

# Integrated ETWW Demand Forecasting and Scenario Planning for Precincts (ETWW: Energy, Transport, Water and Waste)

Michael A P Taylor  
Emeritus Professor of Transport Planning, School of Natural and Built Environments  
University of South Australia  
Program Leader 'Low Carbon Precincts', CRC for Low Carbon Living

**Abstract:** The new Low Carbon Living CRC has a major research program in low carbon precincts, concerning with the planning, design and retrofitting of urban precincts in Australia cities for a low carbon future. An initial research project in this program is on the development of an integrated demand forecasting tool for precinct infrastructure and services. Demand forecasting is currently undertaken separately in each of the service domains, but the CRC provides a unique opportunity for the integration of the forecasting. The project will develop a shared platform for integrated ETWW (energy, transport, waste and water) demand forecasting and scenario planning for ETWW under low carbon futures, focussing on gaps, synergies, alternative approaches and required research directions. Its aim is to seek the development of integrated tools for demand forecasting and scenario evaluation covering ETWW with identified commonalities in data requirements and model formulation, and interactions between the domains (e.g. in energy and transport, water and energy, and waste and transport, etc). It is developing and testing an integrated framework for simultaneous demand forecasting for all four ETWW domains. A method for including the impacts of household behaviour change in demand forecasting will be a major component of the framework. In this way overall carbon impacts of urban developments or redevelopments can be assessed effectively and efficiently.

## Introduction

Infrastructure changes in the built environment, resulting from the expected 60 per cent growth in Australia's population by 2050, will significantly influence and entrench the way we consume energy and our resulting carbon signature. The Cooperative Research Centre for Low Carbon Living, established in 2012, aims to influence these developments by providing government and industry with social, technological and policy tools to overcome identified market barriers preventing adoption of cost effective low carbon products and services, while maintaining industry competitiveness and improving quality of life. The CRC assembles, for the first time, the necessary critical mass and diversity of built environment stakeholders to address this complex multidisciplinary task, and provides government and industry with a vehicle for trialling alternative infrastructure and community engagement solutions.

The CRC has three interlinked research programs:

1. Integrated building systems
2. Low carbon precincts
3. Engaged communities.

Program 2, *Low Carbon Precincts*, focuses on reducing the carbon footprint of our urban systems, with key consideration being given to integrating the interlinked aspects of energy, water, waste, transport and buildings – all of which have significant carbon signatures as well as human health impacts. The challenge is to reduce the carbon footprint of precinct infrastructure through the development of better tools and planning techniques that will make low carbon infrastructure valuable and desirable to the user. As a result, low carbon precincts will be transformed into highly desirable lifestyle options. Improved planning of precincts will allow carbon footprint to be reduced to zero in the longer term, at the same time as quality of life continues to grow.

The Low Carbon Precincts program seeks to develop new knowledge and tools to enable the design of, and stimulate the market for, low carbon infrastructure at the precinct scale. This will facilitate property developers and local government in providing low carbon infrastructure development as well as redevelopment and retrofitting at the planning point of delivery. An emphasis on research and research education and training in building information modelling (BIM) with extension to a new precinct scale Precinct Information Modelling (PIM) platform, will improve design productivity. Integrated tools will be developed for demand forecasting at the precinct level, covering energy, transport, waste and water. Design and assessment tools for precincts, focusing on low carbon performance, will also be developed,

applied and tested. Health and productivity co-benefits analysis will demonstrate the increased value and stimulate demand for low carbon precincts.

The initial workflow structure for the Low Carbon Precincts program is indicated in Figure 1. It includes six connected work packages, which link to the other programs in the CRC.

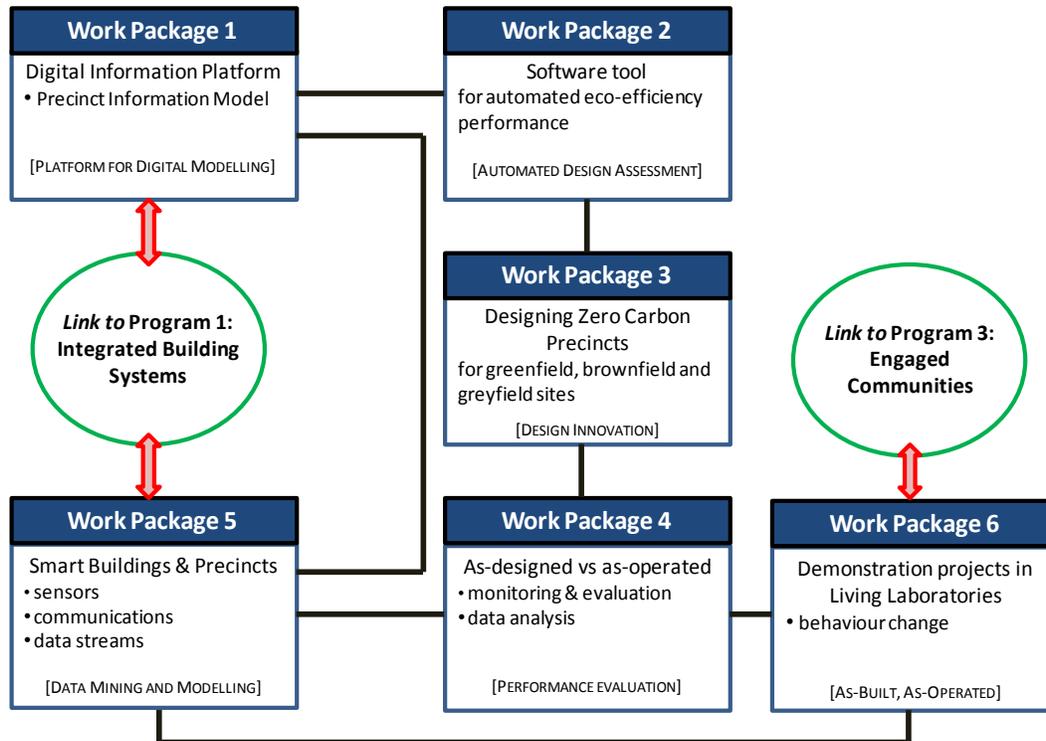


Figure 1: Workflow design for Research Program 2 in the CRC for Low Carbon Living

