65 and over	1760				
Total	11250	1592	241	1749	749
		Food Shopping (2x/week)			
		Walk		**Cycle**	
		Trips	Dist.	Trips	Dist.
0 to 17	3150				
18 to 64	6340	602	232	1961	582
65 and over	1760	166	232		
Total	11250	768	232	1961	582
		Recreation (1x/week)			
		Walk		**Cycle**	
		Trips	Dist.	Trips	Dist.
0 to 10	1960	312	236	0	
11 to 17	1190	187	236	289	545
18 to 64	6340	668	236	1481	545
65 and over	1760	278	236	0	
Total	11250	1445	236	1770	545
		Weekly Totals			
		Walk (16.4%)		**Cycle (21.6%)**	
		Trips	Dist.	Trips	Dist.
Trips/Week	66737	10941	239	14437	678

a "Dist." = Average one way distance (m) to activity

Table 4.6 Energy and trip data for bus and car modes

Age Group	No.	Main Activity (5x/week) - School/University/Work							
		Bus (1.66 MJ/pkm)				Car (3.3 MJ/km)			
		Trips	Dist.	Energy	LDE	Trips	Dist.	Energy	Petrol
0 to 2	520								
3 to 5	560	247	2042	8477	230	279	1603	15123	442
6 to 10	880	268	1427	7469	202	416	890	12638	370
11 to 17	1190	393	2287	14700	398	487	1728	29940	876
18 to 64									
- workers	4340	483	1500	12027	326	983	2000	64878	1897
- students	1350	633	4104	44549	1208	712	4104	94486	2763
- unemployed	650								
65 and over	1760								
Total	11250	2024	2524	87222	2364	2877	2276	217065	6348
		Food Shopping (2x/week)							
		Bus (1.66 MJ/pkm)				**Car (3.3 MJ/km)**			
		Trips	Dist.	Energy	LDE	Trips	Dist.	Energy	Petrol
0 to 17	3150								
18 to 64	6340	1389	2354	21489	1456	2373	1182	37625	1100
65 and over	1760	643	2354	9855	668	946	1127	14348	420
Total	11250	2032	2354	31344	2124	3319	1166	51973	1520
		Recreation (1x/week)							
		Bus (1.66 MJ/pkm)				**Car (3.3 MJ/km)**			
		Trips	Dist.	Energy	LDE	Trips	Dist.	Energy	Petrol
0 to 10	1960	822	1408	7956	539	826	1231	7171	210
11 to 17	1190	343	1500	3903	265	371	1164	3508	103
18 to 64[b]	6340	1113	1411	12533	849	1200	1164	11336	331
65 and over	1760	733	1408	7148	484	744	1231	6436	188
Total	11250	3011	1420	31541	2138	3141	1198	28451	832
		Weekly Totals							
		Bus (25.8%)				**Car (36.2%)**			
		Trips	Dist.	Energy	LDE	Trips	Dist.	Energy	Petrol
Trips/Week	66737	17195	2290	150106	6626	24164	1831	297490	8699

a "Dist." = Average one way distance (m) to activity
b In the case of children traveling by car, parents accompany them using zero energy.
c "Energy" units = MJ/Week; "Petrol" units = Litres/week of petroleum, "LDE" units = Litres/week of diesel equivalent.

According to the TES shown in *Table 4.5*, 38% of trips can comfortably be performed by active transport (cycling or walking). This relatively low possibility for cycling and walking results in an overall moderate to high transport energy requirement. Of the motorised transport, in *Table 4.6*, which makes up 62% of all trips, about 42% of this share (26% of all trips) could be completed by bus following the mode rules in the TES. Several factors contribute to achieving this level of hypothetical TES mode share, such as bus routes connecting the study areas to recreation reserves, schools and supermarkets; however the TES mode share could be increased if there were bus stops within 200 meters of most residents and common activities.

The summarised Transport Energy Specification for the study areas is presented in *Table 4.7*, which shows that an average of 39.79 MJ/Person/Week of transport energy is required for urban and transport system functionality. This is equivalent to the energy required to power a 2 kW electric heater for about five hours.

Table 4.7 The overall TES of the combined study areas

Transport Energy Specification Summary					
Car		**Bus**		**Total**	
MJ/Trip	12.31	MJ/Trip	8.73	MJ/Week	447596
L/Trip	0.36	LDE/Trip	0.39	%Energy Petrol	66%
MJ/Person/Week	26.44	MJ/Person/Week	13.34	%Energy Diesel	20%
L/Person/Week	0.77	LDE/Person/Week	0.59	%Energy LPG	13%
Cars/1000 people	375			MJ/Trip	6.71
Area					
Área (hectares)	772	hectares		**MJ/Person/Week**	**39.79**
Density (ppl/hect)	14.57	ppl/hect			

The TES specifies that moderate to high transport energy is required for the urban layout of the study areas. Low population density (14.6 people per hectare), some unsafe cycle roads and the locations and number of supermarkets, schools and kindergartens contribute to this moderate to high energy requirement.

The TES summaries for the individual Tauranga study areas are given in the following subsections.

4.3.1. Greerton

Greerton has the lowest population density of the three study areas; however it also has the lowest minimum energy requirement. This infers that low population density is not the only important factor contributing to high transport energy consumption. Greerton has activities within walking or cycling distance of many residents and is also well serviced by bus routes that connect residents to their activities. In spite of this, the energy requirement is still high. The TES for Greerton is presented below in *Table 4.8*.

Table 4.8 TES of Greerton

Transport Energy Specification Summary					
Car		**Bus**		**Total**	
MJ/Trip	11.58	MJ/Trip	7.06	MJ/Week	154667
L/Trip	0.34	LDE/Trip	0.32	%Energy Petrol	71%
MJ/Person/Week	26.22	MJ/Person/Week	10.77	%Energy Diesel	17%
L/Person/Week	0.77	LDE/Person/Week	0.49	%Energy LPG	12%
Cars/1000 people	375			MJ/Trip	6.23
Area					
Área (hectares)	336			**MJ/Person/Week**	**36.99**
Density (ppl/hect)	12.44				

4.3.2. Merivale

Merivale has the highest population density but performed the worst of the three study areas, partly due to no kindergartens in the area. The TES for Merivale is presented below in *Table 4.9*.

Table 4.9 TES of Merivale

Transport Energy Specification Summary					
Car		**Bus**		**Total**	
MJ/Trip	12.59	MJ/Trip	5.49	MJ/Week	86567
L/Trip	0.37	LDE/Trip	0.21	%Energy Petrol	80%
MJ/Person/Week	34.49	MJ/Person/Week	8.69	%Energy Diesel	12%
L/Person/Week	1.01	LDE/Person/Week	0.33	%Energy LPG	8%
Cars/1000 people	375			MJ/Trip	7.29
Area					
Área (hectares)	100			**MJ/Person/Week**	**43.18**
Density (ppl/hect)	20.05				

4.3.3. Gate Pa

Gate Pa performs in the middle of the three study areas and one of the reasons is due to bus routes not having bus stops within 200m of a supermarket. The TES for Gate Pa is presented below in *Table 4.10*.

Table 4.10 TES of Gate Pa

Transport Energy Specification Summary					
Car		**Bus**		**Total**	
MJ/Trip	12.90	MJ/Trip	11.47	MJ/Week	206363
L/Trip	0.38	LDE/Trip	0.51	%Energy Petrol	58%
MJ/Person/Week	23.44	MJ/Person/Week	17.31	%Energy Diesel	25%
L/Person/Week	0.69	LDE/Person/Week	0.78	%Energy LPG	17%
Cars/1000 people	375			MJ/Trip[b]	6.88
Area					
Área (hectares)	336			**MJ/Person/Week**	**40.75**
Density (ppl/hect)	15.07				

4.4. Brazil

The Brazil case study was performed using the same TES for the other trials, but in addition, the updated current TES version was applied to the Brazilian study area. Modifications were also simulated for the study area using the current TES version as detailed in the following subsections.

4.4.1. Original TES calculation

The Brazil trial assessment was performed in an inner city area of São Carlos, a medium sized Brazilian city of approximately 200,000 residents. A visual inspection was performed and the study area was estimated to contain approximately 893 house units (one unit equals one bedroom house, two units equals two bedroom house etc.). Applying the Brazilian medium for the South East region of Brazil (IBGE, 2006a) of 1.9 people per bedroom (unit) gives an estimated population for the study area of 1696 residents. The study area comprises 16 blocks of mixed land uses, in a grid format of one way roads as illustrated in *Figure 4.4*.

Figure 4.4 The São Carlos study area – aerial and road map

There are several bus routes that serve the study area and various parks, schools, supermarkets, and workplaces at a short distance from the residents. From observation of the paths and roads within and surrounding the study area, it was determined that walking was safe, although uncomfortable, but cycling was not safe on any of the roads due to insufficient space, busy roads and observed dangerous and intolerant driver behaviour towards pedestrians that was assumed to be similar for cyclists. It was very difficult to see any cyclists in the study area and those seen were generally pushing their bike.

The 2001 census data used for this report shows that 35% of the adult (18 to 65 years old) São Carlos population are unemployed and 6.4% are university students (IBGE, 2006b). Employment and various activities are found to be distributed throughout the study area. These employment locations within the study area are estimated to provide almost 2000 jobs. Following the TES method, workers travel to the closest available work sites. Because there is enough employment inside the study area, no-one is required to travel outside the study area for work.

A visual and aerial inspection of the location of residences within the study area was performed. It was assumed all residents were evenly distributed amongst the available housing in the study areas. Cars and motorcycles were distributed to houses that could not feasibly walk, cycle or use the bus for all required activities. For the study area, (345 vehicles/1000 people) there were enough vehicles to allow all residents requiring a vehicle to use this mode (IBGE, 2006b). The housing and activity locations were then incorporated into TransCAD to allow trip distances to be calculated using the available modes according to the TES method. The following mode energy consumption was used and assumes an average number of 50 people per bus and 2.5 km per liter of diesel for São Carlos buses, these details were verbally provided by the director of the São Carlos transport department, Sandra Ichikawa, on the 10th of October 2006. A 14.5 % share of motorcycles is also assumed (IBGE, 2006b) with an average urban consumption of 32 km/liter based upon actual tests of a HONDA CG 150 (MOTONLINE, 2010; REVISTA DUAS RODAS, 2010), which was the most popular motorcycle sold throughout Brazil in recent years.

1. Walk and Cycle 0 MJ/km
2. Bus 0.31 MJ/pkm or 0.8 L(Diesel)/p.100 km

3. Car/Motorcycle 2.99 MJ/km

Note: For cars the following consumption is assumed: 10 Litres/100km (Petrol - 68%)

11.1 Litres/100km (Alcohol - 32%) (MME, 2006), (MONTEIRO, 1998, p. 61).

Energy calculations were performed for all residents following the TES method and the results of these calculations are presented in *Table 4.11*.

