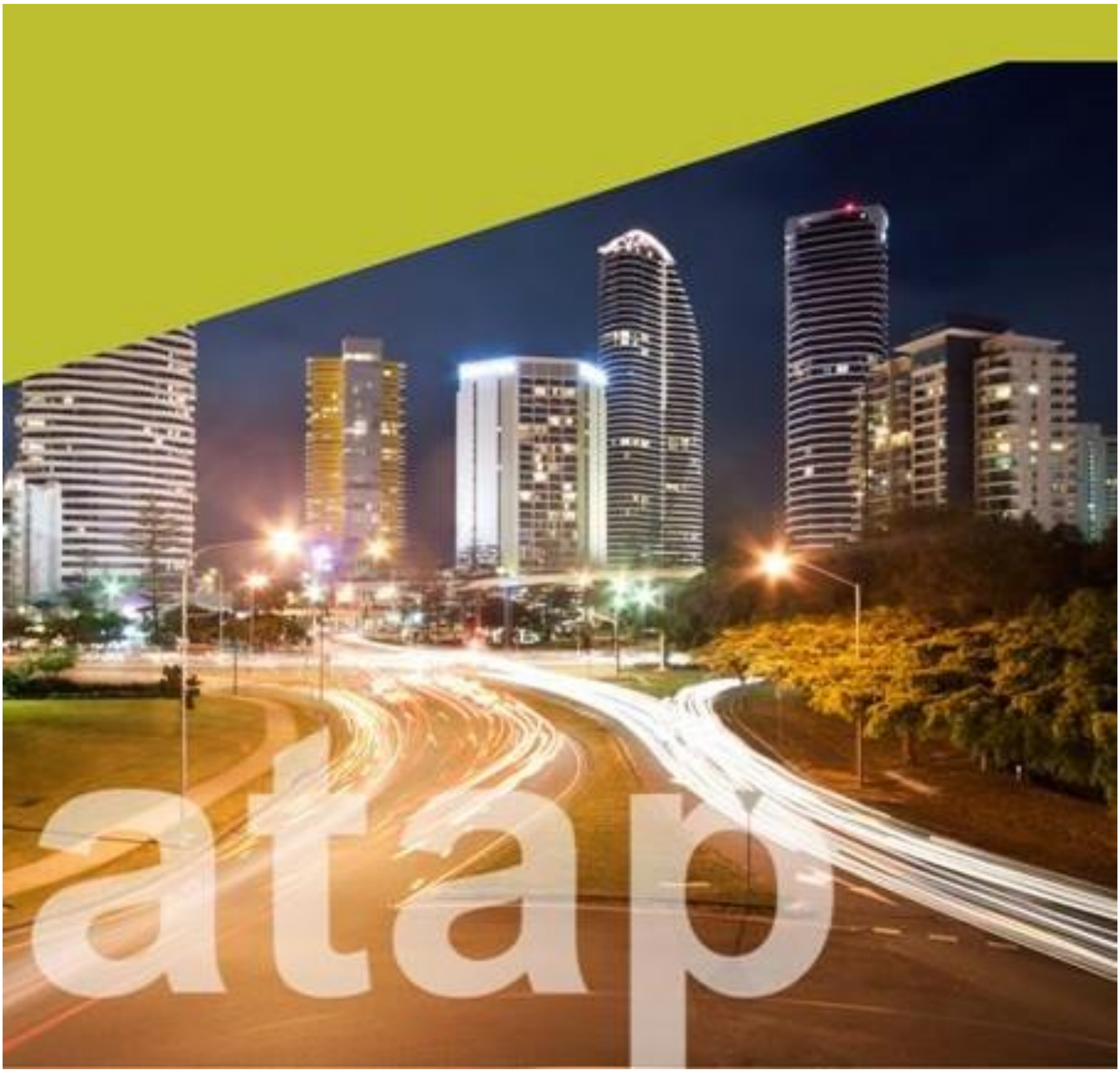
INFRASTRUCTURE AND TRANSPORT MINISTERS

Australian Transport Assessment and Planning Guidelines

T9 Urban freight demand modelling

August 2021



ISBN 978-1-922521-38-5

August 2021

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At a glance

- This Part of the Guidelines provides guidance on urban freight demand modelling for use in transport planning and the appraisal of major transport initiatives in Australia. The guidance is not intended to be comprehensive, but rather represent a minimum level of recommended acceptable practice. It complements Part T1 of the Guidelines which considers demand modelling of person-based travel.
- Urban freight is an important factor in how cities work, providing the ability for the urban economy to function, and plays a key role in the justification of many urban initiatives.
- Urban freight refers to the movement of all types of goods and commercial services to, from, within and through an urban area. Urban freight consists of:
  - *Intra-urban* trips: undertaken entirely within a specified urban area
  - Plus the first or last leg or the through component (all undertaken within the urban area) of the following freight trips: Intrastate trips: entirely within a specified state or territory; Interstate trips: between one Australian state or territory and another; and International trips: between one Australian state or territory and a different country.
- The primary type of urban freight model used in Australia is the trip-based model — also called a truck-trip model, or commercial vehicles model. It is an application of the 4-step model approach that is commonly used in urban passenger demand modelling (see ATAP T1). It typically uses 3 steps: trip generation, trip distribution and trip assignment (mode choice is not typically required).
- For intrastate, interstate and international freight movements, the majority of the movement is typically outside the urban area of interest. In urban freight models, they enter the model at the boundary of the urban area. There have been two ways in which these movements have been modelled:
  - Commodity flow models (or freight flow models)
  - Growth factor models.
- Most Australian jurisdictions are likely to continue to use trip-based and commodity-flow models as their main urban freight modelling tools.
- An important newer model type is the tour-based model, which replicates the itinerary, or sequence of stops, made by a commercial vehicle in its daily rounds. A tour typically begins and ends at the vehicle's garage or depot. A tour consists of multiple trips, each of which corresponds to the movement of the vehicle from one stop to the next.
- Data availability, data age, and the cost of data collection are significant issues for maintaining and improving the quality of urban freight models. The type of freight model in use is highly influenced by the availability (or lack thereof) of suitable data. Collecting freight data is notoriously difficult, often due from private sector freight operators is the commercial sensitivity of the data owned by private freight operators.