Work package 1 in Figure 1 focuses on the development of a PIM data model. The objective of this research is the creation and implementation of a standardised digital information platform for precinct-scale urban design, assessment and management. This standard will improve the flow of data between software tools and associated research aimed at reducing carbon load throughout the lifecycle development of the built environment. The defined standard will be in the form of a structured, object-oriented and semantically-rich database schema capable of integrating the growing amounts of geographical and real-time data available in key urban domains, including buildings, major urban infrastructure, energy, water, waste, transport and health. The PIM data model will provide an underlying information model to support lifecycle management of information held efficiently in a cloud based information repository, capable of handling the vast amount of information required for urban-scale low carbon management. Figure 2 indicates the roles of PIM as envisaged in the precinct-based research of the CRC. The dashed-line bubbles clustered around the cloud indicate the types of tangible deliverables that will flow from the PIM project. Each is driven by the specific needs of partners and end users to deliver benefit from the underlying research and implementation. Figure 2 includes a number of current CRC projects (designated RP20xx) in the figure as well as anticipated future projects.

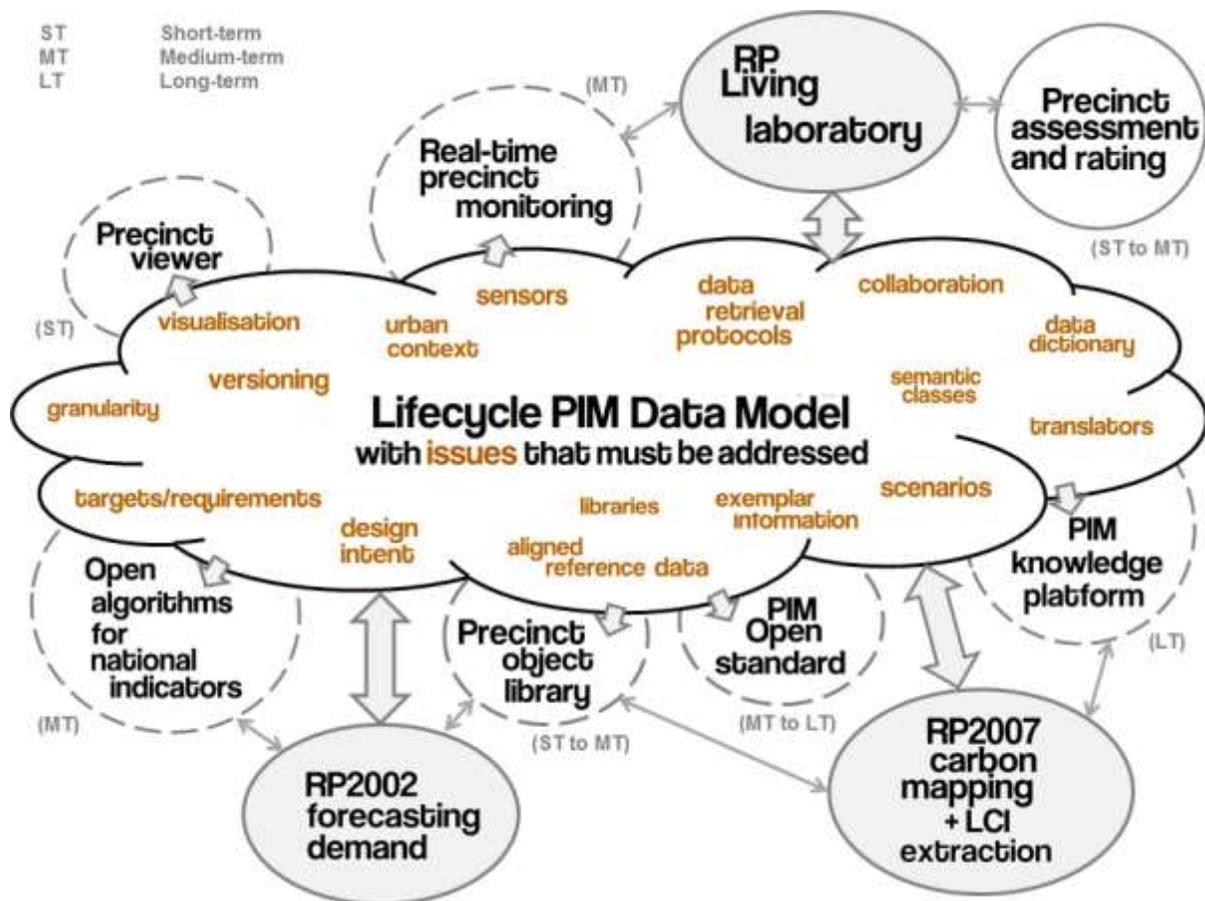


Figure 2: PIM research issues with short-, medium- and long-term deliverables and other project links [source: Plume (2013)]

An initial major project for the CRC, to meet the needs of work packages 2 and 3, is the 'ETWW project' on integrated demand forecasting and scenario planning for precincts (project RP2002 in Figure 2). This current project is developing a shared platform for integrated ETWW (energy, transport, waste and water) demand forecasting and scenario planning for ETWW under low carbon futures, focussing on gaps, synergies, alternative approaches and required research directions. It includes a series of facilitated national workshops on demand forecasting for ETWW utilities and services and on scenario generation and appraisal. The aim is to seek the development of integrated tools for demand forecasting and scenario evaluation covering ETWW with identified commonalities in data requirements and model formulation. It will first (Phase 1) develop an integrated framework for demand forecasting that will then be fully developed and implemented in Phase 2. A method for including the impacts of household behaviour change in demand forecasting will be a major component of the framework. In this way overall carbon impacts of urban development or redevelopment can be assessed effectively and efficiently.

This paper is intended to illustrate the unique opportunities provided by the Low Carbon Living CRC in facilitating not only multidisciplinary research but indeed research across separate domains of expertise and administrative responsibility. The ETWW project is a good case in point. Whilst this project is still in its early days and so cannot yet display the integrated demand forecasting platform that is its objective, it is still possible to indicate the nature of the research in progress.