Table 4.11 Energy and trip data for the study area separated into "common activities"

Age Group	**No.**	**Main Activity (5x/week) - School/University/Work**										
		Walk		**Bus (0.31MJ/pkm)**				**Car/Motorcycle (2.99MJ/km)**				
		Trips	Dist.	Trips	Dist.	Energy	Diesel	Trips	Dist.	Energy	Petrol	Alc.
0 to 5	138	74	199	12	320	12	0	52	644	1002	21	12
6 to 14	275	181	245	2	320	2	0	92	678	1867	39	22
15 to 17	120	79	245	1	320	1	0	40	678	811	16	10
18 to 64 - workers	552	552	75	0		0	0	0		0	0	0
- students	108	0	0	29	1050	94	2	79	1505	3557	74	43
- unemployed	348											
65 and over	155											
Total	1696	886	135	44.42	797	110	3	263	920	7237	150	87
		Food Shopping (2x/week)										
		Walk		**Bus (0.31MJ/pkm)**				**Car/Motorcycle (2.99MJ/km)**				
		Trips	Dist.	Trips	Dist.	Energy	Diesel	Trips	Dist.	Energy	Petrol	Alc.
0 to 17	533											
18 to 64	1008	243	328	362	730	328	8	503	662	3984	82	48
65 and over	155	37	328	41	730	37	1	77	662	610	12	7
Total	1696	280	328	403	730	365	9	580	662	4594	94	55
		Recreation (1x/week)										
		Walk		**Bus (0.31MJ/pkm)**				**Car/Motorcycle (2.99MJ/km)**				
		Trips	Dist.	Trips	Dist.	Energy	Diesel	Trips	Dist.	Energy	Petrol	Alc.
0 to 9	275	254	250	0		0	0	21	630	79	2	1
10 to 17	258	238	238	0		0	0	20	630	75	2	1
18 to 64[a]	1008	930	238	0		0	0	37	630	140	3	2
65 and over	155	143	238	0		0	0	12	630	45	1	1
Total	1696	1565	240	0		0	0	90	630	339	7	4
		Weekly Totals										
		Walk (64.6%)		**Bus (10.1%)**				**Car/Motorcycle (25.3%)**				
		Trips	Dist.	Trips	Dist.	Energy	Diesel	Trips	Dist.	Energy	Petrol	Alc.
Trips/Week	10148	6555	177	1028	744	474	12	2565	793	12170	246	146

a "Dist." = Average one way distance (m) to activity
b In the case of children traveling by car, parents accompany them using zero energy.
c "Energy" units = MJ/Week; "Petrol" units = Litres/week of petroleum, "Diesel" units = Litres/week of diesel, "Alc." units = Litres/week of alcohol.

According to the TES shown in *Table 4.11*, 64.6% of trips can comfortably be performed by walking. This relative high walking possibility results in an overall moderate to low transport energy dependence. Of the motorised transport, which makes up 35.4% of all trips, about 28% of this share (10.1% of all trips) could be completed by bus following the mode availability rules in the TES. Several factors contribute to achieving this level of hypothetical TES mode share, such as bus routes connecting the study areas to recreation reserves, schools and supermarkets; however the TES mode share could be increased if there were bus stops within 200 meters of all residents and common activities.

The summarised Transport Energy Specification for the study area is presented in *Table 4.12*, which shows that an average of 7.45MJ/Person/Week of transport energy is required for urban and transport system functionality. This is equivalent to the energy required to power a 2kW electric heater for about one hour.

Table 4.12 The São Carlos TES summary

TES Summary São Carlos, Brazil					
Car/Motorcycle		**Bus (Diesel)**		**Total**	
MJ/Trip	4.74	MJ/Trip	0.46	MJ/Week	12644
L/Trip	0.15	L/Trip	0.01	%Energy Petrol	70.5%
MJ/Person/Week	7.18	MJ/Person/Week	0.28	%Energy Diesel	3.7%
L/Person/Week	0.23	L/Person/Week	0.01	%Energy Alcohol	25.8%
Cars/1000 people	345			MJ/Trip	1.25
Area					
Total Area (hectares)	17			**MJ/Person/Week**	**7.45**
Density (ppl/hect)	101.6				

The TES specifies that moderate to low transport energy is required for the urban layout of the study area. Medium population density (101.6 people per hectare), unsafe cycle roads and the locations and number of supermarkets negatively contribute to this moderate to low energy requirement.

4.4.2. Updated TES calculation

The application of the current updated version of the TES method to the São Carlos study area produced an expected smaller energy dependence result; this was largely due to increased walking distances in the model making more activities accessible by foot. Even with the requirement for external work and shopping trips, the updated TES result was less than half of the original result. The updated TES model assumed 10% work trips must be to the city centre and no other major work centres were applied, for shopping trips 10% were assumed to the city centre and a further 5% to the Iguatemi shopping centre, which is the next closest major shopping area. The other shopping trips (85%) were assumed to all take place within the study area, as the study area contains an estimated 150 retail shops with an estimated total of more than 10,000 m^2 of shopping floor space (data estimated by visual walkabout of the study area). Without explicit knowledge of retail requirements, this is assumed to be sufficient for 85% of the study area population. The TES summary is provided in *Table 4.13*.

Table 4.13 TES summary for São Carlos – Brazil, using the updated TES method

Updated TES Summary São Carlos, Brazil					
Car/Motorcycle		**Bus (Diesel)**		**Total**	
MJ/Trip	3.99	MJ/Trip	0.39	MJ/Week	5667
L/Trip	0.13	L/Trip	0.01	% Petrol	63%
MJ/Person/Week	2.89	MJ/Person/Week	0.45	% Diesel	13%
L/Person/Week	0.09	L/Person/Week	0.01	% Alcohol	24%
Cars/1000 people	345			MJ/Trip	0.56
Area					
Área (hectares)	17			**MJ/Person/Week**	**3.34**
Density (ppl/hect)	101.6				

4.4.3. Simulations of land use modifications

To reduce energy dependency, two scenarios were simulated for the São Carlos neighbourhood. The first simulation included provision for residents to use bicycles to access all required activities. This option would require traffic calming, constructing cycle lanes and providing bicycle storage infrastructure; nothing can be done about the topography. The TES transport energy dependency result for this option was 0.39MJ/Person/Week, more than 8 times less than the current situation. The second simulation assumed the bicycle option was not possible and instead involved the addition of a new supermarket to the centre of the study area as shown in *Figure 4.5*.

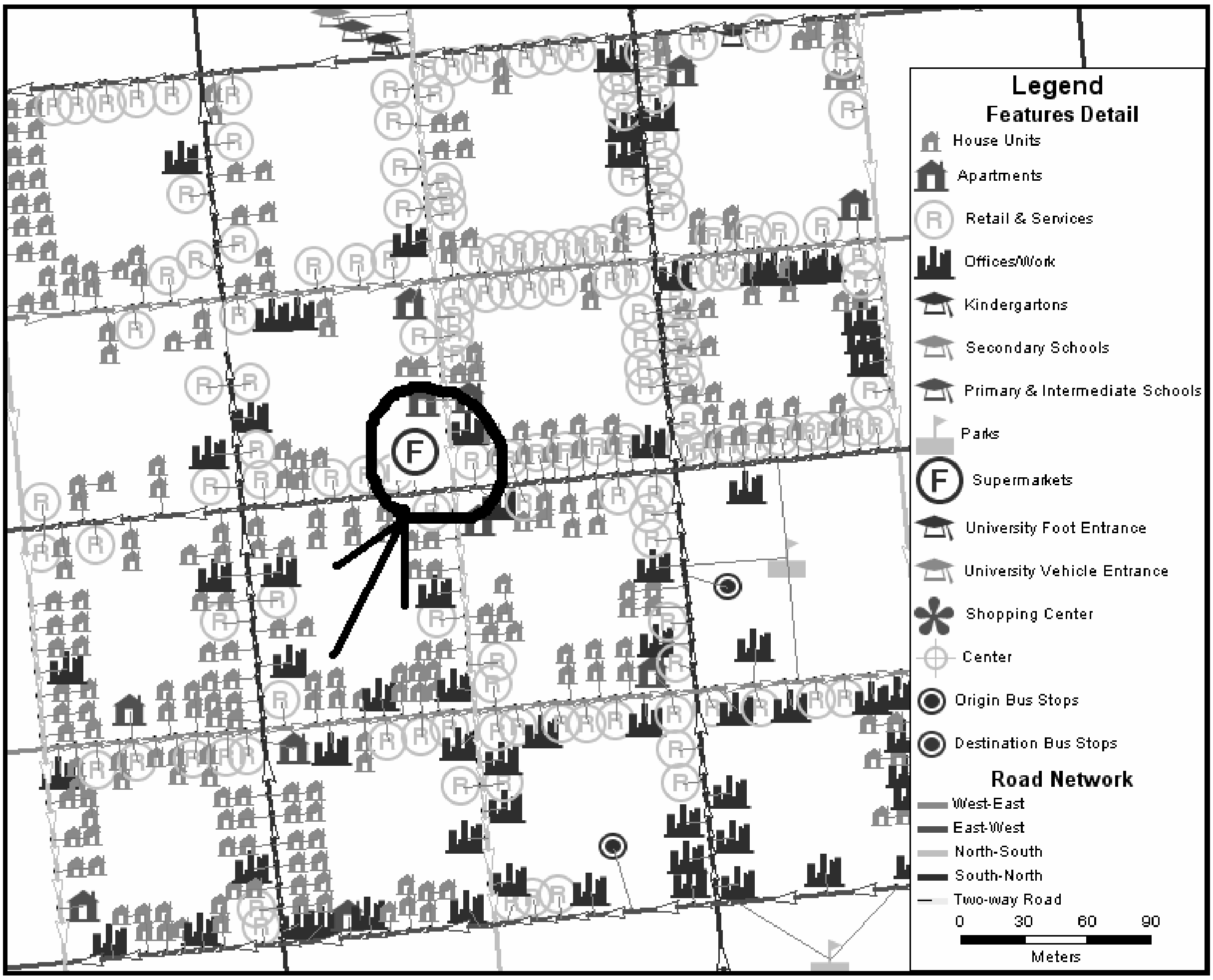


Figure 4.5 GIS representation of the São Carlos study area, including addition of a new supermarket

The TES transport energy dependency result for this option was 0.43MJ/Person/Week, similar to the bicycle option. A third simulation was performed that assumed the application of both options in tandem, the result was close to zero energy dependence - 0.01MJ/Person/Week.

In the case of the supermarket option, complete control is beyond the power of local authorities. However, the desired area could be zoned commercial and special incentives placed for supermarket operators to open a store in this location. Another option would be for the local government to construct an area and provide incentives for a farmers market to operate in this location.

4.4.4. Comparison using observed travel behaviour

While the TES focuses on the minimum energy use possibilities available, it is also interesting to compare the minimum energy possibility to a real world situation. This topic is dealt with further in the analysis and discussion section and specifically in Section 5.2 (Urban form and energy).