- When deciding on the most appropriate form of freight model for an urban area, a range of factors should be considered. These include: model purpose; city size; availability of data; financial resources available; timeframe; and availability of skilled resources to build and operate the model.
- The US Federal Highway Administration publish freight trip generation rates and trip distribution coefficients for use in cities that have no access to trip generation data. Consideration could be given to developing such an approach in Australia.

1. Introduction

This document provides guidance on urban freight demand modelling.

Urban freight is an important factor in how cities work, providing the ability for the urban economy to function. Not only are unit urban freight time cost reduction benefits higher than for the average urban vehicle, but across some parts of urban networks, freight accounts for a significant proportion of total traffic. Urban freight therefore plays a key role in the justification of many urban initiatives.

The BITRE (2019, 2021) reports that:

- Total freight activity in Australia has been forecast to grow by approximately 25% between 2018 and 2040
- Growth in road freight has been forecast to be much higher, 56%
- Road freight in capital cities and major provincial urban centres account for 30-40% of total road freight kilometres
- Capital city road freight in Australia is projected to grow by around 62 per cent between 2018 and 2040, from around 47.3 billion tkm in 2018 to around 76.7 billion tonne kilometres by 2040.

The modelling and assessment of urban freight demand is therefore already important and will continue to grow in importance over time. In this context, these urban freight demand modelling guidelines provide the basis for consistent best practice assessment across the country.

This guidance for applying urban freight (urban goods/city logistics) models considers: a number of relevant factors such as transport system objectives, policy objectives, scope of application, data availability, model structure and functionalities and model transferability. The guidance is not intended to be comprehensive or recommend a singular best approach. Rather, it represents a minimum level of recommended acceptable practice for each level of model complexity (model type) based on relevant factors. It provides a sound foundation for further development of the guidance in future.

In this guidance, the term urban is interpreted to mean the metropolitan areas that are represented in Australian transport models.

1.1 Links to other parts of the Guidelines

This guidance complements the other ATAP guidance on demand modelling, Part T1 Travel demand modelling which focuses on modelling person-based travel demand across road and public transport networks.