### ETWW project background

Planning agencies, infrastructure providers and operators and private developers all need to forecast future demands for their services and resources as delivered to urban precincts. Forecasting tools already exist in domains such as energy, transport and water, if not yet so well advanced for domains such as waste. The methods and tools used in these domains have been developed and used largely in isolation from each other. However, they share common data input requirements, even if their models and

forecasting methods are different. For instance, basic socio-demographic and household variables are used in different demand forecasting tools. The ETWW project is developing an integrated suite of demand estimation tools, compatible with PIM and the precinct design and assessment tools to be developed in other research by the CRC.

Phase 1 of the project brings together experts in forecasting from the different domains to share information and to design and specify the requirements and characteristics of an integrated demand forecasting system. Phase 2 will see the development, testing, application and evaluation of the integrated demand forecasting system.

In addition there is a need to investigate methods for scenario planning in the development of low carbon policies related to ETWW, and demand forecasting tools play a vital role in scenario analysis and thus in policy formulation. One particular area of interest is how to include the impacts of household behaviour change in demand estimation and forecasting. This is certainly an issue in transport demand estimation.

The initial objective is the specification of an integrated framework for (residential) demand estimation for ETWW. This will require clear espousal and comparison of the methods used for demand estimation in each of the domains, and a strong collaborative effort between experts from the domains to establish potential commonalities, shared data needs, and possible approaches to the development and implementation of models and tools for integrated demand forecasting. The second aim is the development and application of the integrated demand estimation system, which will use the PIM (Precinct Information Modelling) schema (being developed in parallel in the CRC, see work package 1 in Figure 1) as its platform for data inputs and model outputs.

Demand estimation for services and facilities is an important component of urban and regional development, being required for the determination of the level of provision and coverage of infrastructure and related facilities to serve the needs of present and future populations and to do so in ways that are economically efficient, environmentally sound, and equitable (Zaman and Lehmann, 2013). Quantitative analysis of the demands is essential, and this has led to the development of mathematical models and tools, generally computer-based, for demand estimation in each of the domains of energy, transport, waste and water.

Integrated planning, especially for low carbon precincts, will be enhanced by the examination of the potential for an integrated approach to future demand estimation across all of these domains.

### ***Project phases***

Phase 1 of the project involves a series of expert reviews of demand forecasting methods and models in each of the ETWW domains, from which a framework for integrated demand estimation and forecasting can be developed, using commonalities of approaches and data requirements from each of the domains, potentially enhanced by the consideration of a range of alternative model forms and applications, so that each domain stands to learn from the others and contribute its ideas to the others.

The development of the integrated framework, as a gateway to further research and development of an integrated demand estimation tool for low carbon precincts, will be undertaken using a series of national workshops that bring domain experts – the key researchers and other experts – together, and linked by a synthesis of approaches, data needs and model forms. Phase 1 will occupy the first year of the three year project.

Phase 2 of the project will involve the implementation of the framework including an integrated set of demand estimation models that together will form a forecasting tool that includes harmonised outputs about carbon performance across the ETWW domains. Close cooperation between the domain experts and researchers will enable the use of best available methodologies for all of them, with cross-fertilisation expected to lead to major innovations in the component models and their applications. This phase will involve model development, implementation and testing, within the integrated framework which will allow for data sharing (and hence modelling efficiency) as well as integrated outputs enabling assessment of the full carbon implications of the precinct under design or analysis.

## ***Project progress***

The project commenced in January 2013 and at the time of writing is midway through Phase 1. Project participants include:

- CSIRO Energy transformed Flagship, providing research expertise on energy demand forecasting
- University of New South Wales, providing research expertise on water demand forecasting
- University of South Australia, providing research expertise on travel demand forecasting and waste generation forecasting,

along with industry partners AECOM, Renewal SA, SA Department of Planning, Transport and Infrastructure, SA Water, and Sydney Water.

An initial workshop was held at project commencement, and a second workshop is scheduled for September 2013. The second workshop will provide full information on demand forecasting for each domain, through a series of state-of-good-practice reviews (e.g. Holyoak 2013) and a subsequent synthesis of commonality of approaches, data sharing and domain-specific attributes.

The focus of the project is on residential precincts, and methods to incorporate behaviour change in demand estimation for all domains will be sought. The inclusion of behaviour change factors in demand estimation will be a major contribution of the research.

## ***Project methodology***

Carbon emission performance is a key consideration in precinct analysis. Indeed, reduction of such emissions is a key objective of the CRC. Quantitative estimation of carbon performance at the precinct level is required so that full knowledge of this is available to developers, planners, designers, infrastructure systems managers and service providers. Thus the demand forecasting tools need to be capable of use in estimating carbon emissions at the precinct level and to relate these to the demand for infrastructure and services use by precinct residents and occupants.

The main tasks of the project are to elucidate the methods for demand estimation used in each domain, to compare the approaches and data needs, and then to synthesise an integrated framework/ method for simultaneous demand estimation covering all domains (Phase 1). The framework and associated models will then be implemented as an integrated tool for use in planning and design of urban precincts (Phase 2). The following subsections summarise the current methods used for demand estimation in each domain, and then provide a definition of a precinct that should be suitable for use in demand forecasting.

### ***Energy demand***

For energy demand estimation, the focus is on short term demand forecasting, over hours of the day. Recent methods include genetic algorithms and neural network heuristics and learning techniques for bare-bones, sensor-free, energy forecasting from historical inverter data. The approach determines optimal weights for historical recordings to anticipate energy outputs and potential loading for a single residence across several hours. Building on existing algorithms, the technique can deliver a low-cost baseline system that can be installed on existing inverters without requiring additional sensors or network connectivity. Such coarse forecasts could then be used as part of a battery control scheme to allow aggregated solar resources to meet medium-term forward contracts or as part of a load-management/matching system.