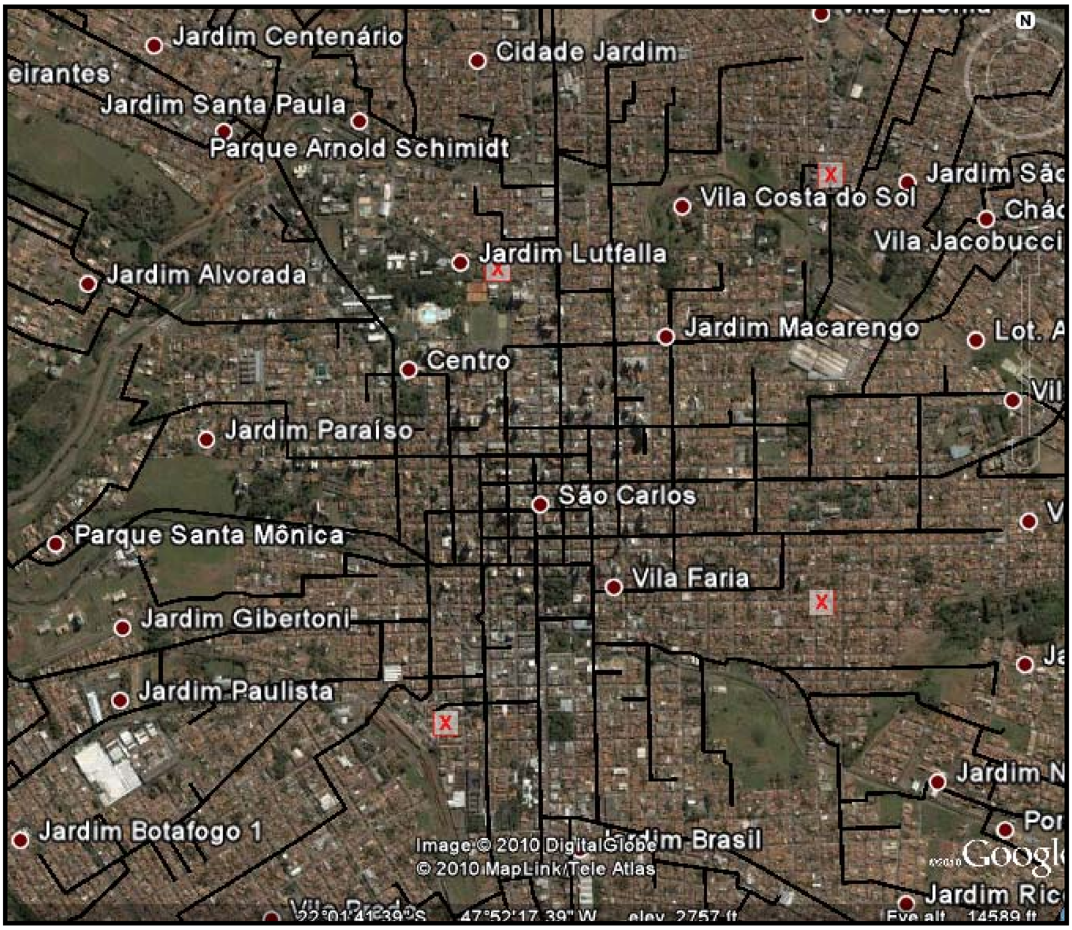


Figure 4.6 São Carlos origin destination network as displayed on Google

The case study in São Carlos presents an opportunity to compare some aspects of actual travel behaviour with the TES because a separate origin destination (OD) survey was completed

(SILVA, 2008) during the course of the TES study; *Figure 4.6*. For example, the below table compares the TES minimum energy mode use possibilities with the actual observed mode use from the OD survey:

Table 4.14 Comparison TES mode share possibility vs observed mode share

Mode Share Comparison for São Carlos, Brazil		
Mode	**Percentage TES**	**Percentage OD Survey**
Walk	64.6%	12.5%
Bicycle	0%	2.4%
Car	25.3%	45.7%
Bus	10.1%	27.1%
Other	0%	12.3%

The comparison of mode share suggests that although walking to many activities is possible, many residents prefer other modes (64.6% TES c.f. 12.5% observed). This is to be expected because while energy is available and affordable for residents, many residents will likely make use of energy, however if energy becomes less affordable or available it is possible that a lot of trips could be substituted from motorised modes to walking. This is one of the aims of the TES; to determine the flexibility of mode transfer to lower energy modes if required.

Further analysis and comparison of actual travel behaviour compared with the TES minimum energy possibility will be interesting as discussed in Section 5.2.1 and will require modification of the standard OD survey questionnaire to allow collection of all trip data, mode use and motor size (for energy consumption calculation purposes) for all family members of all households within an entire study area for the duration of a standard seven day week (i.e. a week not occurring on school or other holidays).

5. Analysis and discussion

The results of the case studies and professional evaluation of the TES tool proved interesting and valuable for further TES development considerations. The case study results and several points of interest are analysed and discussed in detail in the following subsections.

5.1. *Professional evaluation of the TES*

The TES method and applicability were evaluated by transport professionals from the Energy Efficiency and Conservation Authority (EECA) of New Zealand and the Transport Department of São Carlos, Brazil. The EECA provided the following comments:

> We are very enthusiastic about the principle of the TES, and think that it could have widespread application in assisting Councils in making planning and transport decisions. However … we think that it probably needs a bit of repositioning to be most effective.
>
> … the TES has to reflect (or more closely reflect) an approximation of the real world, [however] … it does not necessarily at an initial stage have to be recalibrated for each area.

The EECA suggested several specific changes that were incorporated into the revised TES model as outlined in *Chapter 3* - the method. However, one point raised by the EECA has only initially been dealt with and requires further research; relating TES energy dependence data to energy consumption estimates is discussed in *Section 5.2* and *Chapter 6* - conclusions and further work.

Representatives from the São Carlos Transport Department, including the former director of transport, Sandra Ichikawa, reviewed the applicability of the revised TES tool in transport and urban planning. The following summarised comments were given (translated from Portuguese):

> [São Carlos city is dependent upon transport energy because] … a large majority of residents use cars, buses, motorcycles etc. for work, general travel and leisure etc.
>
> The method [TES] … appears adequate and realistic for application to the characteristics of Brazilian cities.
>
> [The barrier to implementing the TES regulation is] … to relate [the TES] … to urban planning politics.

Barriers to implementing the TES in practice were identified as being largely political. The response and feedback for using such a tool in policy has been positive, however, respondents in this evaluation were not decision makers or politicians and believe that this is an important fact to consider.

5.2. Urban form and energy

The TES tool measures energy dependency of urban areas and transport supply, dependency is related to but different from transport energy consumption. Most previous studies have tended to focus on energy consumption estimates of different urban forms. However, it can be seen from the case study results in this thesis that calculated *energy dependence* trends are very similar to previously documented urban form *energy consumption* trends. The case study results infer that increasing density reduces per capita *energy dependence*, which is parallel to previously completed studies inferring that increasing density reduces per capita *energy consumption*. The high density urban neighbourhood of Karlsruhe was more than an order of magnitude less dependent on transport energy than the low density neighbourhoods of Tauranga. The São Carlos neighbourhood had a density and energy dependency in the middle of the two extremes. What is interesting to note is that when densities are relatively close, as in the Tauranga neighbourhood example (from 12.44 to 20.05 people per hectare), energy dependence is not solely a factor of density, but more related to accessibility. In actuality, the density range is not even that close, twenty being almost double twelve. However, the highest density neighbourhood achieved the worst (highest) energy dependence result of the Tauranga neighbourhoods. In contrast, the lowest density neighbourhood achieved the best (lowest) energy dependence result. This was a result of the good location of activities and transport (bus) services available in the lowest density neighbourhood and lack of these factors in the highest density neighbourhood. These are important considerations in urban planning and the TES allows these factors to be considered through energy dependence data and land use and transport system change simulations as described in *Section 4.4.3* for São Carlos and as illustrated in *Table 5.1* for Tauranga neighbourhoods.

Table 5.1 Energy dependence reduction opportunities

Region	Action	Energy Reduction
Greerton	Move/Create Bus Stop Close to Countdown (Supermarket)	5%
	Open Intermediate and Secondary School	10%
Total	Combined Actions Total Savings	**15%**
Merivale	Open Kindergarton(s) in Merrivale	7%
	Open Supermarket(s) in Merrivale	15%
Total	Combined Actions Total Savings	**22%**
Gate Pa	Move/Create Bus Stop Close to Kindergarton	5%
	Open Additional Primary School	7%
Total	Combined Actions Total Savings	**12%**
All Regions	More Cycle Ways, Safer Roads	10%
Total	Combined Actions for All Study Regions	**27%**

The opportunities in *Table 5.1* describe opportunities for energy dependence reduction. The subtle difference between energy consumption and dependence lies in the fact that actual travel behaviour data is not used and therefore not required, thus reducing time and costs. Weighted activity frequencies, based on observed travel behaviour, give weightings to neighbourhood activities, depending upon their current or desired importance. If the two results (energy dependence and consumption) are highly correlated, it may be argued that consumption estimates could be replaced with calibrated energy dependence data. Even in the case of relatively uncorrelated results, energy dependence may be of more use as it describes the minimum energy state possible using the available transport options in a comfortable manner. The energy dependence result provides a target as apposed to an energy consumption estimate that just describes the current state. Achieving or arriving close to this minimum energy state is then dependent upon transport policy. What is important about energy dependence is it can be easily related to land use and transport supply, thus allowing the most effective land use and transport infrastructure changes to be realised that will reduce energy dependence. Not only is the transport energy dependence result a target, but this target can also be moved.

Even in the case of energy dependency not being entirely correlated to energy consumption, this relationship is interesting to explore, because if successfully correlated, the TES result could provide both actual energy consumption estimates (current situation) and energy dependence data (target). Finding this correlation is explored in the following subsection.

5.2.1. Energy consumption/dependence correlation

Using data from a previous study completed by Silva, Costa and Pampolha (2001, p. 84) of energy consumption in various Brazilian, European, Asian and American cities a correlation will be attempted between energy dependence and consumption. It is interesting to note that each grouping of countries have remarkably different energy consumption characteristics with respect to density, therefore an aggregated consumption density relationship will not represent the individual countries very well. For this reason, only the São Carlos TES will be attempted to be correlated to actual energy consumption, as the study by Silva, Costa and Pampolha (2001) contains data for 27 Brazilian cities and no specific data for Germany or New Zealand.

According to Silva, Costa and Pampolha (2001, p. 84), there exists a linear correlation between energy consumption and inverse density (area per person), with an r square value of 0.459. The equation (modified from energy per year to energy per week) is shown in *Figure 5.1*.