Used together, these two parts provide the basis for demand modelling of both passenger and freight movements in metropolitan areas.

1.2 Structure of this guidance

Chapter 2 provides a high level overview, considers the need for urban freight modelling and lists models used in Australia.

Chapter 3 is intended to provide practical guidance to practitioners on the different types of Commercial Vehicle (CV) models that may be used in an urban context.

Chapter 4 discusses new and emerging model types which are not practical for implementation in Australia today but may become more practical in the future. This includes supply chain (logistics) models (section 4.1), agent-based models (section 4.2.1), and changing delivery and purchasing practices (section 4.2.2). Section 4.3 outlines some ideas for steps required to maintain and improve urban freight modelling in Australia.

Lastly, three appendices accompany the guidelines.

Appendix A provides further technical details on the model types described in these guidelines.

Appendix B provides a glossary of terminology and definitions that users of these guidelines will find useful.

Appendix C briefly summarises national freight models, given that they provide some of the inputs to urban freight models.

Appendix D provides more detailed discussion of overseas practice (in support of section 2.4).

Appendix E shows the Australian vehicle classification.

2. Urban freight modelling overview

2.1 The need for urban freight modelling

The modelling of urban freight is an important input and requirement for a range of planning and assessment situations. Urban freight modelling facilitates:

- An understanding of the scale of urban freight, and its geographical and temporal features
- Estimation of the impact of a range of policy measures and projects on urban freight
- Estimation of the economic, social and environmental impacts of urban freight.

Table 2-1 summarises the wide range of applications where urban freight modelling can be used. Several observations can be made:

- The applications are a mix of considerations: short-term and long-term, traffic operations, land use and infrastructure planning, investment plans and priorities, funding applications, policy issues and more. This is a much wider focus than the traditional use of such models to identify future capacity deficiencies.
- Many applications have a national and international perspective. Urban freight models thus represent one component of this broader analytical need. They serve to analyse the impacts of locally-generated flows on the broader multi-modal transport network and, in reverse, the impacts on the local road networks of long-haul freight traffic entering or leaving the urban area via ports, terminals and airports.
- Urban freight models are not intended as micro-scale tools (e.g. microsimulation traffic modelling) in their own right. However, they can inform micro-scale analyses, e.g. traffic operations and site access design.
- Needs are evolving, with the rapid evolution in logistics – notably, the rapid growth in e-commerce purchases by individual households and businesses has changed delivery patterns in significant ways.

2.2 Urban freight components

Urban freight refers to the movement of all types of goods and commercial services to, from, within and through an urban area. It is helpful to categorise urban freight into the following components:

- Intra-urban: Freight movements made by commercial vehicles entirely within a specified urban area
- Intrastate: Intrastate freight movements are made by commercial vehicles, rail, marine or air entirely within a specified state or territory. This guideline considers the urban leg, e.g. the last-kilometre delivery of a container that arrived in the urban area by transcontinental rail
- Interstate: Interstate freight movements are made by commercial vehicles, rail, marine or air between one Australian state or territory and another. This guideline considers the urban leg, e.g. the last-kilometre delivery of a container that arrived in the urban area by transcontinental rail
- International: International freight movements are made by marine or air between one Australian state or territory and different countries. This guideline considers the urban leg, e.g. the last-kilometre delivery of a container that arrived in the urban area through a marine port.

Note that whilst this report focuses on the urban component, because of the nature of much of commercial vehicle travel in Australia there is often a need to consider the interactions with regional freight movement – i.e., freight activity generated outside the urban / metropolitan area that starts, ends or passes through the area. These externally based trips are described in the ensuing discussion.