### ***Transport demand***

Transport demand estimation methods and tools have seen significant development and application since the mid 1950s. The basic unit for analysis is the household, given that interactions between household members have strong influences on the travel behaviour of each of those individuals. Thus socio-demographic and economic variables related to the household are prime inputs into the demand estimation. Current methods are largely based around a 'five step' procedure which considers (1) the total amount of travel (trips) to be undertaken by the household over a specified time period, (2) the destinations of those trips, (3) the forms of transport to be used for those trips, (4) the timings of the trips (start times) and (5) the routes to be taken. The most modern tools treat daily travel behaviour by each household member as a 'tour' or 'trip chain'. The models are estimated using data collected in household travel surveys, which typically include 'activity-travel diaries' for household members.

As an example of the domain-specific demand forecasting methods, the next section of this paper provides a more detailed account of methods for transport demand forecasting and the steps required to estimate the transport component of precinct carbon performance.

### ***Waste demand***

Current methods of quantitative waste and material flow demand estimation use the weight of waste generated as unit to quantify different scenarios. Forecasting this amount and its impact is largely based on the following indicators: (1) kg of waste per capita, (2) current recycling and re-use rate in percentage terms, (3) current diversion rate and rate of resource recovery, (4) consumption patterns and changes in affluence of residents, (5) expected household behaviour change towards waste avoidance, (6) implications of supply chain and disposal. Improvements in basic data and methods for long and short-term demand estimation and input-output-analysis would have ramifications for waste treatment and composting facilities and the wider waste treatment infrastructure interdependencies. Zaman and Lehmann (2013) provides an introduction to current models of waste demand estimation.

### ***Water demand***

Forecasting water demand requires input from a variety of disparate information sources. Estimates of population growth and expected demographic changes are used to forecast basic water demand over a given timeframe. This is augmented with projections of the expected uptake of water efficiency measures (e.g. leak-reduction, residential and non-residential programs and regulatory initiatives) and water recycling initiatives. Demand forecasts are typically scenario based, e.g. considering high, medium and low population and water use projections, in combination with varying levels of water efficiency savings. In recent years, forecasters have also begun to consider the effects of climate change on water demand.

### ***Definition of a precinct***

Basic to the project and the wider research program is a definition of what constitutes a precinct. Newton et al (2013) provided a working definition of a precinct for use in the CRC if not more widely:

'a precinct can be represented an urban area of variable size that is considered holistically as a single entity for specific analyses or planning purposes, as well as in a contextual sense to represent the interactions that occur with elements of the surrounding urban area. It typically comprises land parcels occupied by constructed facilities (generally buildings), including open space, and often clustered in to urban zones that share some common characteristics (uses) and supported by physical infrastructure services to manage energy, water, waste, communication and transport as well as a range of social infrastructures related to health care, education, safety, retailing and entertainment' (Newton et al 2013, p.6).

The precinct may thus be taken to consist of a small geographic area including building and facilities, serviced and connected by infrastructure networks. The networks will include streets and pathways for physical movement, so that the precinct contains its own transport network(s). It can be considered as a set of micro-zones, which represent the buildings, facilities and other activity zones within in, all connected by an internal network, and represented in a PIM.

### ***Transport demand forecasting***

The transport demand forecasting paper (Holyoak, 2013) produced for the ETWW project describes the general methods used to estimate travel demand and transport network performance at the regional level, including the travel demand of a specified precinct. The use of the forecasts produced by these methods in estimating carbon performance requires further consideration.

In the case of travel demand, the precinct has to be viewed as a source of carbon emissions, although (e.g. for precinct-based travel that takes place outside the precinct) the location of the emissions generation may be outside the precinct. All such emissions need to be accounted for. This is a particular issue for transport demand because the carbon emissions by precinct occupants from travel activity may occur regionally, at many locations outside the precinct. Thus the transport demand forecasting tool must be able to produce outputs that capture or represent the magnitudes and extent of the carbon emissions attributable to that demand. Similar issues are also apparent for the other domains (energy, water and waste) but the transport domain is particularly 'footloose' in this regard. The standard representations of travel demand and resulting loads on transport networks have the capability to provide suitable representations of precinct travel demands, but some re-adjustment of the ways to present the demands will be required.

### **Regional travel demand forecasting**

In terms of the standard representation of a study region in the travel demand models, i.e. through the use of small scale traffic activity zones (TAZ)<sup>1</sup> to represent the distribution of land uses and population across the region, the precinct may be considered as an individual TAZ. This is in line with the definition of a precinct provided earlier in this paper. It provides a first step in representing precinct travel demand, as the demand is then explicitly included and readily identifiable in the outputs from the regional travel demand model. One issue here is that the given precinct may be part of an existing TAZ in an existing regional model, depending on its physical size or its population. In this case, and in general to meet the requirements of precinct level planning and design, the precinct should be treated as a TAZ in its own right in the regional model. This could in some circumstances require partitioning of an existing TAZ in to two separate TAZs, one for the precinct and one for the remainder of the original TAZ. For purposes of the following discussion the precinct is considered to be a TAZ and given the set  $i=1, \dots, n$  of TAZ in the region, the precinct is designated as the TAZ with  $i = \psi$ .

The designation of the precinct as a TAZ may be seen in Figure 3, which is a schematic representation of the precinct and the (urban) region in which it is situated.

