INTEGRATED APPROACH TO URBAN/NON URBAN FREIGHT AND LAND-SIDE PORT DEMAND

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This paper presents work done on a new combined road freight/personal travel model of southern Queensland, including South-East Queensland and the Surat Basin. The model includes two major ports - Brisbane and Gladstone, and includes a detailed operational model of road freight vehicles with multiple classes and complex operating cost components. Alternative approaches to freight modelling are considered, along with the special difficulties associated with freight demand. The underlying theory behind our approach is TransPosition's 4S model, which allows these complex, high level issues to be combined with a detailed, local transport model; in this case it includes all roads and full public transport/active transport. This approach offers many benefits, and allows urban and non-urban freight interactions to be considered in a consistent manner; this is important for land-side demand at ports, which are usually in urban areas and influenced by significant non-freight traffic. It also allows the consideration of tolling impacts on regional freight demand, critical for the consideration of projects such as the Toowoomba Second Range Crossing.

1. INTRODUCTION

Road freight in Australia is a crucial component of the economy and a major factor in traffic demand and road maintenance costs; with over 200 billion tonne km carried per year in 2012-13, and a growth rate exceeding the population growth rate, its significance will continue to grow (BITRE, Information Sheet 62, 2014). There are high level freight models (such as BITRE's Freightline model) that consider only freight, and some urban models are now including more comprehensive freight models. However, the interaction of wider freight demand with urban car traffic; and the impact of freight on regional cities is often not considered. In particular, the complex issues regarding the land-side transport of major Australian ports, their interaction with surrounding urban activity and their connection to rural areas, is not well considered in the existing models.

This paper presents work done on a new combined personal travel/road freight model of southern Queensland, including South East Queensland, the Darling Downs and the Surat Basin. The model includes two major ports - Brisbane and Gladstone, and includes a detailed operational model of road freight vehicles with multiple classes and complex operating cost components. The underlying theory behind the model is TransPosition's 4S model, which allows these complex, high level issues to be combined with a detailed local transport model; in this case it includes all roads and full public transport/active transport. This offers many benefits, and allows urban and non-urban freight interactions to be considered in a consistent manner. It also allows the consideration of tolling impacts on regional freight demand, critical for the consideration of projects such as the Toowoomba Second Range Crossing.

1.1. Background

Freight movements, both domestic and international, play an important part in Australia's economy. With a documented road freight task of 182.5 billion tonne km carried in 2007 (BITRE Report 121, 2010), freight transport by road is the predominant mode for moving freight across Australia. In 2011/12, over 95% of road freight in Australia was transported by heavy vehicles (BITRE, Freightline 1, 2014).

Total freight task is expected to double by 2030 from 2010 estimates, with the majority being moved as land freight. (BITRE, Freightline 1, 2014). Most of these freight movements have a major city at one or more ends, particularly as the major Australian container ports are located in capital cities. Urban congestion is thus an increasingly important constraint to freight movements, which in turn causes additional congestion on private urban travel.

Thus it is increasingly important that freight demand be modelled well, with models that can assess the range of issues affecting freight (including private urban travel), and the impact of freight on wider network operations.

1.2. Factors affecting freight demand

Understanding freight demand is complex - there are a wide variety of freight tasks and a range of issues that influence how those tasks are undertaken. The following list shows some of the key factors that influence where and how freight is carried.

- Location of industry and demand
- Local and global economy
- Business operations (globalization, just-in-time inventory)
- Logistics operations (warehousing, high performance vehicles)
- Regulatory environment (taxes and charges, size and weight limits)
- Costs (wages, fuel costs, vehicle operating costs)
- Transport network (congestion, tolls)

Ideally the freight model should be explicitly sensitive to all of these factors, both for the sake of realism and to allow the full range of policy initiatives to be tested.

2. KEY DIFFICULTIES IN DEVELOPING RELIABLE FREIGHT MODELS

Transport modelling started with modelling (mainly) car traffic on highways, and throughout its relatively short history, most of the focus has been on urban travel. Because urban travel is dominated by private demand, the focus has been on modelling car travel, with some secondary consideration of public transport and (sometimes) active transport. Urban freight demand is generally included in the models, but is usually given far less attention. This is starting to change, given the growing importance of freight, but it has a number of new challenges.

When it comes to modelling freight over larger areas, but still with a consideration of urban congestion, all of the problems of urban freight modelling are still present, but are compounded by the particular problems of combined urban/rural modelling.

The following list summarises some of the difficulties that affect freight modelling, and the difficulties that affect urban/rural modelling generally. Freight modelling in rural areas suffers from both sets of problems.

Problems with freight modelling

- Lack of reliable data and difficulty collecting it
- Large variation in travel behaviour, and more complex land use description
- Multiple modes of transport with quite different costs and interchange options
- Different commodities
- Complex choice of vehicle type and diverse nature of vehicles
- Higher importance of chained trips (cf. personal travel)
- Demand more strongly linked to economy and forecast economic variables

Problems with rural/urban modelling

- Difficulty in obtaining any data
- Large zones in rural areas - poor land use resolution
- Big variation in zone size (scale varies by at least 2 orders of magnitude)
- Big variation in trip lengths
- The importance of irregular trips

3. FREIGHT DATA SOURCE

The difficulty of understanding freight is compounded by the lack of data; traditionally there has been less investment in collecting freight data, and there are additional complexities in obtaining the information.

Whereas private travel can be understood by asking people about themselves and how they travel (in the census and household travel surveys) freight information is more difficult to obtain for the following reasons.

- Much of the data is commercially sensitive
- Freight decisions can be split between multiple decision makers including producers, customers, freight operators and truck drivers. It may be that no individual has the complete picture.
- Freight is geographically dispersed, so it is difficult to undertake localised surveys. At the road or corridor level it is possible to collect information on vehicles but not on what they are carrying or where they have come from (except in a limited sense using numberplate surveys).
- It is difficult to determine a suitable sampling frame, due to the wide range of participants in the freight sector.

The existence of these difficulties is affirmed by the relative sparsity of good quality data on freight in Australia. There is generally fairly good data on rail, sea and air freight, but less on the dominant mode - road freight.

The following summarises the key data sources.