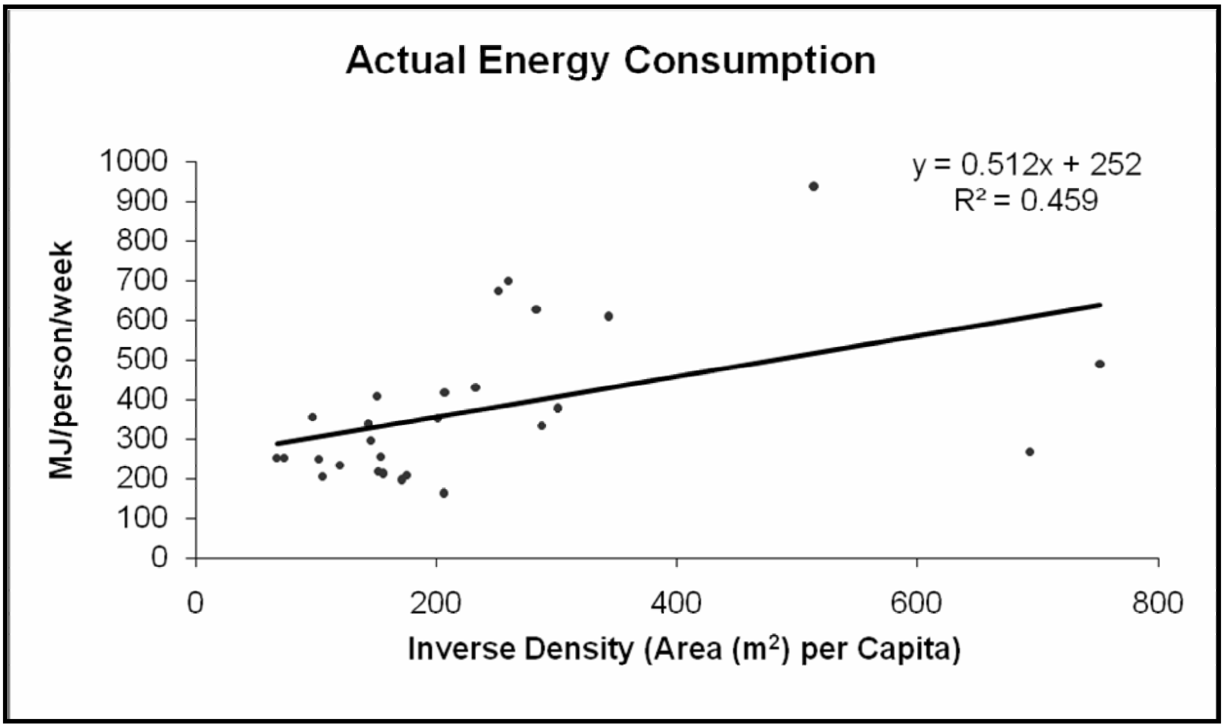


Figure 5.1 Brazilian cities energy consumption vs inverse density

In the São Carlos case study, the TES was performed on an area with an approximate density of 100 people per hectare. This equates to an inverse density of 100 square meters per person, which would place estimated actual energy consumption at approximately 303 MJ/person/week.

As was discussed previously in this chapter, density is not always closely correlated to *energy dependence* with small changes in density. However, when considering considerable changes in density as is the case from Karlsruhe to São Carlos to Tauranga, there appears to be more of a correlation. It has to be noted here, that the use of different countries with different socio-economic characteristics will not significantly influence the energy dependence correlation to density (contrary to the case of energy consumption) because energy dependence does not take into account actual behaviour; therefore it is largely independent of socio-economic characteristics.

As was discussed in the method and illustrated in the case studies, there are two TES methods (old version and updated version), resulting in two different TES values. However, TES data for all three case studies (Karlsruhe, São Carlos and Tauranga) is only available from the older version. A rough attempt has been made to calibrate data from the old TES version to the new version using the data from the São Carlos trial that used the updated version. It must be noted that this correlation will require much further calibrating as is discussed in *Section 6.3.3* - Further work. The two linear equations of dependence versus inverse density are represented in *Figure 5.2*.

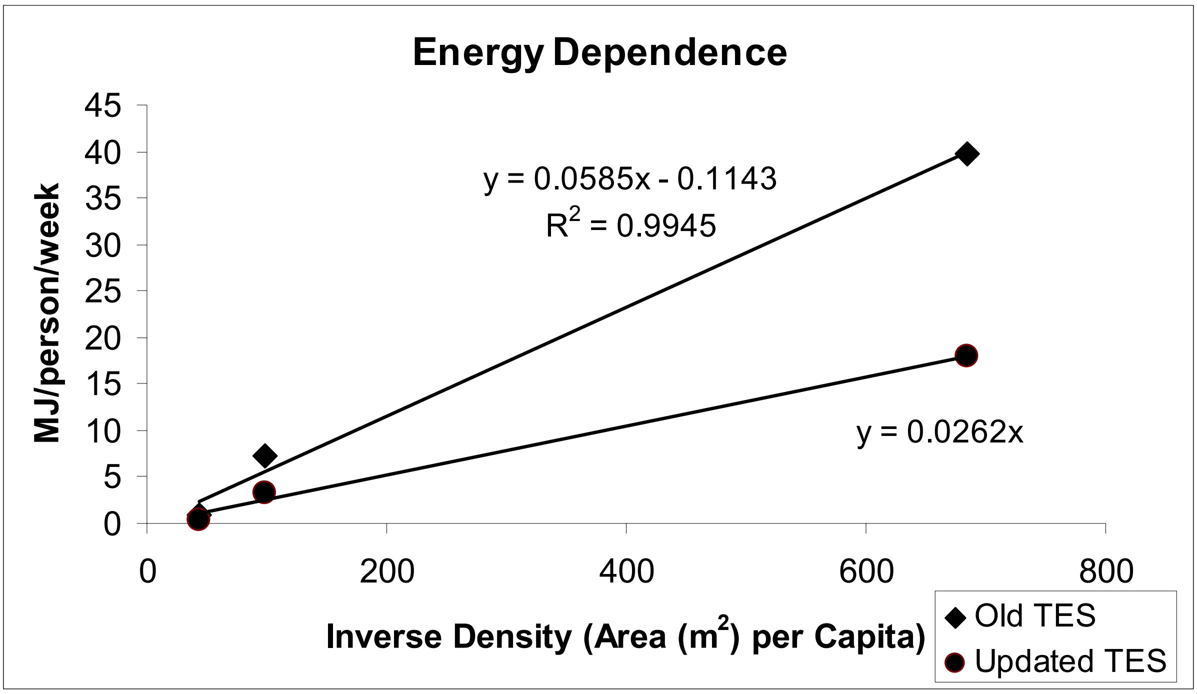


Figure 5.2 Energy dependence vs inverse density

To obtain the updated TES equation, it was assumed that updates for Karlsruhe and Tauranga would reduce the TES by an identical factor as occurred in the São Carlos study. This cannot be entirely justified and is a rough estimate because of the inability to re-calculate updated TES values for Karlsruhe and Tauranga due to other parties holding the GIS information required to perform new TES calculations. Obtaining necessary data to more accurately define the relationship is discussed in the next chapter under further work. The updated TES equation has also been adjusted to pass through the origin, as negative energy dependence is not possible.

Combining the relationship for Brazilian energy consumption in *Figure 5.1* with TES energy dependence in *Figure 5.2*, a new relationship is defined as shown in *Figure 5.3* that correlates estimated consumption to energy dependence.

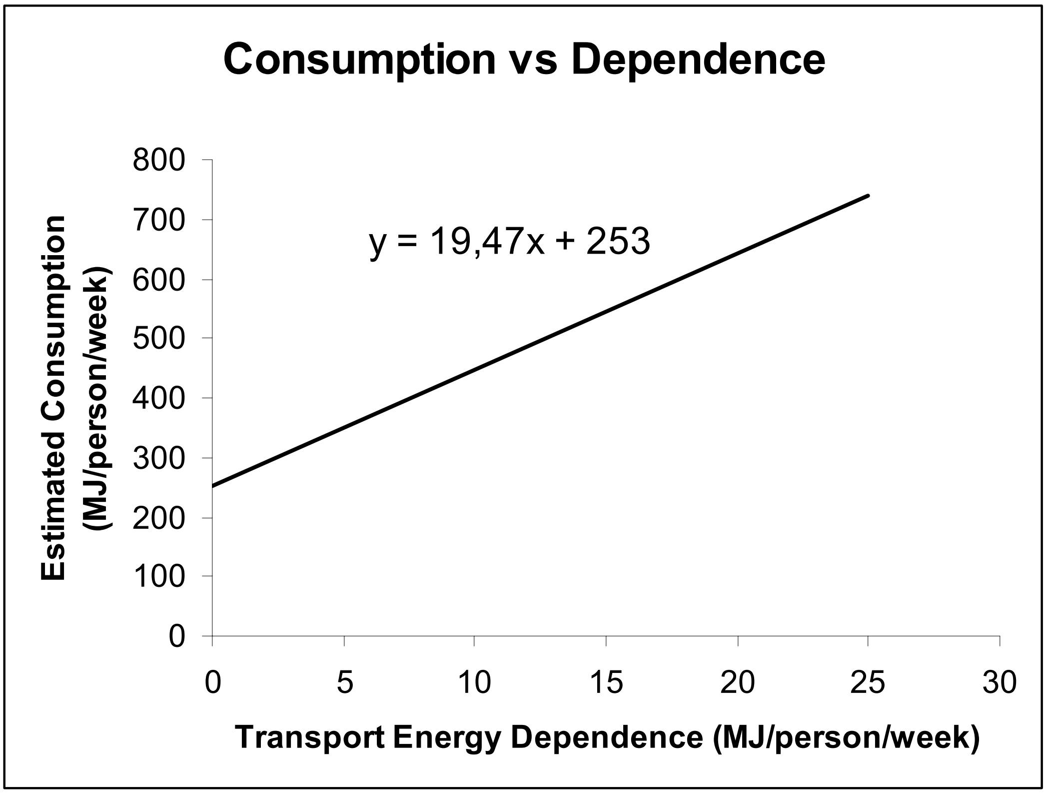


Figure 5.3 Relationship between transport energy consumption and dependence for Brazil

From the above graph, the São Carlos study area TES result of 3.34 MJ/person/week corresponds to an estimated actual energy consumption of approximately 300 MJ/person/week as was previously determined. Using this graph, estimations can now be made for actual energy reductions resulting from TES reductions. For example, the São Carlos case study involved simulations to the study area that resulted in a TES reduction to almost zero energy dependence (supermarket addition and cycle friendly). From the above graph, this would result in estimated actual energy savings of (303 - 253) 50 MJ/person/week (20% reduction), which is a significant energy saving. The other advantage of the consumption/dependence relationship, is that density is eliminated from the relationship (being a secondary factor), which allows smaller urban areas (neighbourhoods) to be possibly more accurately correlated to energy consumption. The TES result, although related to density, is also related to accessibility and the actual location of activities and infrastructure and transport service supply, thus the TES energy dependence is likely to be more closely correlated to actual energy consumption at the micro-scale. This hypothesis can only be determined through future studies as discussed in *Section 6.3.3*. The next section discusses placing energy dependence limits on urban development.

5.3. Determining urban development energy limits

Urban development energy limits for the TES require careful consideration and can only be provided as recommendations to local and regional authorities. At the current stage of research, with only three trials completed, the recommended limits will be a moving target until many more trials are completed on different urban forms with different densities from many cities in each country that wishes to use the TES as a policy tool. However, at this stage, a grading system has been created with tentative limits suggested for urban development. These limits are derived for the updated TES version and have been chosen from analysis of the case study results, with knowledge that the case study results used an earlier TES version. Special attention was given to density and ease of energy dependence reductions. For example, in the São Carlos case study (for which the updated TES was applied), making the area cycle friendly or introduction of a new supermarket reduced the energy dependence result by a factor of eight, from a Grade B (3.26 MJ/Person/Week) to a Grade A (less than one mega joule per person per week). Because these changes are seen to be feasible, this limit is applied for this level of density: medium sized city - central, as illustrated in *Table 5.2*.