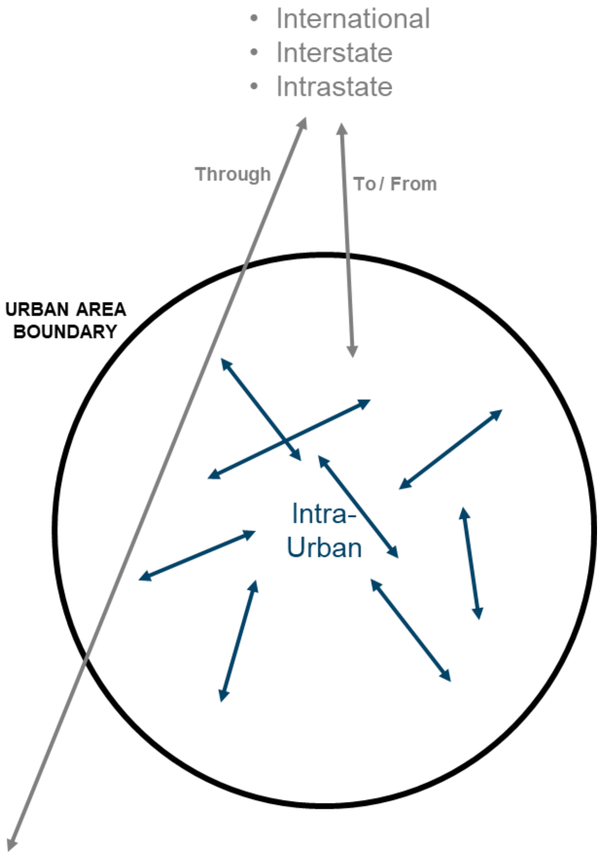
Table 2-1: Applications where urban freight modelling is required

Application	Description
Business cases	Business cases play a central role in funding submissions at National, State, Federal and Local levels of government. Robust modelling of people and freight movements is a key requirement of a good transport business case.
Transport, economic development and trade policies	The identification of nationally significant corridors requires an understanding of how long-haul freight (and other traffic) could be served by other modes. Also, forecasts of long-haul freight traffic can inform local, state and national economic development and trade policies.
Infrastructure Improvements	Freight vehicle forecasts are required in network planning to identify future deficiencies and other problems, and in options assessment to determine the merits of alternative improvement options.
Toll roads and mobility pricing	Vehicles can be priced to pay for the cost of new infrastructure (e.g. a toll road), or to manage traffic (e.g. cordon pricing). In the former case, typically commercial vehicles are a relatively small component of traffic but have a much bigger impact in terms of revenues, infrastructure rehabilitation, operations and maintenance costs. The success of a toll road forecast is partially dependent on the ability to properly model and assess the willingness to pay of commercial vehicle users. In the case of traffic management schemes, potential future policy measures such as heavy vehicle charging schemes rely on being able to properly model and assess the impact that such a measure has on commercial vehicle generation, distribution, mode choice and assignment. Such policies can also help manage traffic flow at access roads and access points to intermodal terminals, spreading traffic to less congested times of day, avoiding certain routes and even shifting modes.
Asset management	Estimates of freight traffic are needed to inform pavement and structure rehabilitation cycles. These estimates also could inform the allocation of road user charges for heavy vehicles.
Development approvals / land use planning	Estimates of freight traffic generated by proposed land developments impact the design of site accesses, on-site circulation, loading and parking.
Planning for intermodal hubs and freight generators	Freight vehicles typically comprise an important and even dominant component of the traffic along accesses to marine ports, airports, intermodal rail terminals and major freight-generating land uses.
Traffic operations	Estimates of freight vehicle movements are required for micro-scale analyses of traffic operations at intersections and along corridors.
Safety	The presence of larger freight vehicles creates a higher severity potential on the road network, particularly for vulnerable road users. The forecasted number of freight movements is therefore often an input into a road safety assessment / road safety audit. The desire to protect vulnerable road users from large freight vehicles is often the foremost motivator behind the introduction of the Complete Streets transport policy and design approach.[1]
City logistics	Rapid and pervasive improvements in communications and computing technologies have allowed households and businesses the ability to purchase goods anywhere and anytime, avoiding the need for in-person shopping and generating new delivery patterns and frequencies at urban locations and all times of the day. The emergence of new technologies, such as self-driving vehicles and electric vehicles, and the promotion of carbon-neutral vehicles could have profound impacts on urban freight.
Environmental and Noise Emissions	Freight movements are a significant contributor to environmental and noise emissions. Freight modelling enables estimation of these impacts for Environmental Impact Assessments (EIA).
Climate resilience	Plans for climate adaptation and mitigation will require an understanding of freight flows.

[1] ‘Complete streets’ is a transport policy and planning where streets are planned, designed and operated for the safety, access and needs of all people (American Planning Association 2010).