3.1. ABS Freight Movement Survey (FMS)

The ABS collected a range of data in 2000-2001 regarding road, rail, sea and air freight. For rail, sea and air a census was undertaken, with questionnaires sent to all rail and air freight operators, and port authorities. The response rates for this were very high (almost 98-100%) and the data on non-road freight was very good.

For road freight only a sample of data could be collected; 14,000 articulated vehicles were selected from a sample frame of 63,000 across Australia. Only articulated vehicles were surveyed; rigid trucks and light commercial vehicles were excluded. The sample size was chosen to give reliable estimates of total distance travelled, tonnes carries and tonne-km travelled at the state/territory level.

The full sample of 14,000 vehicles was split into 26 fortnightly periods - this equated to a sample of around 500 selections in each fortnight. Vehicle owners were asked to record information on their vehicle and their use of it over the two week reporting period.

From these surveys a very comprehensive picture of freight demand can be obtained - the data is broken down by commodity, statistical sub-division and method of transport. Since the road demand is based on a limited sample, the reliability decreases as the data is segmented; for the matrices of demand by commodity at statistical division level most cells have a relative standard error of >25% and many >50% with the exception of major commodities in capital cities.

Unfortunately, due to funding constraints, this survey was discontinued and the 2001 survey is the most recent one. Nonetheless, this data source is a key input into the two models described below, and has guided the development of the TransPosition model. (ABS, 2001)

3.2. ABS Survey of Motor Vehicle Use

This survey is conducted by the ABS based on 16,000 surveys of vehicle owners. It was done annually till 2007, with the most recent releases in 2010 and 2012. It reports vehicle kilometres travelled, broken down by vehicle type and state/territory. It also reports tonne-kilometres for articulated trucks, rigid trucks and light commercial vehicles. Finally it reports fuel consumption by fuel type (petrol, diesel and LPG).

The surveys participants are prompted to give information on themselves and their vehicle, and record their odometer reading at the start of the four month survey period. At the end of the period they are asked to give summary information on their vehicle use over that period, and to record the closing odometer reading. For freight operators, they are asked to estimate their overage load weight, number of trips per week, and the percentage breakdown by commodity.

This survey gives good information on the total freight task, and importantly allows for time series comparisons. However it has no information on origins and destinations, and due to its basis in recalling averages over a four month period, it presumably has better information on kilometers travelled than the other variables. (ABS, 2012)

3.3. IMIS Freight Movement Model (FMM) Surveys

As discussed below, IMIS Integrated Management Information Systems Pty Ltd have developed a modelling approach to freight that they have applied in Adelaide, Brisbane, Gladstone, Melbourne, Perth and Sydney. In each of these cases they have undertaken surveys of freight businesses (300 in Melbourne; 150 in Brisbane; around 1200 in total), including GPS based truck tours and associated runsheet data. The surveys focused on manufacturers, wholesalers and transport/storage business, and asked questions about employment and tonnage production by commodity. The GPS and runsheet data gave information on trips, mode share, tours and loading/dead running.

IMIS have aggregated data from their surveys, and provided summary information in the reports provided with each model development exercise. Although focused on metropolitan areas, these surveys give good information on freight generation rates and vehicle operations. IMIS have used them as a key input in the development of their various Freight Movement Models, and we have made use of the summary data in the development of the 4S commercial vehicle model. (IMIS, 2009)

4. EXISTING APPROACHES TO FREIGHT MODELLING

Freight demand modelling is still less advanced than the modelling approaches used in passenger demand modelling. There are three kinds of freight model methodologies - econometric models, spatial price equilibrium models, and freight network equilibrium models (Harker, 1985). These different types of models are discussed briefly below.

4.1. Econometric Models

Econometric models are useful when testing the impacts of economic changes/development across different regions/industries. They provide insight into questions such as "how will growth at the port affect transport demand in the future?" Econometric models use time series data to estimate industry-wide cost/production functions and also demand functions. A detailed description of the transport network is generally not incorporated into econometric models, but instead broad assessment of transport costs are included through industry-wide cost/production functions. Thus econometric models are not used to analyse freight routing or specific link demand. (Harker, 1985)

4.2. Spatial Price Equilibrium Models

Unlike econometric models, the spatial price equilibrium model is described explicitly by a high level representation of the transport network. These contain nodes (which represent terminals, ports and other facilities) and links (which represent the highways, railways and other connections). A single node or a group of nodes in the network will lie in producing regions or consuming regions, or both, and the links connect these regions. Each consuming region has an associated demand function and each producing region has an associated supply function. An equilibrium is then reached between the producing and consuming regions under the following conditions (taken from Harker, 1985).

- if there is a flow of commodity i from region A to region B, then *Cost of commodity* i in A + *Transport Cost* from A to B = *Cost of commodity* i in B
- there will be no flow of commodity i from region A to region B if *Cost of commodity* i in A + *Transport Cost* from A to B > *Cost of commodity* i in B

The transport demand is therefore derived through the equilibrium between prices, transport cost and demand. Due to the complexity of the supply/demand/pricing equilibrium the spatial aspect is generally simplified, with only a rudimentary treatment of capacity and congestion (if any).

4.3. Freight Network Equilibrium Models

Freight network equilibrium models are those were a demand matrix is created and then assigned to the transport network using standard network equilibrium techniques. This is commonly done by combining an external freight demand model with a standard four-step transport model, and using a technique such as multi-class assignment to simultaneously determine freight flows and traffic flows on network links.

The techniques used for determining the freight matrix vary, and can include standard gravity models; matrix estimation; or complex combinations of distribution models and synthetic data.

5. SUMMARY OF SOME EXISTING FREIGHT MODELS

The two models (or model families) described below approach the problem of freight from opposite ends. FreightSim is a top-down, high level model that includes a detailed breakdown of commodities and incorporates a series of individual commodity production forecasts. The IMIS model is a detailed urban freight model designed to be closely integrated with a traditional four step transport model.

5.1. BTRE Freight Model - FreightSim

In 2001 the FreightSim model was developed by the then Bureau of Transport and Regional Economics (BTRE), now the Bureau of Infrastructure, Transport and Regional Economics (BITRE). They were commissioned by Austroads to develop an improved interregional transport model. BITRE subcontracted FDF Pty Ltd to assist in this project. This section gives a brief overview of the methodology of the FreightSim freight model. More information can be found in BTRE's paper "Freight Measurement and Modelling in Australia Report 112".