Table 5.2 Proposed energy limits (MJ/person/week) for urban areas

Category/Grade Table					
		Energy Efficiency Grade			
City Category	**Density (people/hectare)**	**A**	**B**	**C**	**D**
Large City[a] - Central	≥ 200	0	<1	1-5	>5
- Outer Central	< 200 but ≥ 100	<1	1-5	6-10	>10
- Suburbs	< 100 but ≥ 50	<5	5-10	11-20	>20
Medium City[b] - Central	< 150 but ≥ 50	<1	1-5	6-10	>10
- Suburbs	< 50 but ≥ 10	<10	10-20	21-30	>30
Small City[c] - Central	< 80 but ≥ 40	<5	5-10	11-15	>15
- Suburbs	< 40 but ≥ 0	<20	20-30	31-40	>40

A = No action required, B = Opportunities, C = Action required, D = Urgent action required
a Over 500,000 residents
b Over 80,000 residents but less than 500,000
c Less than 80,000 residents

A grading system provides some flexibility to allow individual cities to customise grades to their specific circumstances. However, it is envisaged that in the future this flexibility will be replaced with a stricter "yes" or "no" type regulation. When grading proposed or existing urban developments, it is also envisaged that land use and transport infrastructure recommendations will be provided to allow the developer to achieve the required energy dependence level. Cities, regions or countries wishing to use such a grading system could begin by setting a regulation at Grade D and then moving this to Grade A over time, depending upon the level of commitment shown by the respective authorities. The city categories and population densities are again placed as an indication only as each individual city will need to determine where they wish to categorise themselves.

Because a retrial of the updated TES could not feasibly be applied to the Tauranga neighbourhoods, it is unknown which grade they would receive. However, it is assumed that the updated energy dependence result would be approximately half of the original, as it was for the São Carlos neighbourhood. This would put Tauranga neighbourhoods somewhere in an estimated range of between 15 and 25 MJ/person/week, resulting in a B or C Grade, which could be theoretically adjusted to an A or B Grade range through applying the recommended changes previously described in *Table 5.1*. The Karlsruhe neighbourhood receives an A Grade even before adjusting to the updated TES version, suggesting no changes are required for this neighbourhood. The São Carlos neighbourhood currently sits at Grade B and could me moved to Grade A (less than one mega joule per week) as previously discussed.

5.4. Sensitivity analysis

A sensitivity analysis allows model characteristics to be assessed as to their individual effects on the final result (KONTORAVDI *et al.*, 2005). In the case of the TES, these characteristics are the weighted activity frequencies and mode energy consumption parameters for a certain spatial layout (urban form). The interesting point to note is that, from deduction, sensitivity results will be different for each urban form. For example, if work locations are further spatially located for one urban area, compared with another, the weighted activity frequency parameter for the work activity will have a higher sensitivity in the first urban area c.f. the second. This brings a problem or a challenge to sensitivity analysis for the TES, as results will always only be relevant for the specific urban form for which the sensitivity analysis was applied, furthermore, as the urban area changes over time, the sensitivity analysis will become inaccurate.

It may, however, be possible to create a table of sensitivity analysis for common spatial separation combinations (urban forms) and after applying the TES to a specific urban area, the urban area's spatial characteristics could be matched to such a table to determine the approximate sensitivities of the parameters. This would avoid the necessity to perform a new sensitivity analysis for each TES urban area assessment, thus reducing time and costs. It could also be argued that a sensitivity analysis is not entirely necessary, as the model inputs are standardised against approximate observed travel behaviour data. Creation of these standardised inputs pre determines the relative sensitivity of each parameter. Therefore a sensitivity analysis may be seen as a circular exercise. A more interesting approach may be to examine sensitivity as a function of the size of an urban study area, so as to determine an optimal study area size or range. This is discussed further in the following subsection.

5.4.1. TES study area size and sensitivity

The TES was performed on a range of study areas from a maximum population of 11,250 people in the aggregated Tauranga case study to a minimum number of 1,700 people in the São Carlos case study. For the purpose of analysing the TES sensitivity at different urban sizes, the São Carlos study area was broken down into two smaller sizes containing 364 and 150 people respectively. The lesser of these two sizes (150 people) represents the area of one block, seen as the smallest possible neighbourhood unit that can be evaluated by the TES. The study range is therefore from 150 to 11,250 people. The Tauranga study was completed as both an aggregate study of three adjacent areas and also as an individual study of each of the three adjacent areas. The Karlsruhe neighbourhood is not included here, as only one study was completed, therefore no size comparisons can be made. The full range of urban sizes as related to the TES that will be investigated are presented here:

- 11,250 people (Tauranga – 3 adjacent aggregated urban areas)
- 6,186 people (Tauranga – 2 adjacent aggregated urban areas – Gate Pa excluded)
- 2,005 people (Tauranga – Merivale individual study area)
- 1,696 people (São Carlos – original study area size)
- 364 people (São Carlos – reduced study area size)
- 150 people (São Carlos – minimum possible study area – one block)

Investigation of the Tauranga areas will demonstrate what happens to the TES sensitivity as urban areas become large, whereas the São Carlos areas will demonstrate the other end of the scale, when the urban study area is reduced. In the first instance, Tauranga will be investigated.

The three urban area sizes can be visualised in *Figure 5.4*, the detail of the GIS data is too small to read, but for the purposes of visualising the three study area sizes, it is not important.

In order to understand how the TES sensitivity changes as the study area increases, the case of adding a supermarket to the Merivale study will be examined. For the Tauranga sensitivity analysis, first Merivale (size: 2,005 people) will be examined, then a larger study area including both Merivale and Greerton (size: 6,186 people) will be examined and finally the aggregated study area (size: 11,250 people) will be examined.

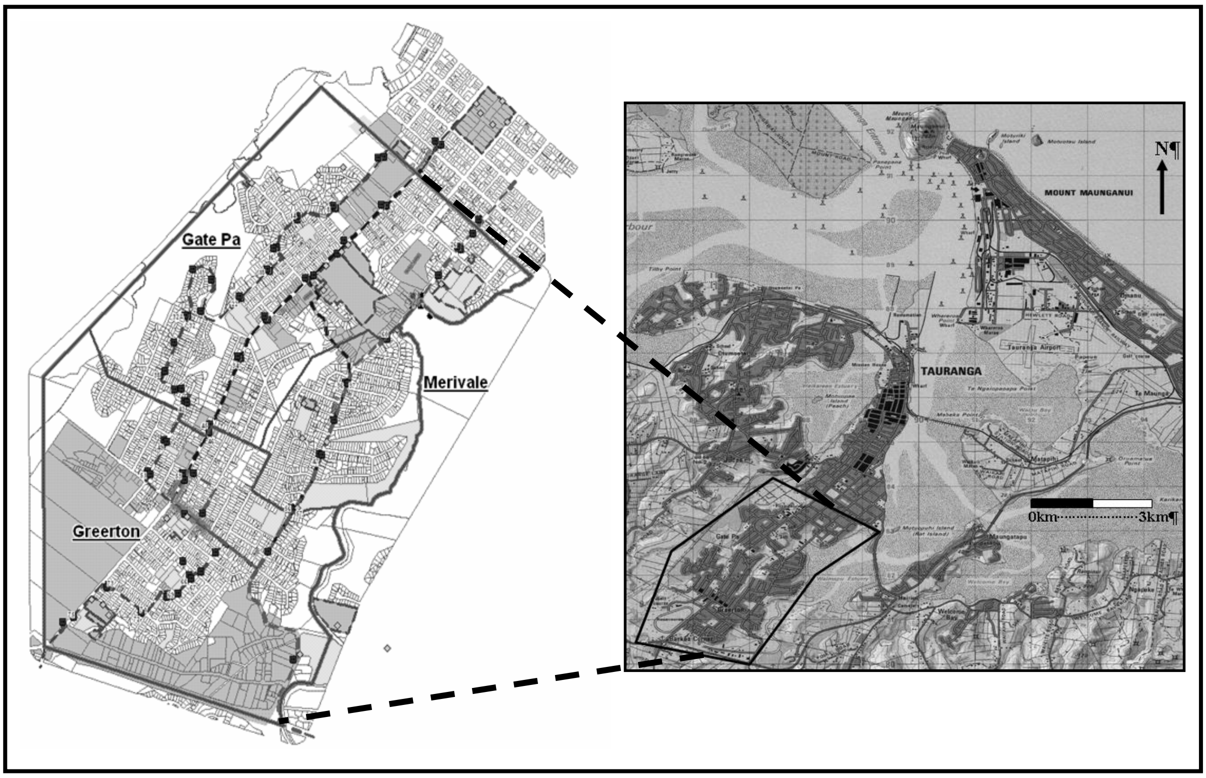


Figure 5.4 Tauranga study areas showing different study sizes

As was shown in *Table 5.1* the energy dependence reduction opportunity for Merivale adding a supermarket was 15%. This means that the TES result for the Merivale study area would reduce by 15% if a supermarket was built in the centre of Merivale's study area. If the study area is increased to include both Merivale and Greerton, the study area population becomes approximately three times larger, with most of the population situated in the Greerton side of the new study area. The TES result for Greerton of 36.99MJ/person/week and the TES result for Merivale of 43.18MJ/person/week result in a combined TES of 39.00MJ/person/week, obtained by simply multiplying the individual study area TES's by their population, adding together and dividing by the combined population. Similarly the density of Merivale (20.05 people per hectare) and the density of Greerton (12.44 people per hectare) are combined to give a new combined study area density of 14.19 people per hectare. Already it can be seen, as expected, aggregating the two study areas results in loss of information. The two study areas, before being combined, where not so homogenous, and are now represented as a single TES result with a single population density, which is substantially different to the TES and densities of the individual study areas.

Returning to the supermarket sensitivity analysis, the TES of the combined Greerton-Merivale study area will only be reduced by 5%, which is 3 times less than the 15% TES reduction of the individual Merivale study area. This can be deductively determined because the combined Greerton-Merivale study area population is 3 times larger than the individual Merivale population, thus the TES reduction for one action will become three times less (per person). Considering further aggregation by including the adjacent Gate Pa study area (total combined population of 11,250 people) will result in a TES reduction of just 2.7% for adding a supermarket in the previously mentioned location. Further loss of data will also occur as one aggregated TES result and density replaces individual results for areas, which in the Tauranga case are not exceedingly homogenous. It follows that further aggregation, in the case of adding a supermarket, will result in benefits being barely recognisable. Extrapolating out to one TES for the whole city would result in a TES reduction for the addition of one supermarket being fifty times less (because Tauranga city's population is fifty times greater than Merivale's population) than for the individual Merivale TES, resulting in a TES reduction of just 0.3%, which is barely noticeable.

Changes to neighbourhood level infrastructure and activity locations become easier to interpret in the TES results as urban study areas become smaller. In other words, the TES becomes more *sensitive* to infrastructure and land use changes as study areas are reduced. The case could be put forward that for the TES, the smaller the study area the better. Also, small adjacent areas can easily be aggregated into larger areas through simply averaging the results using the respective population weightings. To investigate what happens when study areas are further reduced down to the smallest neighbourhood element (one block), the case of São Carlos will be examined.

For São Carlos, the addition of a supermarket to the study area will also be examined, in order to remain consistent with the Tauranga analysis. The original São Carlos study area of 1,696 people with a density of 101.6 people per hectare resulted in a TES of 3.26 MJ/person/week as shown in *Section 4.4.2*. Two additional TES calculations were performed of smaller areas within the original study area as shown in *Figure 5.5*.