Figure 2-1 shows the four urban freight components in a stylised manner. An urban freight model considers all of these components. Intrastate, interstate and international freight movements each contain two further categories: to and from the urban area; passing through the urban area.

Figure 2-1: Urban freight movement components



2.3 Model types currently used in Australia

2.3.1 Trip-based models

The primary model used in Australia is the trip-based model — also called a truck-trip model, or commercial vehicles model. It is an application of the 4-step model approach that is commonly used in urban passenger demand modelling (see ATAP T1). For this type of modelling, the urban area is first divided up into geographical zones that are treated as both origin and destination zones for the modelling. A 4-step model has four sequential steps:

- Trip generation: Estimation of the number of trips generated from each zone
- Trip distribution: Estimation of how trips originating in each zone are distributed to destination zones
- At the end of the trip distribution step, the output is a trip matrix for one or more time periods, showing the number of trips between each origin-destination pair.
- Mode choice: Determination of mode selection. With nearly all urban freight carried on road, the mode choice step is typically not required in urban freight modelling.
- Trip assignment: Assignment of trips to a designated road network.

2.3.2 Modelling intrastate, interstate and international components

For intrastate, interstate and international freight movements, the majority of the movement is typically outside the urban area of interest. In urban freight models, they enter the model at the boundary of the urban area. There have been two ways in which these movements have been modelled:

- Commodity Flow Models and Freight Flow Models: A commodity flow model, a formulation commonly used in Australia, models the movement of goods or commodities across a state or across the country by various long-haul modes. From this, flows to, from and through urban areas are extracted. The flows are derived from forecasts of economic activity and are typically expressed as annual or monthly flows. These estimated commodity movements are subsequently converted into estimates of the number of daily commercial vehicle-trips required to transport these commodities within the urban area.

  These flows can involve the movement of goods into and out of the urban area via intermodal terminals (airports, marine ports and rail terminals), which are then distributed to or collected from multiple sources within the urban area by commercial vehicle. Some long-haul flows can be moved entirely by commercial vehicle, moving between an external location and one or more locations within the urban area.

  Commodity flow models are not typically deployed solely within urban geographies.

- Growth factor models: In earlier models, truck movements crossing the urban boundary were measured in a base year. Boundary surveys allowed information to be gathered on origins and destinations, allowing trip distribution to be undertaken. For future model years, growth rates were applied based on information about state, territory, national and international economic and demographic projections.

2.3.3 Current Australian urban freight models

Each of the capital cities in Australia either has an existing urban freight demand model or is planning to develop one in the near future. As mentioned above, the two model types used are: truck or commercial vehicle (CV) trip-based models; plus commodity flow and freight flow models.

Table 2-2 highlights the models currently used in Australian cities, plus in Auckland, New Zealand (NZ).

The outputs from a national freight model may form part of the input to an urban freight model. Appendix C introduces national freight models.

Table 2-2: Existing urban freight models in major Australian cities plus Auckland NZ

City / location	Type of model	Description
Sydney	Commodity Flow and Trip-Based	As part of the STM, there are several freight models; for heavy vehicles a commodity-based flow model is utilized to determine distribution of trucks, whilst truck trip models are used for light commercial vehicles. The key models in this suite were updated in 2017 based upon the 2014 ABS survey data, heavy vehicle traffic counts and other information provided by relevant stakeholders (ABS 2015). Further development work for light commercial vehicles (LCVs) was undertaken in March 2020. The models estimate LCVs, heavy commercial vehicles (HCVs, i.e. rigids and articulated).
Brisbane	Commodity Flow	The Queensland Freight Model (QFM) is a commodity flow model that extends into urban areas, but it is fundamentally a state-wide model with a more inter-regional focus.