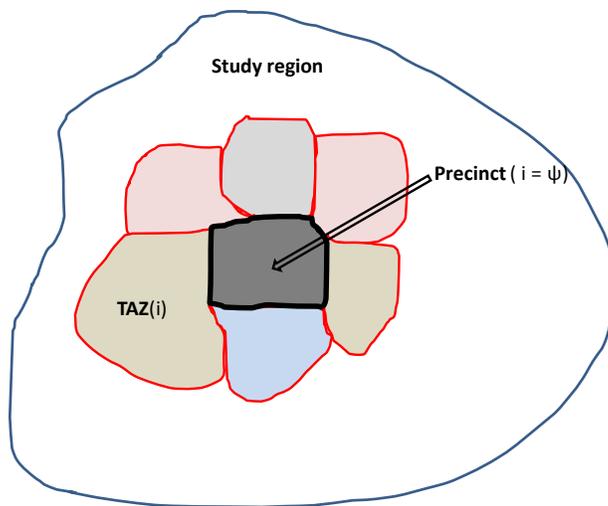


Figure 3: The precinct as TAZ  $\psi$  in the study region

On the basis of treating the precinct as a TAZ, a full travel demand forecasting analysis can be undertaken for the region. This will include the generation of travel, trip distribution, mode choice, time of day analysis and traffic assignment to yield traffic volumes, passenger movements and freight flows on the strategic transport network of the region, which will be in balance (equilibrium) with the final modelled travel costs (including travel times, and hence congestion levels) on the network. This is the conventional output from a regional travel demand model. Given that there will be good data for a given precinct, the issue of the precinct being smaller than an existing TAZ (which contains the precinct) will be resolved simply: all necessary information for use in the regional travel demand model will be available as part of the precinct design data, including data for alternative design scenarios.

For precinct-based analysis we need to be able to focus on, identify and utilise the transport demand associated with the precinct. This can be done by examining the origin-destination (O-D) trip matrices

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<sup>1</sup> A TAZ is defined in principle as a small geographic area of homogeneous land use, compatible with administrative boundaries and conventionally separate from the major transport networks (i.e. network links may form part of the spatial boundary of the TAZ but would not puncture it). The size of the TAZ generally depends on the basic level of aggregation of available socio-economic and demographic data. Thus, for example, the TAZ could be no smaller than a census collector district (CCD) (or its equivalent). Historically, due to computational and computer memory and storage constraints, TAZ would have been composed of 2-4 contiguous CCDs, but the advances in computer technology now mean that a TAZ can often and reasonably be taken as an individual 'CCD'. This definition is within the scope of the definition of a precinct provided in Newton et al (2013) and described previously in this paper.

available from the regional analysis (Holyoak, 2013). There will be a family of these matrices, indicating travel by trip purpose ( $k$ ), mode ( $m$ ) and time of day ( $t$ ) in the region. Specifically, each matrix may be written as

$$\mathbf{T}^{kmt} = \begin{bmatrix} T_{11}^{kmt} & \dots & \dots & T_{1n}^{kmt} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & T_{ij}^{kmt} & \dots \\ T_{n1}^{kmt} & \dots & \dots & T_{nn}^{kmt} \end{bmatrix} \quad (1)$$

in which  $T_{ij}^{kmt}$  is the number of trips between origin  $i$  and destination  $j$  for trip purpose  $k$  made by transport mode  $m$  and starting in time interval  $t$ .

For simplicity of notation in the following model definitions, let us just consider a generic O-D matrix  $\mathbf{T}$  defined as

$$\mathbf{T} = \begin{bmatrix} T_{11} & \dots & \dots & T_{1n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & T_{ij} & \dots \\ T_{n1} & \dots & \dots & T_{nn} \end{bmatrix} \quad (2)$$

while remembering that this is one of a family of such matrices.

Accompanying the O-D matrix is a similar matrix  $\mathbf{C}$  containing the travel costs between zone pairs, i.e.

$$\mathbf{C} = \begin{bmatrix} c_{11} & \dots & \dots & c_{1n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & c_{ij} & \dots \\ c_{n1} & \dots & \dots & c_{nn} \end{bmatrix} \quad (3)$$

which also forms part of the output of the regional travel demand model ( $c_{ij}$  is the travel cost between origin  $i$  and destination  $j$ ). There will be a family of these matrices, e.g. by mode and time of day. In addition, there may be alternative definitions of travel cost, including distance, travel time, or generalised cost. Distance will be determined by network topology but travel time and generalised cost will also depend on levels of congestion on the network. Generalised cost may also include fares, tolls and road user charges imposed on some parts of the network and perhaps differentiated for different traveller/network user classes, as well as destination-specific charges such as car parking fees.

The region-wide travel demand of the precinct is in two parts, both of which are held in matrix  $\mathbf{T}$ :

1. trips originating from the precinct, given by the row vector  $\mathbf{r}_\psi$

$$\mathbf{r}_\psi = [T_{\psi 1} \quad \dots \quad T_{\psi m}] \quad (4)$$

and

2. trips finishing in the precinct, given by the column vector  $\mathbf{s}_\psi$

$$\mathbf{s}_\psi = \begin{bmatrix} T_{1\psi} \\ \dots \\ T_{n\psi} \end{bmatrix} \quad (5)$$

These two vectors are the row and the column for  $\psi$  in the O-D matrix of equation (2). While these two vectors describe all travel demand with a trip end in the precinct, they cannot be used directly to model that demand due to double counting of the intra-precinct demand  $T_{\psi\psi}$ .

To remove the double counting, define two new vectors of trips: (1) extra-precinct travel demand with origins in the precinct ( $\mathbf{u}_\psi$ ) and (2) extra-precinct travel demand with destinations in the precinct ( $\mathbf{v}_\psi$ ). These two vectors are:

$$\mathbf{u}_\psi = [u_1 \quad \dots \quad u_n] \quad (6)$$

in which  $u_j = T_{\psi j}$  for  $j \neq \psi$  and  $u_j = 0$  for  $j = \psi$ ; and

$$\mathbf{v}_\psi = [v_1 \quad \dots \quad v_n] \quad (7)$$

in which  $v_i = T_{i\psi}$  for  $i \neq \psi$  and  $v_i = 0$  for  $i = \psi$ . The intra-precinct travel demand  $T_{\psi\psi}$  is then treated as a separate quantity (which, for example, is not assigned to the regional transport network in the regional travel demand model because it does not leave the precinct).

The total travel demand generated by the precinct is then given by the trip sum  $N(\psi)$ , which is

$$N(\psi) = \sum_{j=1}^n u_j + \sum_{i=1}^n v_i + T_{\psi\psi} \quad (8)$$

noting that  $N(\psi)$  may not always be a fixed number (e.g. in an analysis including elastic travel demands as would be the case in the study of travel behaviour change).