FreightSim operates at the level of ABS statistical sub-divisions (132 across Australia) and includes six modes of transportation - urban road; non-urban road; public-access railway; private railway; sea; and air. FreightSim contains 15 bulk commodity categories and one non-bulk commodity category, with separate models for non-bulk and bulk commodities.

Non-bulk freight comprises of manufactured products and is forecast using a gravity model (Section 6.1 of the BTRE report 112). This model assumes that the total freight flow between two regions is proportional to the product of the economic activity of the two regions and inversely proportional to the average cost of transporting the goods between the two regions.

$$\text{Freight}_{ij} = \frac{A_{ij}(EA_i \times EA_j)^{\beta}}{C_{ij}^{\gamma}}$$

where,

Freight_{ij} = kilotonnes non-bulk intercapital freight movements - road, rail and sea for seven intercity corridors;

EA_i = a measure of economic activity within region i, measured by population in i multiplied by national gross domestic product per capita;

C_{ij} = the real average generalised cost of transporting non-bulk freight between regions i and j

Once the non-bulk freight flow forecasts between regions have been calculated, the modal flows are estimated by using the original mode split specified in the base year dataset. To derive the forecast freight volumes by mode, the base year mode split is gradually altered to follow historical trends; in some scenarios completely different mode choice factors are assumed.

Bulk freight covers 15 commodity groups - grains and oilseeds; sheep (live); cattle (live); meat; other agriculture; coal and coke; metallic minerals; non-metallic minerals; oil and petroleum products; gas; steel and metals; fertilisers; cement; timber; and other bulk.

The bulk base case does not use the gravity model to forecast freight flows, but instead uses fundamental inputs such as production, imports and consumption. Base year information on commodity production, consumption and flows are used to define the basic freight context. For future years, each commodity is considered in turn to predict the change in production; these production forecasts are exogenous to the model and are based on a variety of other sources. Consumption is driven by economic and population growth. The model uses "mass-balance equilibrium" to prepare forecasts; for each commodity class, total annual production plus regional imports must equal total annual consumption plus regional exports (for each freight region). This is achieved by predicting freight movements necessary to transport commodities from regions with a net excess of production to regions with a net deficit of supply (or excess demand). An iterative process is used until the equilibrium is satisfied; any excess production is transported to the nearest port for export. Once again, mode choice is not explicitly modelled, but assumed to match base year proportions with trend changes. It does not consider mode choice as a function of changes to transport supply or mode specific costs.

In order to produce freight traffic estimates, the fundamental commodity demand matrices are processed using algorithms from FDF Pty Ltd's FreightTrucks model (BITRE 2009, Pg 56). These processes assign the commodity demand to nine different freight vehicle classes, depending on the commodity and trip type. BITRE further assume a continuing trend to higher freight productivity through the use of larger and more heavily laden vehicles; this causes the number of trucks required to grow at 2% less than the growth in the road freight task. The truck matrices are then assigned to a relatively high level road network where costs are based on length and road class; no congestion effects are included.

FreightSim is the only National freight model in Australia, and according to Ernst and Young (2006) has been "recognised internationally as an industry leading model". However it does not explicitly consider issues of transport supply; does not deal with urban congestion or changes to costs or regulatory environments; and bases most behaviour by trend changes to base year conditions.

5.2. IMIS Freight Movement Model (FMM)

Integrated Management Informations Systems Pty Ltd (IMIS) originally developed the Freight Movement Model (FMM) for Melbourne for the Victorian Department of Transport. Since then the underlying modelling framework has been transferred to six other regions - Sydney, Brisbane, Perth, Adelaide, South East Queensland (SEQ) and Gladstone. The FMM produces forecasts for rigid trucks and articulated vehicles. Although the FMM method could be used for light commercial vehicles, these are generally modelled separately, using approaches that vary by city.

The FMM comprises four main sub-models. These are (TDC, Heavy Vehicle Travel Zone Forecasts, 2010):

- Production/consumption models
- Two stage distribution model - between industries and then by areas
- Freight vehicle loading/trip models
- Vehicle assignment models

Employment by industry (ANZSIC 2006 classes) is the key input data for the FMM. Other inputs include traffic counts; production parameters; distribution parameters; consumptions models; and the strategic transport model network.

The **production** model uses generation rates (in t/employee/week) by industry to estimate the total freight tonnage produced/consumed in each location. The distribution model then geographically distributes these tonnages based upon the level of attraction of the freight area by industry class. The **distribution** of produced/consumed tonnage moved between industry classes uses factors derived from the ABS 'Use' Tables. To estimate the distribution of tonnages produced/consumed between areas, a gravity model based on employment and travel time data is used. The **loading** model estimates the trips between freight areas by industry class and vehicle mode. The main inputs to the loading model are surveys of existing mode share; vehicle loading; trip chaining; dead running parameters and employment growth. In the **assignment** model, the origin-destination (O-D) trip matrix gets assigned to the road network using standard 4-step model processes. The initial O-D trip matrix is then adjusted using a matrix estimation process, fitting the initial trip matrix to observed traffic count data. These re-adjusted trip matrices are then used to estimate freight volumes on the road network. (IMIS, 2009)

For the heavy vehicle volume forecasts, the two key inputs required are: forecasts of blue-collar employment by industry class and freight area; and forecast changes in productivity by industry class (TDC, Heavy Vehicle Travel Zone Forecasts, 2010).

The **Light Commercial Vehicle Model** generally estimates trip attractions using attraction rates of LCVs to households and businesses (measured by the number of households and employees respectively). The discussion that follows considers the model used in Sydney. A single attraction rate is used for households, however four different attraction rates are used for businesses - office, industrial, retail and hospitality.

After the estimation of trip attractions, a factor is applied to allow for 'dead running' trips - empty return trips from the drop off location back to the original location. The factor used in Sydney was 0.42 which was obtained from the Transport Data Centre's (TDC) Household Travel Survey. The factor indicates that most, but not all trips will have a return empty trip home - some trips are part of tours in which a LCV could travel to multiple destinations before returning to its original location.

Trip productions in each zone are assumed to equal the number of trips attracted to that zone, then a standard distribution model is implemented using generalised cost matrices from the 4-step model. The LCV O-D matrix is not adjusted using matrix estimation due to lack of available count data for LCV.