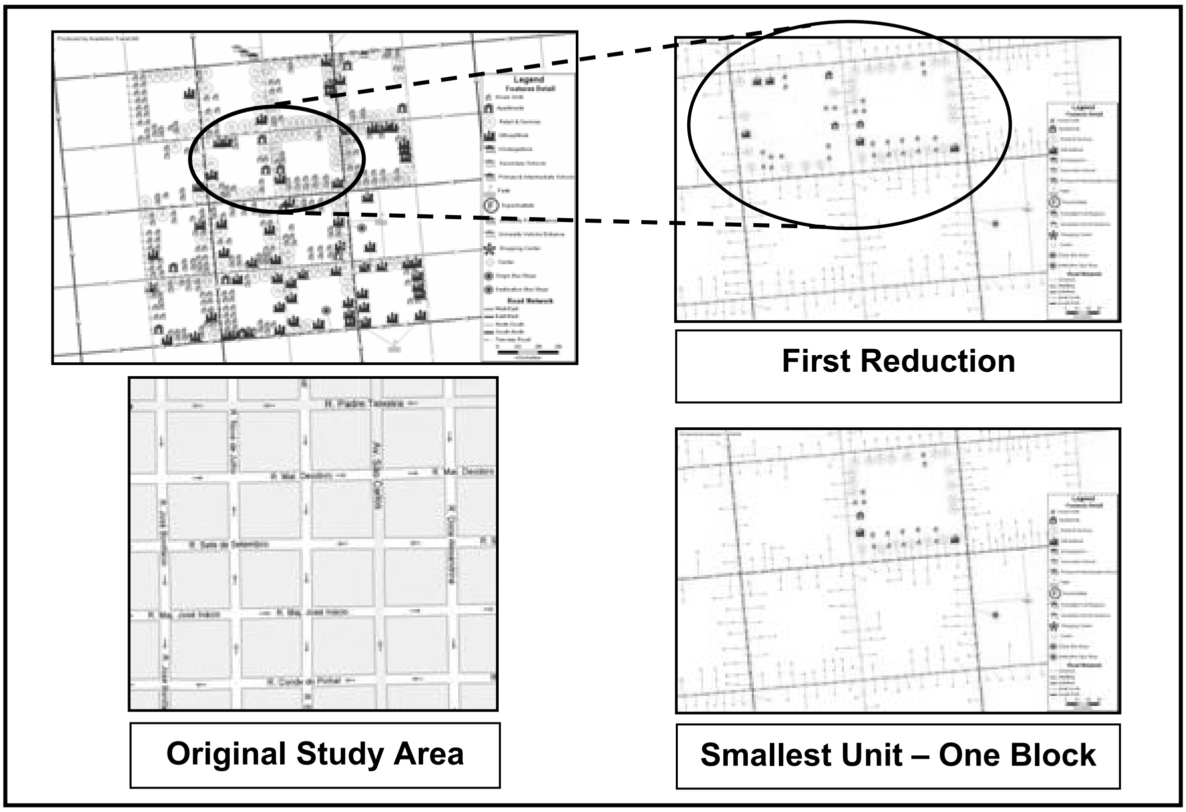


Figure 5.5 São Carlos original and reduced study areas

For the first reduction (size: 364 people), the density changed from 101.6 to 174.4 people per hectare, showing that the selected study area is more dense than the average density noted in the original study area. The resulting TES was, however, 67% greater (5.45 MJ/person/week), further confirming that high density is not the only factor contributing to low energy dependence as was discussed in *Section 5.2*.

The addition of a supermarket to the original study area (1,696 people) resulted in a TES reduction of 776% from 3.26 to 0.42 MJ/person/week. For the reduced study area (364 people), the addition of a supermarket to the same location reduced the TES from 5.45 to 0.25 MJ/person/week (a 2180% reduction or 21.8 times reduction in transport energy dependence). For the smallest study area size of one block (150 people: density 143.7 people per hectare), addition of a supermarket resulted in the "one-block" TES being reduced from 5.13 to 0.26 MJ/person/week, a 19.7 times reduction, similar to the 364 people study area. The two reduced study areas appear to be relatively homogenous in nature, with similar TES results and sensitivities to the addition of a supermarket. However, the sensitivity at this smaller scale is much greater than the original study area size (approximately 20 times TES reduction compared with 8 times reduction), supporting the argument for using small study areas in TES analyses.

The problem encountered when reducing study areas to the one or two "block" level is that although more detail is provided at smaller scales, it comes at an additional data analysis cost and takes longer to interpret. For the case of performing individual block-level studies, a TES calculation and GIS representation is then required for each block of a city. Not only does this require more time to produce than a more aggregated analysis but the data also takes a very long time to interpret for a planner wishing to assess a whole city, which may have hundreds or even thousands of individual TES results at the block level. For this reason, the ideal TES study size is a trade-off between the level of detail desired and the time/cost to produce and easily analyse the data. However, care is required to not over aggregate to the level that neighbourhood infrastructure changes can not be easily recognised by TES simulations. Each city will have their own ideal TES study sizes, depending upon the homogeneity, density, existing neighbourhood/district boundaries and total city size. However, it is recommended from this analysis that TES studies be performed in the range of 200 to 5,000 people. Below 200 being too detailed and time/cost expensive to produce and interpret for a whole city and above 5,000 being too aggregated, not allowing neighbourhood changes to be easily recognisable in the TES result.

It is also important to note that size may also be measured in area as well as population; this may be beneficial when considering Transit-Oriented Development (TOD) applications. The study area could be set to a circle surrounding the transit node of a walking or cycling distance radius, to determine/influence the energy efficiency of the land use and transport infrastructure within walking/cycling distance of a transit node while still observing the population study limits between 200 to 5,000 people.

5.5. Possible activity location regulations and incentives

Activity location incentives are something feasible for local authorities to implement and could include reduced taxes or even subsidies for shop construction. Tax incentives are already provided for some commercial buildings in the USA, for example the Internal

Revenue Service (IRS) currently provides tax deductions for owners of energy efficient buildings (BATTERSBY, 2006). Similar tax reductions could be offered in the case of commercial activities that are located in or have relocated to desired locations identified by the TES. Contrary to this tax reduction, increased taxes could also be imposed for the situation of activities operating in undesirable locations or for land left vacant. Such a tax system should be practicable to implement and regulate.

Using a tax system inside the wider TES urban development framework should be more effective at controlling urban development than relying solely on traditional development tax based systems as supported by Rodier, Johnston and Abraham's statement (2002, p. 243) that "development taxes and land subsidy policies may not be sufficient to generate effective … land uses without strict growth controls." In addition to incentives, consideration of retail and especially supermarket economics needs to be well thought-out when making TES recommendations. According to the TES, the maximum number of supermarkets until all residents are within 400m of a supermarket is the best option. However, the critical number of customers required for economic viability also needs to be considered. While the discussion on activity location incentives here is a start, it is realised that further research is required in this area to make practical use of the TES in policy economically acceptable as discussed in the following chapter.

6. Conclusions and further work

The following subsections outline the major conclusions and contribution of this research to transport and urban planning, including further considerations and research ideas for the TES.

6.1. Major TES results

A new tool was created to quantifiably measure transport energy dependency, the Transport Energy Specification (TES). This tool has been designed for use in a regulatory framework and was successfully trialled in three urban areas in very different cities around the world. The results confirmed numerically that low density, lack of cycle ways and increased spatial separation of activities increase energy dependence. These results are similar to those produced by previous studies on energy consumption and its relation to urban form, particularly density. It is therefore proposed that energy consumption and energy dependence are highly correlated; however further case studies are required to confirm this. The TES results also confirmed that density is not the sole factor affecting energy dependence, accessibility is also a key component of energy dependence.

In addition to quantifiably measuring the energy dependence of current urban forms, the TES has been designed to assess changes to energy dependence as a result of land use or transport supply modifications. A simulation of the modification of an urban area in São Carlos, Brazil was performed. The results showed that the energy dependence for the study area could be reduced by a factor of 8 by either the addition of a supermarket to the centre of the study region or through making the area and its surrounds cycle friendly. Both of these actions would be feasible, however the difficult topography of São Carlos may limit the uptake of the cycle option. The action of placing a supermarket in the desired area would likely involve first zoning the area as commercial and then providing tax incentives for supermarket operators to open shop in this area, or incentives and space for an informal "farmer's market" could be provided by the local authority. In the case of making the area cycle friendly, traffic calming is recommended by restricting vehicle access through some of the "through roads" in the study area, thus diverting some traffic to main roads. Cycle lanes and cycle education campaigns are also recommended for this option.

A major attestation to this work is the recent decision (3rd of May, 2007) of the New Zealand Ministry for the Environment to include the concept of this tool, the Transport Energy Specification, in their Urban Design Protocol (MfE, 2007). The Urban Design Protocol is a guide passed to all local authorities in New Zealand outlining principals and tools that can be used to achieve or improve upon good urban design.

6.2. Relevance of the TES to urban and transport planning

The TES contributes to the field of urban and transport planning by allowing new "decision-maker independent" controls to be placed on urban and transport development. Many urban areas are currently heavily dependent upon transport energy because of their urban density and land use configuration characteristics. This situation has most likely occurred as a result of the inability of traditional planning and policy measures to effectively control urban growth so as to dramatically reduce energy dependence. To address this issue, a new framework has been proposed in this thesis that requires land use and transport system regulations that relate to transport energy dependency. These regulations make use of the TES, which is a new GIS based tool that quantifiably measures urban/suburban transport energy dependency. It is envisaged that a significant reduction in urban transport energy dependence could be achieved in the future by utilising a combination of market forces, commercial incentives, inter-governmental cooperation and the TES in an urban development framework.

6.3. Further work required for the TES

The TES is a new tool contributing to the field of urban and transport planning. Further research and development of this tool is recommended for the most effective future application in an urban development framework, as described in the following subsections.

6.3.1. Activity location regulations and economics

Activity location incentives are something feasible for local authorities to implement. However, interviews and consultation with industry and government professionals are required to gain a better understanding of exactly how this could function. Consideration of retail and especially supermarket economics needs to be well thought-out when making TES recommendations. The critical number of customers required for economic viability needs to be considered. Further research is required in this area to make practical use of the TES in policy economically acceptable.

6.3.2. Refinement of energy limits

As the TES is new, deciding or recommending energy dependence limits for urban development cannot be undertaken solely by local authorities. To address this issue, an initial analysis of the three case studies provided a starting point for possible development limits, as outlined in *Chapter 5*. These limits will however be a moving target until the completion of many further case studies in different countries and urban areas.

6.3.3. Software development

As was discovered during the case studies, the current manual TES calculation method is very time consuming and prone to small discrepancies in the results. Before future studies can continue at a faster pace and larger scale, software development is required to automate the TES calculations and re-calculations (after land-use/infrastructure change simulations). The author of this thesis is currently entering into negotiations to develop this software and it is hoped all future research will make use of custom TES software. The manual process is outlined further in Annex A.

6.3.4. Relating energy dependence to consumption

An attempt was made to create a correlation between estimated actual energy consumption and energy dependence. However, the defined relationship was based on limited data obtained in the case studies. To further calibrate the relationship will require many more TES energy dependence case studies to be performed in tandem with actual energy consumption estimates. The ideal situation would be to perform the tandem studies for each city that has an interest in using the TES, as each city (and country) may have its own socio-economic characteristics that will affect the calibration of consumption to dependence. Individual city calibrations would result in each city being able to apply its city specific equation to more accurately estimate energy consumption for each of its urban areas.

This area is of particular interest and should be pursued by any city wishing to use the TES in urban development policy. This thesis has presented an overview and demonstrated how to obtain the relationship between consumption and dependence. It is now up to researchers or interested cities to apply the concepts provided here to develop their own city specific consumption-dependence relationships.