The total travel cost  $Z(\psi)$  of precinct-generated travel is

$$Z(\psi) = \sum_{j=1}^n c_{\psi j} u_j + \sum_{i=1}^n c_{i\psi} v_i + c_{\psi\psi} T_{\psi\psi} \quad (9)$$

Knowledge of precinct trip interchanges and travel costs may be used to estimate energy consumption, air quality emissions, greenhouse gas emissions, and carbon performance of precinct-related travel, given additional information or assumptions about the proportions of different vehicle/fuel types used for that travel. Previous research has developed a family of suitable models for this purpose, from simple fixed rate per unit distance models to models reflecting variable congestion levels across a network (Taylor et al, 2005).

### **Estimation of energy, pollutant and carbon for precinct travel**

Equation (9) indicates that travel costs associated with travel out of the precinct, into the precinct, and inside the precinct can be identified separately.

A convenient representation of precinct-related travel and its costs is as a trip length frequency distribution (e.g. Figure 4), which can be derived from the available trip numbers and travel costs (see equations (3) – (8)). The frequency distribution may also be used to estimate energy, general emissions and carbon performance of the precinct-based transport demand at the regional scale. Separate trip length frequency distributions for out-bound precinct travel and in-bound precinct travel can be generated. In addition,

distributions for travel by time of day, for a given mode, or for a given trip purpose can also be computed given the individual frequency distributions.

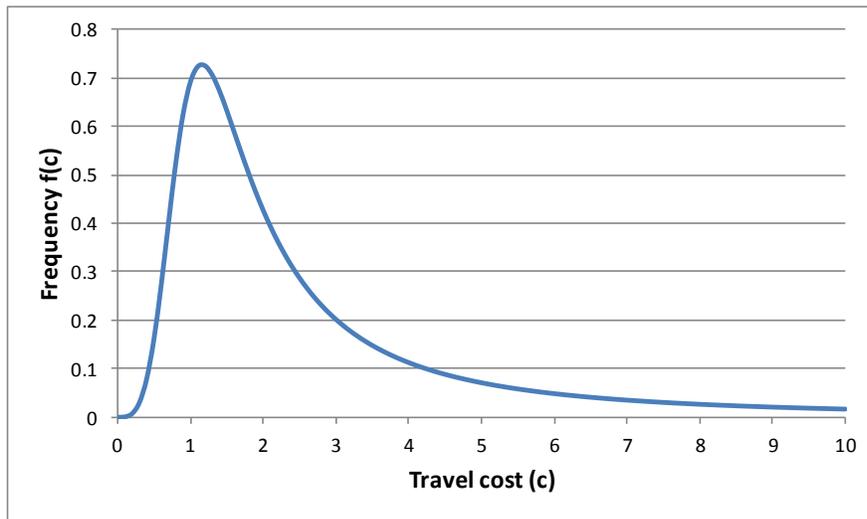


Figure 4: Example trip length frequency distribution for a precinct

There are previously established methods for estimating energy consumption and pollutant emissions from the outputs of regional travel demand models (Taylor et al, 2005). These methods are also suitable for estimation of carbon performance of precinct-based travel. Appendix A describes a generic model for energy and emissions estimation. This model is formulated for use at the network link level but may also be applied at more aggregate levels such as that of the trip length frequency distribution.

If more detailed information on network travel conditions and congestion levels is required (i.e. a link-level analysis identifying when, where and by whom energy is consumed or emissions are generated) then this can be obtained through further modelling and analysis, initially using a multi-class traffic assignment model and when necessary a path-flow estimator such as that described by Bar-Gera, Boyce and Nie (2012).

#### ***Intra-precinct travel demand analysis***

Given the energy/carbon focus of the CRC's low carbon precincts research, further consideration has to be given to intra-precinct travel, as low carbon options may seek to maximise this, e.g. through mixed land use development. This will also give direction as to the appropriate form of the travel demand estimation models at the precinct level. On this point, note that behaviour change is an important consideration in the general research activities of the CRC, and so modelling approaches that can accommodate behaviour change are also important.

The precinct design methods under consideration will also mean that the precinct will be defined in some detail and that a comprehensive data description of the precinct will be available, through the *Precinct Information Model* (PIM), see Newton et al (2013). The precinct may be taken as consisting of a small geographic area including building and facilities, serviced and connected by infrastructure networks. The networks will include streets and pathways for physical movement, so that the precinct contains its own transport network(s). It can be considered as a set of micro-zones, which represent the buildings, facilities and other activity zones within in, all connected by an internal network, and represented in a PIM. Figure 5 provides a schematic representation of a precinct suitable for the purposes of travel demand estimation.

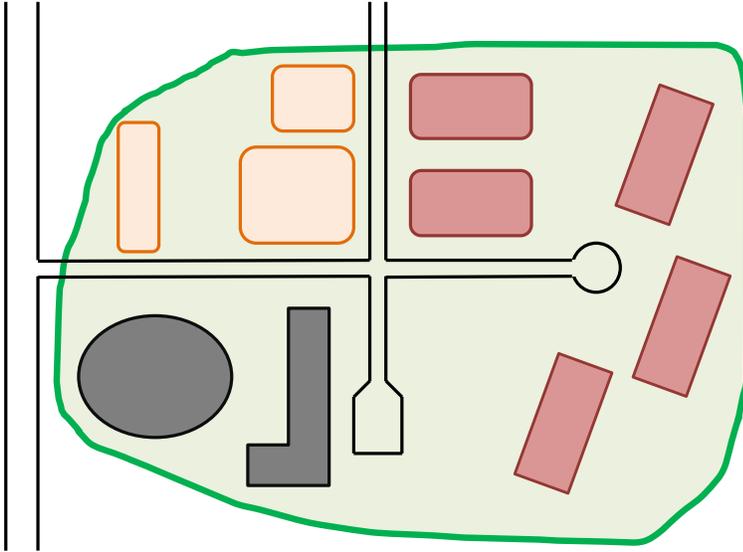


Figure 5: Representation of a precinct as a connected set of buildings and facilities (which can be represented as ‘micro-zones’)