The forecasts for the light commercial vehicles are estimated by calculating the future trips ends by travel zone and using the Fratar method to generate future trip tables based on zonal growth factors. The main inputs to calculating the future zonal trip ends are employment and household forecasts by zone. (TDC, Light Commercial Vehicle Travel Zone Forecasts, 2010)

6. TRANSPOSITION'S 4S MODEL

6.1. Model Description

The TransPosition 4S model has been developed over the last 5 years. The model is structured differently from the usual four-step-model; it is based on a micro-economic utility framework and has strong capabilities in modelling multi-modal systems, freight, pricing and regional analysis.

The Segmented Stochastic Slice Simulation (4S) model is named for the following features:

- Segmented: Uses a comprehensive breakdown of different travel markets, and allows all behavioural parameters to vary by market segment (value of time, tolls, destination utilities etc.)
- Stochastic: Uses Monte Carlo methods to draw values from probability distributions. Every parameter can be a random variable
- Slice: Takes very efficient slices (samples) of the travel market across the whole model area and through the distributions
- Simulation: Uses a traveller/vehicle state-machine with very flexible transition rules to effectively simulate all aspects of travel choice

It differs in many ways from the traditional Four Step Model, and has many compelling advantages over many of the newer models as well.

- It has an elegant, theoretically sound basis that allows for realistic modelling of a very wide range of issues. This includes active transport, mode choice, toll modelling, behaviour change, induced demand and time-of-day analysis.
- Models can be prepared with much less effort and arbitrary coding - by eliminating zones, centroids, and centroid connectors the manual effort in putting networks together is vastly reduced. Also these

aspects (zones, centroids and centroid connectors) are somewhat arbitrary abstractions that make the model highly dependent on manual inputs and individual assumptions.

- It is very computationally efficient - by focusing all of the computational effort on tasks that are likely to contribute to the final outcome, and by having a single iterative structure (rather than traditional models' use of a whole range of separate iterations for convergence) complex models can be run with practical run times. The full multi-modal model for Southern Queensland, including freight, tolling and every single road and PT service, takes around 5 hours.
- Its simple core allows it to be extended to include time choice models, tour-based models, activity models, links to micro-simulation, latent class models and land-use/transport interaction.

More details on the theoretical Basis to the 4S Model, the background and benefits to this approach can be found in a paper presented by Peter Davidson to the Australian Transport Research Forum in 2011 - "A new approach to transport modelling - the Stochastic Segmented Slice Simulation (4S) model and its recent applications." Another paper "Modelling Toll Roads - Where have we gone wrong?" by Peter Davidson investigates the weaknesses of existing approaches for toll road modelling.

6.2. Behavioural assumptions in the model

The 4S model uses a similar approach for modelling personal travel and commercial travel. In each case the model is based on travellers making decisions that maximise their net utility. The net utility is the utility of their chosen activity at their chosen destination (attraction utility), minus the cost of travelling to that destination. For private travel the attraction utility reflects the satisfaction that people get from being able to undertake an activity at a suitable location; for freight the attraction utility reflects the underlying value of delivering the freight to the destination.

As is usual for utility models, a generalised cost approach is used- all components of travel impedance are converted into dollar cost values. There are three main components of generalised cost; the value of the time spent travelling (including the time value of freight); the costs of operating the vehicle (including fuel cost, maintenance etc); and any other costs (including fares, tolls, parking etc).

At the heart, the model considers a large number of potential travellers - these are drawn from the full range of private and commercial travel market segments. Each traveller has a set of behavioural parameters, including time of day preferences, destination utility preferences and cost coefficients - these are all Monte Carlo draws from specified probability distributions. The model finds the optimal choices for that traveller - where they should go; what mode they should take; and what route they should take. By sampling a large number of travellers, the model can accurately predict the aggregate behaviour of those travellers - traffic volumes, average costs, travel demand etc.

6.3. Personal Travel

The private travel model covers all of the travel made by individuals, whether it is for private purposes or related to work. It is assumed that all personal travel has some discretion with respect to mode choice, although the preferences may vary by person type and travel purpose. The model allows for any combination of car driver, car passenger, walking, cycling and public transport.

The model uses a fairly detailed trip purpose breakdown, including highly segmented non-home-based travel. Travel is trip based, with separate trips for the forward and return journeys, and for any substantial stops in multi-stop tours. Trip production is based on trip rates for each market segment - the rates give people's average desired number of trips in a day. If the circumstances are not amenable for the trip (either the costs are too high or the Monte-Carlo selected utility is too low) then travel will not occur. Thus the model has some degree of accessibility-responsive trip rate; strictly it is based on relaxation of suppressed demand rather than induced demand but the overall effect is very similar. The coefficients in the model that describe personal travel are calibrated using data from the South East Queensland Household Travel Survey (SEQHTS), conducted by the Department of Transport and Main Roads between 2008 and 2011 and the Toowoomba Region HTS. This survey involved asking households to record all of their travel over one or more days. The trip rates, trip lengths, mode choice and time of day choice are used directly or compared with model outputs in calibration. The model is also calibrated against traffic counts and observed toll road usage.

6.4. Commercial Travel

The commercial travel model uses a similar structure to the private travel model, but considers a separate set of markets and uses different probability distributions.

The markets for commercial travel are driven by linkages between different industries. Similarly to the IMIS model, factors are derived from the ABS "Use" matrices (part of the Australian National Account Input-Output tables). The cells in this table were aggregated into higher level segments, matching the ANZSIC 2006 Divisions - these were used because they match the employment projections available in Queensland. The most significant cells in the matrix were identified, and each was used as a basis for a number of commercial vehicle market segments. At this stage, the model does not make an assessment of the mode share for each commercial vehicle, nor does it determine the allocation to different vehicle types. Instead, fixed proportions have been assumed for each industry linkage. These have been estimated from a variety of sources, including the ABS Road Transport Margin on Supply and the Rail Transport Margin on Supply, as well as published statistics from BITRE. The current model ignores the rail demand, and splits the road demand into three commercial vehicle types - medium commercial vehicles (rigid trucks), heavy commercial vehicles (semi-trailers and non-combination articulated vehicles), and super heavy commercial vehicles (B-doubles and above). These correspond with Austroads classes 3-5 (Medium), 6-9 (Heavy), and 10-12 (Super-heavy).