6.4. Final considerations

The Transport Energy Specification and its corresponding urban development framework represent an original contribution to the area of urban and transport planning. It is hoped that future work and trials will allow the TES to develop to a stage where it can feasibly be included into government policy in the near future, however, this will require a focused effort that needs to continue after this project is concluded. This project is just the beginning of a long path of future research possibilities.

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ANNEX A – TES Manual Calculation

This appendix is provided to be used as an illustrative step by step guide for other researchers wishing to manually perform their own TES calculations. It is recommended to check with the author if software is already existing before performing a manual calculation, as software will greatly reduce the amount of calculation time required. Please contact the author at the following address: michael_kiwi@hotmail.com.

The manual calculation requires two spreadsheets and several worksheets:

1. A land use data spreadsheet (preferably one worksheet)
2. A trip distance data spreadsheet including the following worksheets:
    a. A master worksheet taking data from sub-worksheets
    b. A new sub worksheet for each activity and corresponding mode arranged in order of mode availability (e.g. “supermarket – walking” worksheet, “supermarket – cycling”, “work – walking” worksheet etc.)

1. Creating the Land Use Data Spreadsheet

After placing all the land use data into a GIS package, each point of interest will be given an identification number (usually automatically) by the GIS program. Data then needs to be added to each ID number corresponding to the land use data that was collected during the visual inspection stage. This data can usually be added directly into the GIS package but it is more useful to store it in a spreadsheet for easy reference and to make use of “copy” and “paste” functions to the second trip distance data spreadsheet. A partial example of a land use data spreadsheet is given below in Figure 1.

Apartments		Retail/Services/Entertainment			Office + Other Work		Schools	
ID	# Units	ID	SqMeters	# Workers	ID	# Workers	ID	School Type
77	80	85	200	3	93	5	105	Kindergarton
101	50	87	50	4	114	3	947	Primary/Int School
399	75	89	50	3	159	3	208	Secondary School
401	100	91	50	3	161	20	212	Primary/Int School
494	60	95	50	4	248	10	210	Secondary School
568	60	97	25	2	303	5	214	Kindergarton
718	60	99	50	2	403	10	923	Kindergarton
736	60	103	100	3	404	10		
739	36	107	50	3	406	4		
764	5	109	50	3	408	5		
822	6	111	200	5	410	8		
	592	133	200	10	498	60		
		135	25	2	496	10		
		137	25	2	500	100		
		139	100	5	502	20		
		141	100	2	504	2		
		143	100	2	524	1		
		145	100	3	570	10		
		147	100	3	572	10		
		149	100	3	574	10		
		151	50	3	576	30		
		153	100	20	578	10		
		155	25	2	580	5		
		157	100	3	628	75		

Figure 1 Land use data spreadsheet showing GIS software ID and corresponding data

The above example shows apartments, retail/services shops and office locations as per their GIS software assigned ID numbers. Land use data is added to each ID, for example number of workers per office location and number of workers and estimated retail floor area for shops. In the case of apartments, number of units is estimated, where one unit is equivalent to a one bedroom residence. In Figure 1, Apartment number 77 has an estimated 80 bedrooms contained within the complex. Units are used instead of actual apartments to more accurately estimate residential capacity using census statistics that detail average occupancy rate per bedroom for the study area (e.g. 1.9 people per bedroom for South East Brazil). This same unit measurement needs to be added to each house ID i.e. 1, 2, or 3 units/bedrooms.

2. Creating the Trip Distance Data Spreadsheet

The trip distance data spreadsheet requires the creating of several inter-linked worksheets, taking calculations from sub-worksheets and applying them to the master worksheet which performs the actual TES calculation and TES summary. An example of a finished trip distance data spreadsheet is given below in Figure 2.

	A	B	C	D	E	F	G	H	I
7									
8	**Age Group**	**No.**	**Main Activity (x/week)**				**Kindergarton =**		**3**
9			Walk		Bus (0.31MJ/pkm)				
10			Trips	Dist.	Trips	Dist.	Energy	Diesel	CO2(kg)
11	(with parent) 0 to 5	138	137	313	0	320	0	0	0
12	6 to 14	275	275	335	0	0	0	0	0
13	15 to 17	120	120	335	0	0	0	0	0
14	(10% center) workers 18 to 64	552	497	75	52	774	112	3	8
15	tertiary students 18 to 64	108	0	0	102	1111	281	7	19
16	unemployed 18 to 64	348							
17	65 and over	155							
18	Total	1696	1029	206	154	997	393	10	27
19				**Retail + Other Recreation =**				**3**	**X/Week**
20			Walk		Bus (0.31MJ/pkm)				
21			Trips	Dist.	Trips	Dist.	Energy	Diesel	CO2(kg)
22	0 to 17	533							
23	(15% Shopping Centers) 18 to 64	1008	857	75	143	1729	460	12	31
24	(15% Shp Centers) 65 and over	155	132	75	22	1729	71	2	5
25	Total	1696	989	75	165	1729	531	14	36
26				**Food Shopping =**				**2**	**X/Week**
27			Walk		Bus (0.31MJ/pkm)				
28			Trips	Dist.	Trips	Dist.	Energy	Diesel	CO2(kg)
29	0 to 17	533							
30	18 to 64	1008	243	328	362	730	328	8	22
31	65 and over	155	37	328	41	730	37	1	3
32	Total	1696	280	328	403	730	365	9	25
33				**Open Space Recreation =**				**1**	**X/Week**
34			Walk		Bus (0.31MJ/pkm)				
35			Trips	Dist.	Trips	Dist.	Energy	Diesel	CO2(kg)
36	(with parent) 0 to 9	275	275	296	0		0	0	0
37	10 to 17	258	258	296	0		0	0	0
38	18 to 64[a]	1008	1008	296	0		0	0	0
39	65 and over	155	155	296	0		0	0	0

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Figure 2 Trip distance spreadsheet overview

Figure 2 is a partial view of the trip distance spreadsheet showing the master worksheet. The tabs at the bottom of the figure point to the sub-worksheets arranged by activity and mode. In the example given in Figure 2 it can be seen that for the "recreation" activity, only the walk mode is included. That is because all residents can access recreation by this mode. The next activity "Spmkt = supermarket" has three modes available for use – walk, bus and car, signifying that all three modes are required for this activity and study area. The final activity that can be seen from this partial spreadsheet "Univ = university" does not have the walk mode available (university is too far from the study area according to the mode availability rules). The bus mode is available (signifying a connecting route and convenient bus stops) however, it cannot be seen from the partial spreadsheet if the car mode is required. This spreadsheet example is only a partial view and all other activities and their corresponding modes cannot be visualised, however, the reader should be able to get the basic idea of what a trip distance spreadsheet looks like. The next steps will explain how to obtain each value shown in the cells of Figure 2 using the sub-worksheets. The following cell data is required:

a) Number of residents per age group and activity
b) Number of residents per mode as a subset of activity
    a. This requires estimating percentages of mode availability
    b. External work/shopping trips require special consideration
c) Energy dependence data

Note: Remember each activity has an activity frequency as explained in the thesis. All final trip and energy data needs to be multiplied by this weekly frequency to produce weekly trip and energy data.

a. Number of residents per age group and activity

The number of residents per age group is pre-determined after selecting the study area and estimating the population through counting the number of apartments and houses contained within the study area and applying demographic data from census or other available surveys e.g. if there are 234 houses and 32 apartments having a combined total of 632 units (bedrooms), the estimated population will be 1264 people if census data estimates 2 people per bedroom. This population is then divided into age groups using the percentage census data breakdown of age e.g. 10% between 0 and 10 years etc.

The number of residents per activity and the activities selected for use in the TES can be defined by transport professionals or the researcher undertaking the study. An example of age groups assigned to different activities is given in the thesis in both the method and the Case Studies Chapters.

b. Number of residents per mode as a subset of activity

This step is the most time consuming, it involves first exporting “multiple shortest path” data as explained in the thesis to a sub-worksheet in the trip distance spreadsheet. The example given below in Figure 3 references the supermarket activity. The first step after creating and naming the worksheet and importing the “multiple shortest path” data is to separate the data by supermarket ID, i.e. there may be more than one supermarket serving the study area.

F	G	H	I	J	K	L	M	N	O	P	Q	R
Spmkt ID	HsID	dist	walk(yes/no)	Spmkt ID	HsID	dist	walk(yes/no)	Spmkt ID	ApID	dist	#units	walk(yes/no)
902	72	436.91	0	910	816	261.73	1	897	101	450.29	50	0
902	68	440.1	0	910	789	271.2	1	897	718	482.86	60	0
902	71	444.03	0	910	815	271.66	1	897	736	421.21	60	0
902	69	446.2	0	910	810	273.07	1	897	739	481.82	36	0
902	75	452.19	0	910	788	274.09	1					
902	65	453.53	0	910	774	281.39	1					
902	74	459.46	0	910	814	281.49	1	902	77	548	80	0
902	678	560.89	0	910	809	282.71	1					
902	666	569.96	0	910	772	283.31	1					
902	677	574.2	0	910	813	292.05	1	910	399	344.8	75	1
902	664	585.65	0	910	808	292.18	1	910	401	410.54	100	0
902	627	658.68	0	910	770	292.21	1	910	494	521.23	60	0
902	622	669.15	0	910	790	292.6	1	910	568	519.64	60	0
902	626	679.89	0	910	826	294.67	1	910	764	374.25	5	1
902	620	690.8	0	910	787	299.6	1	910	822	275.28	6	1
			0	910	807	302.28	1				86	

Figure 3 Supermarket-walking worksheet - partial view (Spmkt_Walk from Figure 2)

In the example given in Figure 3 there are three supermarkets, IDs 897, 902 and 910. The IDs to the immediate right of the supermarket IDs represent one unit/bedroom house IDs for columns G and K and apartment IDs for column O.

- **Walking mode**

The next column for both houses and apartments is the shortest path distance along the walking network to the respective supermarket. Originally the multiple shortest path data will provide distances from each house/apartment to each supermarket. In the case of three supermarkets only one supermarket will be the closest for each house/apartment and the other two supermarkets need to be eliminated. This is done by ordering the all house/apartments by house ID for each supermarket and performing an IF (distance of house ID n1 to supermarket ID spmkt1) IS LESS THAN (distance of house ID n1 to supermarket ID spmkt2) THEN 1 ELSE 0. A result of 1 in this case will require that house n1 is associated with supermarket spmkt1. This sequence is performed for all houses apartments and supermarkets until each house/apartment ID is associated with its closest supermarket ID. In Figure 3 this has already been completed as can be seen from the apartment's column (column O) that includes all the apartment IDs and each corresponding closest supermarket (ID 897, 902 or 910).

Note: The apartments have an extra column than the one unit houses (columns G and K) corresponding to the number of units for the apartment complex (column Q). Two and three unit houses also require this column.

The next step is to determine whether residents of each house/apartment can access the activity by walking, according to the mode availability rules explained in the thesis. If the acceptable walking distance is 400 m (as in the example in Figure 3) then a simple function is applied to each house/apartment: IF (dist) IS LESS THAN (400 m) THEN 1 ELSE 0. This has already been completed in Figure 3 and is the final column of each data group (columns I, M and R). Column I records all zeros because even though supermarket 902 is the closest to these houses, no one unit houses are within 400 m of supermarket 902. There are only three apartments within 400 m of a supermarket (supermarket 910); these are apartments 399, 764 and 822.