City / location	Type of model	Description
Melbourne	Commodity Flow	The Freight Movement Model (FMM) was developed around 2008 and a light touch recalibration was done in 2016 against the Freight Movement Survey data of 2014. The model models Rigid and articulated HCVs, whilst B-doubles and HPFVs are modelled as part of a separate port module. The whole model is incorporated into the Victorian Integrated Transport Model (VITM).
Adelaide	Trip-Based	The MASTEM model has a trip-based commercial vehicle sub-model. A minor update to this model last occurred in 2009/2010 period, but the survey data used to build the model is very old (more than 20 years).
Perth	Trip-Based and Commodity Flow	The ROM24 model utilizes a version of the FMM developed for Melbourne but modified for Perth conditions based upon data from the ABS Freight Movement Survey (ABS 2015). The STEM model includes a three-staged trip-based model of LCVs and HCVs (created in the early 2000s and updated in 2010). The models are calibrated on CV survey data from 1996.
Hobart	Trip-Based	Due to lack of local data, the Hobart CV model was developed with parameters borrowed from other states (Brisbane Strategic Transport Model) and calibrated to local conditions. The Hobart CV model uses employment growth factors to grow the base year CV matrix in order to produce travel demand for future years.
Canberra	N/A	The Canberra Strategic Model (CSTM) does not include a CV model at the time of writing these guidelines (June 2021). However, a recent review of modelling in the ACT has identified the development of a CV model as a high priority. The ACT Government has subsequently commenced a scoping study to determine the data requirements and most appropriate structure of a new CV model to be built. These guidelines will inform that process.
Auckland NZ	Trip-Based	Auckland has two models: • The Auckland Strategic Planning Model (ASP), a strategic integrated land-use model, for medium and long-term planning, scenario development and evaluation, and for providing the necessary land use inputs for transport modelling; and • The Auckland Regional Transport Model (ART), a conventional 4-stage and relatively detailed transport model for medium term project and policy planning and evaluation. The overall approach to the modelling of the HCVs was to create a base year HCV matrix from observed data and apply growth factors for the future. HCV forecasting is based on growth factoring of the base year HCV matrix, using: • Ratio of future year and base year trip ends (using trip rates and future land use data), and • An additional factor to reflect the historic trends of HCV usage growing faster than employment (SKM 2008, Beca 2019).

Table note: Private models developed by consultants, universities or other third parties are not listed here. They do, however, play an important role in the suite of available models.

2.3.4 Issues and Opportunities

Several issues and opportunities have been identified in the Australian context. These are highlighted in Table 2-3.

Table 2-3: Freight modelling issues and opportunities

Issue / opportunity	Description
Data availability	It is clear from a review of practice that the availability of conventional data for the purposes of both establishing and updating commercial vehicle models of any behavioural richness has been lacking for some time. The current models rely very heavily on borrowed data from other spatial jurisdictions and on data that are either very old or not fit-for-purpose. Whilst some commodities may have good and up-to-date definition of parameters and movements, other commodities have rapidly changing supply chains with data both spatially and temporally sparse. Modelling freight and commercial vehicles has always been problematic for transport modellers. The primary reason for this is lack of data. Collecting data for CVs is difficult and expensive and for that reason, it isn't done very often. A key issue in all of these models is that the datasets used to calibrate either model type are significantly old and/or rely on very aggregate surveys. One source of data relied upon by many of capital city models is the ABS Freight Movement Survey, which was last undertaken in 2014 (ABS 2015). There are also few recent data on the movement of small/medium CV that engage solely in intra-urban freight movement.
National Telematics Framework and National Freight Data Hub	Transport Certification Australia's (TCA) National Telematics Framework develops common infrastructure rules for collecting transport data across the country. The Framework and related offerings, including the Telematics Analytics Platform, support public policy and private sector decision-making. The Australian Government has committed $8.5m to improve national freight data. Access to robust freight data will help industry and governments plan, make better operational and investment decisions and be more resilient and responsive. At the time of writing these guidelines, the National Freight Data Hub was not yet ready to provide data. However, the Hub has the potential to become a good potential source of calibration/validation data for any future Australian commercial vehicle model.
Impact of E-commerce	The significant growth in on-line purchasing, now spurred by the COVID-19 pandemic, has increased deliveries made by light commercial vehicles and delivery vans throughout the urban area, especially in residential areas, as purchasers seek deliveries to a place of their choice at a time of their choice. However, very little information is available regarding delivery volumes, vehicle patterns and the like. Other impacts propagate throughout the urban area, including the demand for short-term courier parking for pick-up and delivery and the proliferation of distribution centers that enable quick deliveries.
Multi-class assignment	One of the issues associated with freight is the level of definition associated with route choice and appropriately capturing realistic choice particularly where there is regulation or pricing mechanisms. Freight networks are always integrated with the road/highway network although in some cases, certain links may not be available to heavy freight vehicles. Assignment parameters appear to mainly be developed using value of time from ATAP guidance. There is a query whether more needs to be done to update these values regularly and with greater granularity.
Light commercial vehicle definition and double counting	Whilst HCVs are well-defined within most of the Australian models, there is concern that Light Commercial Vehicle movements are sometimes double-counted both within the non-home based (NHB) trips from the general passenger model and by the light commercial vehicle models that exist within most of these models, depending on how the actual trips and the associated LCV counts are categorised. In other words, very little information is available that can be used to distinguish passenger and commercial uses of light vehicles. LCVs arguably represent the 'weakest link' in our urban passenger forecasting models.
Mode choice	Zamparini and Reggiani (2007) suggest that there is increasing evidence that pricing strategies will influence mode choice within urban areas for freight movements. Currently mode choice is statically applied in either trip or commodity-based models. As discussed below, research into agent-based formulations is starting to consider pricing signals and the decisions of individual 'actors' in mode choice.
Emerging model types	New types of freight models are emerging and may play a future role in Australia. These include: tour-based models, supply chain (logistics) models, and agent-based models. These are discussed below in subsequent chapters.