6.5. Value of Time

The value of time attempts to include all factors that influence traveller's perception of time - including the opportunity costs (foregone wages or the utility of other ways of spending time) and the desirability of spending time on different travel options. For private travel this is done by assuming that the value of time is correlated with wages; these in turn are assumed to follow a log-normal distribution (based on ABS analysis) and grow in line with real wages. The basic wage rate is then factored for different person/trip types, and the value of time is adjusted by mode.

For commercial vehicles, the value of time includes a number of components - the value of the driver's time, the opportunity cost of the vehicle, and the value of time of the freight itself. The wage of a truck driver is much less variable than that of a car driver - car drivers come from a very wide range of occupations and incomes, whereas almost all trucks are driven by people with the same occupation - truck drivers.

The value of time for commercial vehicles has been determined by assuming a spread to the hourly wages given in the Road Transport and Distribution Award and then adding some cost for the value of time of the vehicle and the freight itself. The wages vary by vehicle class. In 2013, for medium commercial vehicles (CVM), the relevant grade is Wage Grade 3 ($684.00/week / 38hr/week = $17.65/hr in 2012 prices), for heavy commercial vehicles (CVH) Wage Grade 7 ($723.80/week / 38hr/week = $18.67/hr).

The value of time of the vehicle and the freight is more difficult to determine. Some studies have used stated preference surveys to show that this factor is significant, but very variable depending on load (with the highest value for express, automotive and container loads, and the lowest value for bulk goods). An average rate for Australia in 1998 was found to be $1.4/pallet/hr. These are adjusted for inflation and calculated separately for each vehicle class.

The probability distribution of VOT for commercial vehicles uses a linear distribution instead of the log-normal distribution used for private travel. A linear approach was used for a number of reasons; firstly driver wages are generally fixed to a small number of awards and these put constraints on how low or high wages can be. Secondly, the time value of the freight itself is variable, but significantly impacted by the quantity of freight carried. The model has no assessment of whether commercial vehicles are empty or fully loaded, so a linear distribution is used to reflect the range of loaded conditions between empty and full.

6.6. Tolling Choice

The decision whether or not to pay a toll depends on the trade-off between the time and money saved by using the tolled facility (compared with the best free alternative) and the cost incurred by the toll. The problem is that not everybody makes this trade-off in the same way - some people will have a high value of time, for example, and will be relatively less concerned with the toll. Others will have a high operating cost on the free route, so the benefit of the tolled facility is higher. One answer to this is segmentation - the range of decision factors can be simplified to a smaller number of separate markets. The other approach is to allow for variability in preferences. In some models this is done analytically, using simple assumptions about how variations in cost perception will modify travellers' propensity to use the toll. One particular assumption leads to the logit toll choice model, used in many toll assessments in Australia. The problem with this approach is that it requires unrealistic assumptions about variability. In particular, rather than assuming that value coefficients (such as value of time) vary across the population, it assumes that variability comes from an independent error term, completely unaffected by the characteristics of the alternatives in question. It does not allow for variations in taste, value of time, or vehicle operating costs and also brings into consideration completely unrealistic options.

The approach used in the 4S model is to incorporate toll choice into the standard model choice structure. Because the 4S model has an integrated destination/mode/route choice structure, no decision needs to be made regarding where to put toll choice - it simply becomes part of a holistic travel choice. This is in contrast to the traditional approach, where toll choice is a completely separate sub-model which must be inserted somewhere into the four step model. Another advantage of the 4S model is that the toll choice is integrated with the congestion model, so again there is no need to make difficult decisions about how to achieve convergence between toll choice and mode or destination choice in the face of congestion.

The 4S model allows for taste variation through Monte Carlo simulation. All behavioural parameters, such as value of time, vehicle operating cost, and congestion sensitivity, are specified with random distributions, and the model considers how people will make choices under a range of specific values.

7. MODEL INPUTS

Most of the inputs to the model are similar to the required inputs of any model - information on transport networks; population; and employment. However the fact that the model does not use traffic zones or centroid connectors makes some processes simpler, and opens up new possibilities for land use and demographics.

7.1. Transport networks

The model uses a road network derived from the State Digital Road Network (SDRN). This gives only the alignment of the road, and very basic details (road hierarchy and single/dual carriageway). A manual process was used to capture information on posted speeds, lane configuration and road quality. This information was collected from a number of sources, but in many cases was taken from virtual inspection using Google StreetView. Commercial vehicle route maps from Queensland Department of Transport and Main Roads were used to set constraints on large vehicles. Public transport networks were constructed automatically from extracts obtained from TransLink and in other areas (such as Toowoomba) the local public transport timetables were manually coded. At this point intercity neither coaches nor long distance passenger trains have been included in the model.

7.2. Land use/demographics

The 4S model operates at the level of individual network nodes rather than traffic zones, so the model can specify land use and demographics at exact locations when the information is available. This allows a very flexible process for land use/demographic information to be specified in the model. As with any model, the primary source of data is the Census, so population and employment information is taken at the most detailed level for which it is available - in this case ABS SA1 areas for population and SA2 areas for employment. This gives reasonably good detail in cities, where the census areas are fairly small. However, in non-urban areas particularly, SA2 regions can be very large and do not capture the detailed allocation of employment within each area. To better reflect the local conditions, TransPosition collected land use and employment data for major employment locations within the Surat Basin and wider model area. Data was collected for mining and agricultural industries, as well as educational facilities, hospitals and airports.

Data for the following industries were obtained through the Queensland Government Open Data program, based on data from the Agricultural Land Audit Report published by the Department of Agriculture, Fisheries and Forestry (DAFF): cattle abattoirs; poultry processing; egg production; pig processing; cattle feed-lots; poultry farms; piggeries; cotton gins; mining leases; petroleum leases; current sugar mills; current native timber saw mills; current plantation timber saw mills. For most of these industries, the location and company name were the only information given. For mining and petroleum leases the type of mineral and tenure numbers were also given. Since this data did not include employment, TransPosition searched the individual company websites to find employment numbers. For sites where none of this information was available, assumptions were made based on general industry trends.