The buildings and facilities are occupied and/or used by residents, enterprises, businesses, service providers, workers, customers and service users. The micro-zones may be considered as a study region in microcosm. The intra-precinct travel demand (defined by  $T_{\psi\psi}$  in the previous discussion on regional travel) represents the total amount of travel movement within the precinct, which of itself has origins ( $h$ ) and destinations ( $d$ ) between the micro-zones. Thus there is an internal O-D matrix  $\tau^\psi$  for the precinct,

$$\tau^\psi = [\tau_{hd}^\psi] \quad (10)$$

with

$$T_{\psi\psi} = \sum_{hd} \tau_{hd} \quad (11)$$

Precinct-level travel demand analysis will require knowledge of both ex-precinct travel  $\mathbf{u}^\psi$  and  $\mathbf{v}^\psi$ , together with  $\tau^\psi$ . This may require study of trip chains, in which a traveller makes multiple stops in a tour anchored at a particular site, such as the individual’s home (Primerano et al, 2008). Given the interest in travel behaviour change in low carbon transport, this may be a necessary consideration. Given that the conventional regional travel demand models are not designed for trip chaining analysis, it may be necessary to move to an activity-based modelling approach (which is available in the commercial software packages such as *CUBE* (Citilabs, 2013)). It may also be useful to consider LUTI (land use-transport interaction) models in this regard.

The basic unit for analysis of intra-precinct travel needs to be cast at a finer grain than the TAZ. The most likely units of analysis would be the household for home-based travel and the enterprise (office, shop, etc) for non-home-based travel. This suggests the use of utility-maximising discrete choice models for transport choices at the following steps: vehicle ownership and access, trip generation, trip distribution, modal choice and time of day, as these models can be estimated at the household level and can capture the individual differences between household. Their results may be used in the macro-level models for regional analysis – i.e. the focus of study is always on the precinct, which is examined in detail whereas more aggregated (TAZ-level) analysis is used for all other zones. The precinct models will produce the basic O-D and travel cost matrices, which would then be refined by the use of a regional network traffic assignment model (for ex-precinct travel) and perhaps a multi-modal microsimulation model for intra-precinct travel. Given that we have access to suitable models in this regard (e.g. *Aimsun* (TSS, 2013) and *Commuter* (Azalient, 20130) this is quite feasible.

A key to considering low carbon transport options (or indeed alternatives to transport) may be found in the concept of transport accessibility planning, for which accessibility is defined, for example, as 'the ease for people to participate in activities from specific locations to a destination using a mode of transport at a specific time' (Primerano and Taylor, 2005). Transport accessibility is concerned with the ability of people to access services and facilities within close proximity, and the ability of service providers to cater for the needs of a local community. Accessibility analysis may be used to locate services in and around a precinct and to identify opportunities provided through telecommunication and on-line services as substitutes for physical movement.

### **Interactions between domain forecasts**

A unique feature of the demand forecasting project is that it allows for considerations of the potential interactions between demands in each of the four areas. For example, household usage of energy and water can be studied, along with demands for travel by households and their household energy consumption under different scenarios, such as the adoption of electric vehicles in place of conventional cars, and the needs for recharging those electric vehicles at home.

### **Conclusions and discussion**

The CRC for Low Carbon Living is undertaking applied research in urban planning and design to provide government and industry with social, technological and policy tools to overcome identified market barriers preventing adoption of cost effective low carbon products and services, while maintaining industry competitiveness and improving quality of life. The CRC assembles the necessary critical mass and diversity of built environment stakeholders to address this complex multidisciplinary task, and provides government and industry with a vehicle for trialling alternative infrastructure and community engagement solutions. It has a three pronged approach to its research, through three interlinked research programs covering building systems, precinct planning and design, and community engagement.

The CRC has a major research program in low carbon precincts, concerning with the planning, design and retrofitting of urban precincts in Australia cities for a low carbon future. An initial research project in this program is on the development of an integrated demand forecasting tool for precinct infrastructure and services. Demand forecasting is currently undertaken separately in each of the service domains, but the CRC provides a unique opportunity for the integration of the forecasting. The project will develop a shared platform for integrated ETWW (energy, transport, waste and water) demand forecasting and scenario planning for ETWW under low carbon futures, focussing on gaps, synergies, alternative approaches and required research directions. Its aim is to seek the development of integrated tools for demand forecasting and scenario evaluation covering ETWW with identified commonalities in data requirements and model formulation, and interactions between the domains (e.g. in energy and transport, water and energy, and waste and transport, etc). It provides a unique opportunity for researchers, experts and agencies from each of the ETWW domains to work together, to share and compare their methods for demand forecasting.

The project is first developing an integrated framework for demand forecasting that will then be fully developed and implemented. A method for including the impacts of household behaviour change in demand forecasting will be a major component of the framework. In this way overall carbon impacts of urban developments or redevelopments can be assessed effectively and efficiently. This paper will focus on the development of the integrated framework.

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## Appendix A: A generic transport network model for energy, fuel and emissions analysis

A generic model of energy and emissions performance of transport networks can be defined which uses the outputs of a regional travel demand model and which is responsive to different transport and vehicle technologies, variations in travel demand and levels of congestion on the network. This model may be applied at different levels of aggregation, including:

- a 'simple' model of travel between origins and destinations, requiring information on trip movements between origin-destination (O-D) pairs and the distances between them and average energy consumption and emission generation rates per unit distance for different vehicle, engine and energy types
- a congestion-responsive model of travel between O-D pairs, using the average speed of travel (and hence consumption and emission rates dependent on macro-level congestion)
- a link-based model which allows maximum flexibility and detail for the analysis of where and when fuel consumption and emission generation occurs, and which allows fully for interactions between vehicle flows and resulting traffic congestion across the network.

Further, the generic model may be used for all modes of urban transport.

The generic model is defined by the following system of equations. The equations are described at the network link level in the first instance, but simplified versions of the model may also be applied to flows between O-D pairs, for which the link representation is replaced either by the spatial separation distance between origin and destination or the network path(s) between them. At the link level, the generic model can calculate the total amounts of fuels and energy consumed and emissions produced by all traffic on each link in a network. The system is such that it enables the energy and emissions results to be sensitive to parameters such as increasing load factors, changing proportions of vehicle and fuel types in the vehicle fleet, different road types and different congestion levels. This is important because many transport-land use policy options and transport system management schemes may vary these and other parameters in different ways on a link-by-link basis.