To calculate the number of units within walking distance, all house/apartment units with a 1 on their final column are added. In Figure 3 this can be seen for the apartments only, apartments 399, 764 and 822 have a combined 86 units within walking distance. The number of units within walking distance should be expressed as a percentage of total units in the study area for later use in the master worksheet. Average walking distance is calculated by multiplying the number of house/apartment units by the distance to the supermarket from that house/apartment and summing for each apartment/house ID and then dividing by the total number of units within walking distance.

- **Public transport (bus/tram) mode**

The first percentage mode availability for one activity is now complete, the next step requires calculating the mode availability for the next available mode, which could be cycling (if cycling is safe) or bus/tram modes. For cycling a similar procedure follows as for walking, however all house/apartment IDs included in the walking share must be excluded from all other modes as per the mode availability rules 1st choice, 2nd choice etc. For public transport modes the calculation is slightly more complex as it involves considering distances to bus/tram stops from the house/apartment.

First an analysis is required (this should be completed in the land use/transport infrastructure data collection stage) to determine which bus routes serve the closest supermarkets and if bus stops from these routes are within the defined acceptable walking distance limit to the supermarket. The bus stop IDs serving the study area should then be grouped as “origin” bus stops and a “multiple shortest path” calculation follows from houses/apartments IDs to the identified “origin” bus stop IDs. This data is then required to be imported into a worksheet as in the example shown in Figure 4, which is the “Spmkt_Bus” tab of Figure 2.

K7 f_x =IF(ISERROR(MATCH(H7,$A$2:$A$119,0))=TRUE,FALSE,TRUE)

	A	B	C	D	E	F	G	H	I	J	K
1	walk	stop	HsID	dist	bus(yes/no)		stop	HsID	dist	bus(yes/no)	
2	124	939	82	200.06	1	FALSE	941	63	107.78	1	FALSE
3	126	939	117	200.43	1	FALSE	941	62	114.62	1	FALSE
4	127	939	118	191.97	1	FALSE	941	68	179.54	1	FALSE
5	128	939	528	176.85	1	FALSE	941	69	185.64	1	FALSE
6	130	939	530	163.45	1	FALSE	941	65	192.97	1	FALSE
7	131	939	532	150.54	1	FALSE	941	131	162.52	0	TRUE
8	216	939	534	137.13	1	FALSE	941	130	170.54	0	TRUE
9	218	939	536	120.65	1	FALSE	941	72	201.26	0	FALSE
10	220	939	538	160.55	1	FALSE	941	71	208.37	0	FALSE
11	222	939	540	143.53	1	FALSE	941	75	230.78	0	FALSE
12	223	939	542	130.34	1	FALSE	941	127	237.32	0	TRUE
13	224	939	544	52.51	1	FALSE	941	74	238.05	0	FALSE
14	225	939	546	62.08	1	FALSE	941	126	247.7	0	TRUE
15	226	939	548	127.94	1	FALSE	941	128	250.11	0	TRUE

Figure 4 Supermarket-bus worksheet - partial view (Spmkt_Bus from Figure 2)

A similar procedure is used as previously explained to determine the closest bus stop (ID 939 or 941 in Figure 4) to each house/apartment and exclude the other bus stops so that each house/apartment is only associated with one bus stop (the closest) for each particular activity. The example in Figure 4 continues to reference the supermarket activity and assumes that the cycling mode is not available and the walking availability has already been calculated. The first column “walk” lists all house/apartment IDs that have the walking mode available to them. These IDs therefore need to be excluded from the bus mode availability calculation. This is done by using the function of the highlighted cell in Figure 4. The house ID (HsID) of column H for the concerning row is included in the list of IDs in column A, which means that this particular house has the walk mode available to it so by default the bus mode cannot be used and the value in column J is set to null. Any cell originally with a 1 value must be set to null if the adjacent cell’s value is TRUE. Cells already with a null value are left untouched.

The original value of 1 or 0 in columns E and J depends solely upon the distance in columns D and I. In Figure 4 the original value will be 1 if the distance is LESS THAN 201 m, which is the case for all of column D, therefore E reports all 1s (also because column F has no TRUE values). Column J shows two values less than 201 m that have been manually changed to 0 as a result of the TRUE values that signify that the walking mode is available therefore discounting the bus mode.

The number of units with bus mode availability are summed in a similar fashion as for the walking mode. This is then converted to a percentage of total units. With only the car mode remaining, the car percentage can already be calculated e.g. 100% minus walk% - cycle% - bus% equals car%.

The average distance of the bus mode considers only the distance from origin bus stop to destination bus stop along the bus route. For several routes the average distance depends on the proportion of units with each bus stop and route available to them, e.g. if 50% of the units use bus stop b1 with bus route distance to supermarket stop sp1 of 1 km and 50% use bus stop b2 with distance of 2 km to sp1, the average distance will be 1.5 km.

- **Private motorised vehicle (motorbike/car) mode**

The final mode calculation for residents without other mode availability is the private motorised vehicle mode calculation. In the case of many one-way roads, it requires two "multiple shortest path" calculations – one from houses/apartments to the activity and one from the activity to houses/apartments – because the routes will be different for both directions. The average distance for each house/apartment is the sum of both distances divided by two.

Before calculating the average distance for the private vehicle mode, all house/apartment IDs that have other modes available to them (walking/bus etc.) need to be removed. This is done in a similar fashion as previously explained for the bus mode. Percentages for the car mode are already known through elimination and the average distance calculation is similar for all other modes.

Note: The process described here must be repeated for all activities and modes with special attention given to work/shopping activities that are forced outside of the study area. In the case of these activities the same process is applied as if there were two (or multiple) work locations and the average distance depends on the proportion of the population sent to the external location(s) compared with the internal location(s) and their respective distances similar to the example given in the last paragraph in the previous section for bus stops.

c. Energy dependence data

Before energy dependence data can be calculated, a summary of mode availability and average distance is required for each activity, which can be obtained through following the previous steps. This data could be included in a new "summary" worksheet for each activity or could be included inside one of the activity-mode worksheets as shown in Figure 5.

Mode	Units	%	Av. Dist
Walk	215	24.08%	327.5
Bus	233	26.09%	730.4
Car	445	49.83%	662.1
Total	893	100.00%	

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Figure 5 Supermarket-modes summary data included in the "Spmkt_Walk" worksheet

The data shown in Figure 5 has been taken from the "Spmkt_Walk", "Spmkt_Bus" and "Spmkt_Car" worksheets. This data is now ready to be applied to the master worksheet shown in Figure 2. From observation of Figure 2, each "age group" has a corresponding population. The number of people with the walking mode available to the supermarket ("food shopping" in Figure 2) is calculated simply by multiplying the percentage value for walking in Figure 5 by the number of people in the "age group" in Figure 2. This is repeated for all modes for the supermarket activity and also for all other activities.

The energy dependence data is only relevant for motorised modes and involves the subsequent calculation, following the example (from left to right) in Figure 6:

> $I$2*2*(F23/1000)*E23*H19 from Figure 6 is explained as - Multiply the modal consumption ($I$2=0.31) in mega joules per passenger kilometre (times two for return distance) by the average distance converted to kilometres (F23=1729/1000) by the number of trips (E23=143) and finally the weekly trip frequency (H19=3).
>
> Note: This is the same formula contained in Appendix A.

154	997	393	10	27
+ Other Recreation =		3	X/Week	
Bus (0.31MJ/pkm)				
Trips	Dist.	Energy	Diesel	CO2(kg)
143	1729	=$I$2*2*(F23/1000)*E23*H19		
22	1729	71	2	5
165	1729	531	14	36

Figure 6 Performing the energy calculations inside the master worksheet

This process needs to be completed for all modes, activities and for the entire population of the study area. When finished, the data can be summarised in an easier to understand format as is shown in the Case Studies Chapter of the thesis.

For further questions/assistance please contact the author at michael_kiwi@hotmail.com.

ANNEX B – Publication Summary

Publication summary of work completed or published over the last 5 years:

Journals:

SAUNDERS, M. J., SILVA, A. N. R. d. (2009) Reducing urban transport energy dependence: a new urban development framework and GIS based tool, International Journal of Sustainable Transportation, Volume 3, Issue 2, March 2009, pages 71 – 87, Taylor and Francis.

SAUNDERS, M. J., KUHNIMHOF, T., CHLOND, B., SILVA, A. N. R. d. (2008) Incorporating transport energy into urban planning, Transportation Research Part A: Policy and Practice, July 2008.

SAUNDERS, M. J., KRUMDIECK, S., DANTAS, A. (2006) Energy reliance, urban form and the associated risk to urban activities, **Road and Transport Research**, ARRB, Vol 15 No 1, March, 2006.

DANTAS, A., KRUMDIECK, S., HAMM, A., MINGES, S., SAUNDERS, M. J. (2005) Performance-Objective design for energy constrained transportation system, **Journal of Eastern Asia Society for Transportation Studies**, Vol. 6, pp. 3276 - 3292, 2005.

Invited Presentations:

SAUNDERS, M. J. (2006) Peak Oil and the correlation with active transport and recreation, **Keynote Speech**, Thinking Recreation - NZRA, 26 - 28 July, 2006 – Video conference from Greece to New Zealand.

Conferences:

SAUNDERS, M. J., AUSTIN, N. (2007) New Sustainable Urban Development Tool, proceedings of Transport – the next 50 years (Land Transport New Zealand – LTNZ), Christchurch, New Zealand, July 25-27, 2007.

SAUNDERS, M. J., KUHNIMHOF, T., CHLOND, B., SILVA, A. N. R. d. (2007) Incorporating transport energy into urban planning: A new use for GIS tools, proceedings of the 10th Computers in Urban Planning and Management (CUPUM), Iguaçu Falls, Brazil, July 11 – 13, 2007.

SAUNDERS, M. J., SILVA, A. N. R. d. (2006) Information system control for long term fuel shortages, proceedings of the 25th Urban Data Management Symposium (UDMS), Aalborg, Denmark, May 15 – 17, 2006.

DANTAS, A., KRUMDIECK, S., SAUNDERS, M. J. (2006) Assessing the risk to suburban activities associated with transport energy availability as a function of urban form, proceedings of the 85th Annual Transport Research Board (TRB) Meeting, Washington, D.C., January 22-26, 2006.

SAUNDERS, M. J., SILVA, A. N. R. (2005) Energy and Transport Demand Control for Sustainable Transport, proceedings of the 19^{th} Association of National Transportation Research and Education (ANPET), Recife, Brazil, November 7 – 11, 2005.

HOTTA, L., SAUNDERS, M. J., SILVA, A. N. R. (2005) Transporte Público Individualizado: sonho intangível ou necessidade urgente?, proceedings of the XIII CONGRESO LATINOAMERICANO DE TRANSPORTE PUBLICO Y URBANO (CLATPU), Lima, Perú, 2005.

SAUNDERS, M. J., DANTAS, A., SILVA, A. N. R. (2005) Urban demand management options for a fluctuating energy supply, Proceedings of the 1^{st} Congresso Luso Brasileiro Para O Planejamento Urbano, Regional, Integrado e Sustentável, EESC of the University of São Paulo, São Carlos, Brazil, September 28 – 30, 2005.