To assemble the various data sources, TransPosition developed a new process that can take population and employment numbers at a range of levels and process them to ensure consistency. A full description of this process is beyond the scope of this paper, but in short it allows us to nominate the "source of truth" for various estimates, and factor up or down any unreliable estimates to ensure that the aggregate totals match the nominated values. In the larger regions we might have confidence in ABS' SA2 employment data, and also have some specific employment centres where we are confident in the numbers. We also are likely to have residual employment in the region that has not been located to a specific point. The process combines this data to give specific population and employment data at every node in the network using the best information available. This is an enormously better representation than exists in most models, that simply lumps the entire population and employment in an area into a single zone centroid. It is also more accurate than spreading the population and employment uniformly across the region.

A similar process is used to forecast population and employment at the detailed level, again using projections done by various agencies at various levels - including specific projections for South East Queensland, and the Toowoomba region; high level projections from the ABS; growth rates by industry; and growth estimates at specific sites.

8. BENEFITS AND APPLICATIONS OF THE 4S MODEL

8.1. Freight model integrated with other modelling

Some other detailed freight models sit alongside the main modelling process, using cost skim matrices from the four-step model, and producing new commercial vehicle demand matrices for the full mode. In contrast, the freight assessment within the 4S model is done in conjunction with other modelling. This means, for example, that changes in public transport operations in the city could lead to reduced car traffic, improving the connectivity for heavy vehicles in congested areas. An integrated model can pick up the complex interactions between all aspects of private and commercial travel in a way that separate models have difficulty replicating.

8.2. Wide area but retains detail

In most models there is trade-off between the geographical range of the model and the level of detail in the representation of land use and networks. This is due to the sharp increase in running time in most models as the network size and the number of zones increases; this can be seen directly in the size of trip matrices which increase with the square of the number of zones. In order to retain practical model run times, most models limit the number of zones to 2,000-3,000. This has meant that models have required more and more aggregation as they cover wider areas. The current 4S model of southern Queensland covers an area of 280,000km^2 - in a traditional model the average zone size would be 100km^2 which is around 6km across. Clearly this would have difficulties realistically representing every day travel. If the model is extended to a higher level then these problems compound - a model covering the whole of Queensland would have zones with average areas of 600km^2, and Australia would have zones of 2,500km^2. Clearly the models would not be done with equal zone sizes, so the urban zones would presumably be smaller but this would only further increase the size of rural zones.

The 4S model has none of these difficulties - the model does not use zones and so does not have the same penalties for increasing detail. The run time still increases with network size, but this is an $N\ ln(N)$ increase rather than an N^2 increase, so very large models are still possible. It is also easier to reduce network complexity (by removing local streets and simplifying public transport) without losing important detail. This allows varying levels of detail across the model; the current model allows detail in an area to be turned on and off to allow fine tuning of run time and geographic scope.

8.3. Urban and rural in the same model

Following on from the previous point, because models with large spatial extent (such as the BITRE FreightSim model) are unable to retain detail, it is difficult to include urban and rural areas in the same model. This means that the large rural model will necessarily have a stylised representation of what happens in cities. However many of the important issues with freight concern the interaction between rural and urban issues - this is particularly the case given that all of the large container ports in Australia are connected to major cities. In a traditional approach this would require some iteration between the two models to produce realistic assessments. In the 4S model this is unnecessary - a single model can be used for all analysis. This also makes it easier to consistently evaluate projects across a wider area, since rural projects and urban projects in different cities can be evaluated using the same tool.

8.4. Integrated tolling analysis

Rather than having a separate toll model, the 4S model treats tolls in a consistent manner in the generalised utility functions that define travel. This is possible because all behavioural variables in the model (such as value of time) are specified as random variables with specified probability distributions. This is in contrast to a traditional model that has fixed parameters, and requires separate methods (such as a logit toll choice model) to allow variability in response to tolls.

8.5. Can work with minimal data

As noted earlier, there are significant problems in obtaining freight data, particularly in rural areas. It is generally not possible to have the level of individual trip making data required for traditional disaggregate behavioural model calibration. However in a traditional model it is difficult to estimate key behavioural variables without this process - mode choice and gravity model coefficients cannot be easily guessed *a priori*. In contrast, the 4S model uses a first-principles approach where many of the parameters (including probability distributions) can be estimated from other sources. These can then be tested against whatever aggregate data is available and revised where necessary. Even if the parameters are slightly uncertain, the inherent realism of the approach and the fuzziness associated with the Monte-Carlo method means that the final outputs are reasonable, and any comparisons are robust. And if more data is available then it can be incorporated to improve parameter estimation and model confidence.

8.6. Implicit accessibility analysis and economic analysis

The random utility framework at the core of the 4S model lends itself to comprehensive accessibility analysis. Each travel market segment can be considered to find the average net utility at each location, which is an optimal accessibility index. The model can give accessibility by market segment under different scenarios to find both the winners and losers of any initiative, as well as a measure of the net economic value of the change. Using the approach obviates the use of simplified methods such as the "rule of half", and allows the economic assessment to be based on the behavioural utility values. It is also possible to use external economic values, based on resource costs rather than user costs.

The economic outputs, combined with the Monte Carlo process, can be used to perform new types of analysis. For example, recent applications of the model have addressed the impact of flooding on the network. By encoding the different type of flooding events that can occur, multiple runs of the model allowed traffic impacts to be assessed and plots of volume differences were produced. The travel times associated with the change can also be calculated, and the change in total travel time on the network estimated. But this does not show the whole picture - people will often modify their behaviour during events such as these; they may switch to alternative destinations or forego some travel altogether. The change in accessibility due to flooding is a more complete measure that picks up these changes in behaviour, and thus more accurately reflects the economic impacts of the flood. This approach also allows an assessment of the benefits of projects that mitigate flooding, or improve the resilience of the network by providing alternative routes.

8.7. Easily extended

Since the heart of the model is a simple assessment of benefits and costs of any travel choice, it is a relatively simple matter to extend the model to include new factors or new markets. The original 4S model has already been extended to include an intersection delay model; the impact of road grade on speeds and vehicle operating costs; factors related to network legibility; a more comprehensive fuel use model; and a detailed time of day model. Work has started on the development of a multi-modal freight model (which will include rail, air and sea freight) and we have plans for better intercity public transport (including coaches, train and air travel) and urban public transport congestion. Issues like inter-modal facilities, road user charges, vehicle productivity improvements and the shift to autonomous vehicles are all easily included in the model without any structural change. This makes it a very powerful framework for model improvements, and ensures that the models will continue to align with transport policy initiatives.