The basic input to the fuel and emissions modelling system is the result of a multi-class user equilibrium traffic assignment for the network. This model will provide data not just on total flows on the network links and paths but also on the flows of individual vehicle types. The average traffic volume (veh/unit time) on link (or path)  $a$  in time period  $t$  is  $q_t(a)$ , given by

$$q_t(a) = \frac{1}{U_t} \sum_r Q_{rt}(a)$$

where  $U_t$  is the duration of time period  $t$  and  $Q_{rt}(a)$  is the total number of type  $r$  vehicles assigned to link  $a$  in  $t$ . [The total time period (e.g. one day) for the analysis is given by  $U = \sum_t U_t$  .]

The average link speed  $v_{at}$  in time period  $t$ , which reflects the level of congestion on the link in the period, is also an output from the assignment model, is

$$v_{at} = v(q_t(a), L_a)$$

where  $L_a$  is the link class for  $a$ . Let:

$E_X(a, t)$  = emission rate per unit distance for pollutant type  $X$  emission on link  $a$  in time period  $t$  (g/km)

$G_X^t(a)$  = total mass of pollutant type  $X$  emitted on link  $a$  in time period  $t$  (g)

$G_X(a)$  = total mass of pollutant type  $X$  emitted on link  $a$  per day (g)

$f_s(a, t)$  = energy/fuel consumption rate per unit distance for energy/fuel type  $s$  on link  $a$  in time period  $t$  (e.g. L/100km)

$F_s^t(a)$  = total volume of energy/fuel type  $s$  consumed on link  $a$  in time period  $t$  (e.g. L)

$F_s(a)$  = total volume of energy/fuel type  $s$  consumed on link  $a$  per day (e.g. L)

$p_{rs}$  = proportion of class  $r$  vehicles in fleet using energy/fuel type  $s$

$g_{rsX}$  = base type pollutant  $X$  emission rate per unit distance for vehicle class  $r$  and energy/fuel type  $j$  (g/km)

$h_{rs}$  = base energy/fuel consumption rate per unit distance for a class  $r$  vehicle using energy/fuel type  $s$  (e.g. L/100km)

$v_{at}(q_t(a), L_a)$  = average travel speed on link  $a$  in time period  $t$

$\mu_{rsX}(v_a)$  = speed correction function for type  $X$  pollutant emission from vehicle class  $r$  and energy/fuel type  $s$  on link  $a$  with average speed  $v_a$

$\rho_{rs}(v_a)$  = speed correction function for type  $s$  energy/fuel consumed by vehicle class  $r$  on link  $a$  with average speed  $v_a$

$\lambda_{rsX}$  = load correction factor for type  $X$  pollutant from vehicle class  $r$  and fuel type  $s$

$\omega_{rs}$  = load correction factor for energy/fuel type  $s$  consumed by a class  $r$  vehicle

$d_a$  = length of link  $a$  (km)

The energy/fuel consumption rate for fuel type  $s$  per unit length on link  $a$  in time period  $t$  is then given by

$$f_s(a, t) = \sum_r p_{rs} Q_{rt}(a) h_{rs} \rho_{rs}(v_{at}(q_t(a), L_a)) \omega_{rs} \quad (A1)$$

so that total quantity of energy/fuel type  $s$  consumed on link  $a$  in time period  $t$  is

$$F_s^t(a) = d_a f_s(a, t) \quad (A2)$$

and the total quantity of energy/fuel of type  $s$  consumed on the link per day is

$$F_s(a) = \sum_t F_s^t(a) \quad (A3)$$

For pollutant emissions, the emission rate per unit distance for pollutant  $X$  on link  $a$  in time period  $t$  is given by

$$E_X(a, t) = \sum_r Q_{rt}(a) \sum_s p_{rs} g_{rsX} \mu_{rs}(X, v_{at}(q_t(a), L_a)) \lambda_{rsX} \quad (A4)$$

so that the total quantity of  $X$  emitted from the link in time period  $k$  is

$$G_X^t(a) = d_a E_X(a, t) \quad (A5)$$

and the total quantity of  $X$  emitted per day on the link is

$$G_X(a) = \sum_t G_X^t(a) \quad (A6)$$

The speed correction functions are used to incorporate the impacts of travel demand and traffic congestion (as well as road design standards) into transport energy and emissions analysis. Higher levels of demand and congestion generally imply lower average travel speeds. Road design standards also affect travel speeds. In previous research we have established a suitable family of models covering wide ranges of vehicle and fuel types, and including many emissions of interest (Taylor et al, 2005). The basic forms for the family of models were taken from the European emissions inventory guidebook (EEA, 2002) then modified for Australian conditions using the available local databases. The guidebook also suggested

a model for the effects of varying vehicle loading levels on fuel and emissions performance, which is useful for considerations of the performance of goods vehicles and transport and logistics policies that encourage load consolidation. The models relate energy/fuel consumption and emissions generation rates to average travel speeds, using piecewise functions to cover the possible range of speeds. The chosen functions are either power functions or polynomials. The generic form of the speed correction function is, for the energy/fuel consumption factor  $\rho_{rs}$  for fuel type  $s$  for a given vehicle class/subclass  $r$ ,

$$\rho_{rs}(v) = \begin{cases} z_{1rs}(v) & v_0 \leq v < v_1 \\ z_{2rs}(v) & v_1 \leq v \leq v_2 \end{cases}$$

where

$$z_{ors}(v) = Kv^{-n} \quad \text{or} \quad z_{ors}(v) = A + Bv + Cv^2$$

where  $v$  is the average travel speed and  $K$ ,  $n$ ,  $A$ ,  $B$  and  $C$  are constants. In the generic model presented in this appendix,  $v$  is taken to be the average link travel speed. Similar models are also available for the pollutant emissions of interest.