The model is also easily extended in a spatial sense; its scalability and limited data requirements mean that it is possible to develop models for new areas, or increase the scope of an existing model with reduced effort compared with traditional models. Much of the tedious work associated with new model development (designing zoning system, establishing centroid connectors, coding network etc.) is either unnecessary or mostly automated. The model will soon be extended to cover all of Queensland, and work is under way to continue south - adding in NSW, ACT and Victoria. The goal is to develop a detailed national model, which will allow any transport policy or project to be tested and compared in a consistent and coherent approach.

9. APPENDIX: EXAMPLE OUTPUTS

The following plots show typical outputs from the model. They are just a sample of the wide range of plots that can be produced from the 4S model, given the breadth of behavioural detail retained through the model process.

9.1. Network Plot

The figure below shows a plot of the network for Southern Queensland. The roads are represented by the links in the figure and have been coloured by road hierarchy. The thickness has also been set by the road hierarchy.

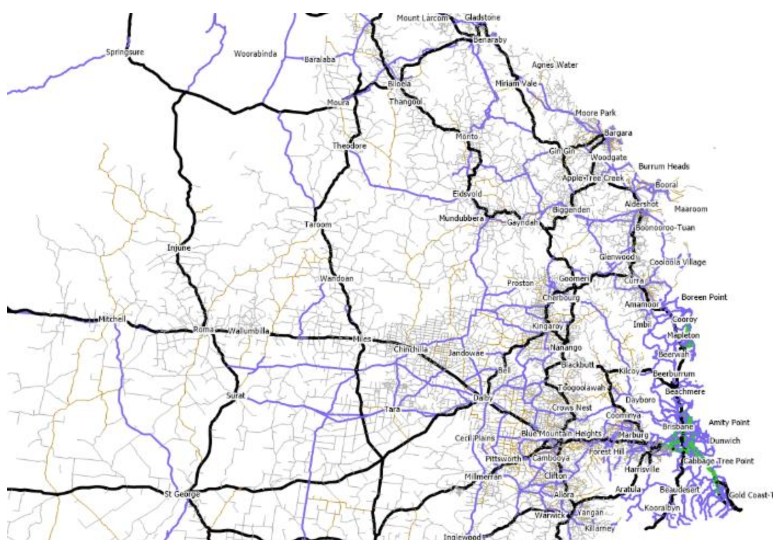


Figure 9.1: Network plot of Southern Queensland

9.2. Volume Plots

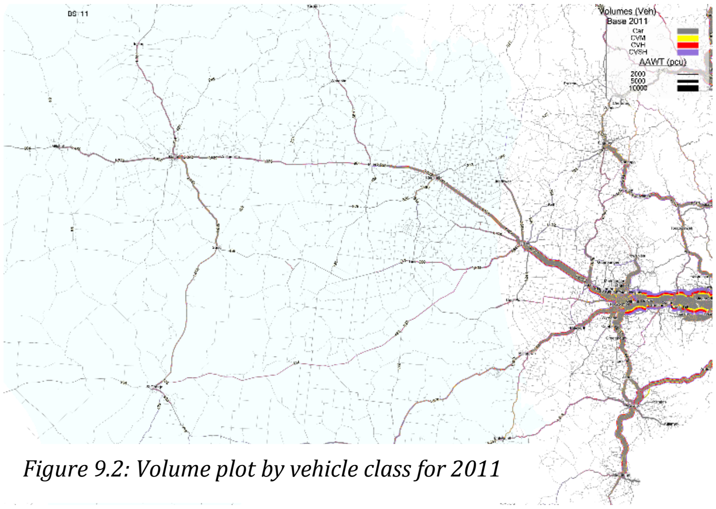


Figure 9.2: Volume plot by vehicle class for 2011

The figure to the left shows a plot of the volumes on the network by vehicle class for 2011. The legend on the plot shows the following: the grey colour represents the car volumes; the yellow represents medium commercial vehicle (CVM) volumes; the red represents the heavy commercial vehicles (CVH); and the purple lines represent the super heavy commercial vehicles (CVSH). The top black line in the legend shows the thickness corresponding to a volume of 2,000 vehicles and bottom black line shows the thickness corresponding to a volume of 10,000 vehicles. Note that in order to properly reflect the importance of commercial vehicles to congestion and traffic impact, the volume plots have weighted the classified traffic by Equivalent Car Units (ECU), sometimes known as Passenger Car Units (PCU). Thus medium commercial vehicles have been increased by a factor of 1.5, heavy commercial vehicles by 3.5 and super-heavy commercial vehicles by 5.5.

9.3. Desire Line Plots

These plots show the key demand movements in the model; where traffic is generated and where it is being attracted to. The desire line plots can be broken down into individual market segments. The plot below shows the desire lines for the combined heavy and super heavy commercial vehicle (CVHSH) travel. Note that the desire lines show demand movements between major urban areas. For demand within an area (intra-urban or intra-regional demand) the plot shows circles whose radius grows with the level of internal demand. For the demand that is not based in an urban centre, an arbitrary point in the region has been selected, and marked with a purple 'sun' symbols; this represent the rest of the LGA in which it is located, that is not included in the major urban areas within that LGA. Note that the desire lines are directional, and show demand from the source to their attractor. This is somewhat different from flow lines, which are generally symmetrical. The value of the desire lines is that it is easier to understand the key drivers of demand.

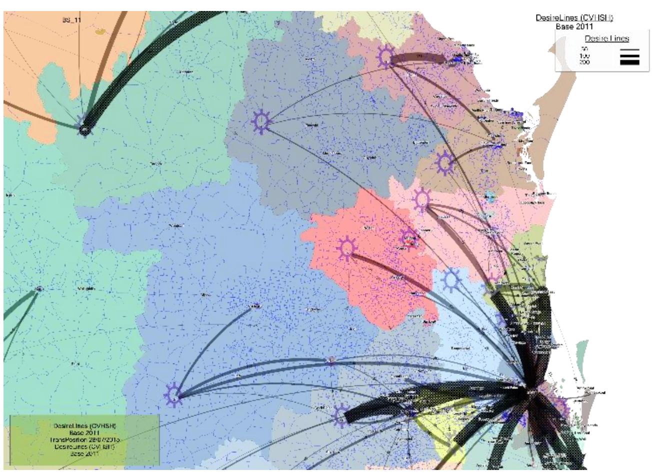
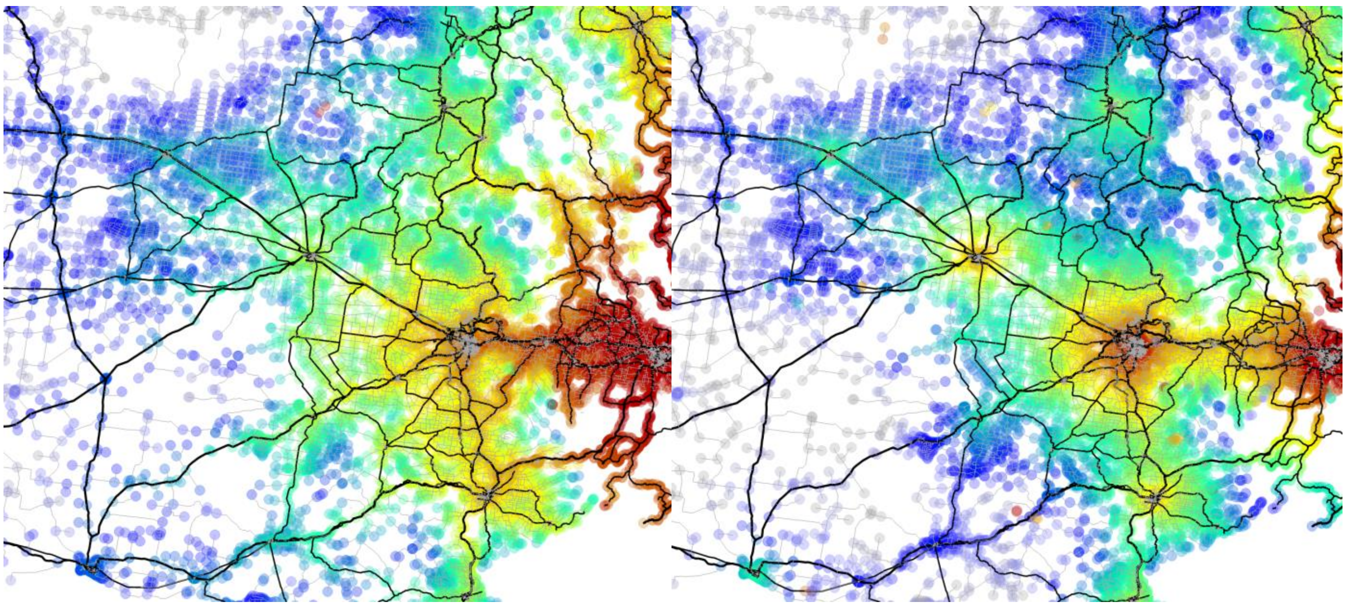


Figure 9.3: Desire line plot for CVHSH for 2011

In order to avoid unreadable plots, the small level of demand that occurs from place to place is excluded; any demand lower than a threshold is ignored. Finally, the high levels of demand in South-East Queensland can make the plots insensitive to the relatively smaller demand in the rural areas. For this reason we have put maximum limits on how wide a desire line can get - if the demand would make the desire line go thicker than the maximum then the width is capped and the desire line is filled with hatch pattern. The same is done for the circles that represent internal demand. The lower and upper thresholds, and the width scale of each plot, have been adjusted to give reasonably readable plots. The legend at the top right of the plot shows the scale, and the width of the hatched lines shows the maximum.

9.4. Accessibility Plots

The accessibility plots show the net utility of travel from a particular place for a particular travel market - that is it shows the average net benefits of all of the trips possible from that location minus the cost of making those trips. This is a properly weighted, linear accessibility measure (unlike many of the Hanson, or population catchment accessibility measures that are non-linear accessibility measures). The red areas show those locations where travel has high net utility - they are close to attractive destinations. Those blue and grey areas show the poorly located areas for the travel market in question - those with high travel costs, or unattractive local destinations. The two plots show different commercial vehicle markets in the areas west of Ipswich (the three major centres shown in the map are Dalby, Toowoomba and Ipswich); the first is for heavy vehicle traffic connected to the ports – this shows a steady decline as we move away from the cost and the Port of Brisbane. The second shows light commercial traffic associated with Business-to-Business movements; these are more localised around each of the centres, although still higher as we approach SEQ.



(a) *(b)*

Figure 9.4: Accessibility plot for (a) HCV - Import/Export and for (b) LCV - Business-to-Business

10. REFERENCES

Australian Bureau of Statistics (ABS), 2012, Survey of Motor Vehicle Use, Canberra

Australian Bureau of Statistics (ABS), 2001, Freight Movements: Australia Summary, Canberra

Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2014, Australia road freight estimates: 2014 update, Information Sheet 62, Canberra

Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2014, Freightline 1 - Australian freight transport overview, Canberra

Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2010, Road freight estimates and forecasts in Australia: interstate, capital cities and rest of state, Research Report 121, Canberra

Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2009, National road network intercity traffic projections to 2030, Working Paper 75, pg 56, Canberra

Bureau of Transport and Regional Economics (BTRE) (2006), Freight Measurement and Modelling in Australia Report 112, Canberra ACT

Davidson, P, 2011, A new approach to transport modelling - the Stochastic Segmented Slice Simulation (4S) model and its recent applications, Australian Transport Research Forum (ATRF), Adelaide

Harker, P, 1985, The state of the art in the predictive analysis of freight transport systems, Transport Reviews: Vol 5, No. 2, pg 143-164

Integrated Management Information Systems Pty Ltd (IMIS), 2009, Stage 3 - Final Report: Brisbane Freight Movement Model, Victoria

Transport Data Centre (TDC), 2010, Heavy Vehicle Travel Zone Forecasts, February 2010 Data Release: Technical Documentation, NSW

Transport Data Centre (TDC), 2010, Light Commercial Vehicle Travel Zone Forecasts, February 2010 Data Release: Technical Documentation, NSW