Issue / opportunity	Description
Covid-19 Pandemic	We are in the midst of the pandemic. No one knows how long it will last. At the time of writing this report, there are promising new vaccines that may be available soon. However, the future is uncertain. What we do know is that there has been a significant increase in e-commerce to date which has resulted in a dramatic increase in light CV trips. These changes to e-commerce have accelerated a trend that was already happening before the pandemic began and the changes are likely to be permanent although we can't be 100% certain.

2.4 Overseas practice

Appendix D provides a discussion of some major models used overseas. The key learnings for Australia from those experiences are:

- Much of the focus on recent model development in North America and Europe has been on transitioning from trip-based to tour-based models, which portray how urban delivery / pick-up stops are grouped into itineraries. They provide a more precise basis for analysing policies and, especially, CV operations on the urban road network. They serve as the urban freight complement to urban passenger tour- and activity-based models, whose deployment is advancing rapidly.
- Urban commodity flow models are not commonly used, at least in North America. Instead, the focus has been on modelling the trip first and the commodity second, rather than deriving the CV trip from the commodity flow model. The difference reflects the focus of the trip- and tour-based models on ultimately understanding how CV activity interacts with the urban transportation network and its impact on congestion, air quality, traffic operations and so on.
- Some urban trip- and tour-based models have integrated long-distance trips generated by national commodity flow models into their urban models. The deployment ranges from the extraction of long-distance CV trip origin-destination matrices for importation into the urban freight model to agent-based models of how decisions made along the supply chain ultimately impact urban freight activity.
- Surveys have been developed to capture the behavioural choices of the urban establishments that generate freight and of the itinerary, routing and time-of-day choices made by the CVs that serve them. These data are used for model estimation.
- Complementing these surveys is the availability of GPS traces that provide a continuous record of CV routings, travel times, stops by time of day and information about the vehicle. Their 24/7/365 availability provides a basis that can be leveraged by the establishment surveys and the CV surveys to provide the necessary specifics for modelling behavioural, routing and time-of-day choices, and more.
- Mobile apps and other technologies are being used to capture CV activity with greater precision and accuracy. Even so, data collection is still relatively expensive. Some recent model calibrations have adapted trip rates and variables from other models to complement limited local data. The FRETURB model in France has developed a database of CV trip rates for urban areas of different sizes and densities as the basis for estimating CV origin-destination matrices for models in western Europe (Toilier 2018).

3. Practical guidance

Chapter 2 demonstrated that:

- Current Australian practice typically involves some combination of a 4-step trip-based model and a commodity flow or freight flow model
- Data availability, data age, and the cost of data collection are significant issues for maintaining and improving the quality of urban freight models
- A number of new modelling approaches are emerging, with tour-based models the most advanced from a practice perspective.

These observations have directly influenced the specific focus in this chapter, which aims to provide guidance for the areas of most immediate need of practitioners in Australia. As a result, the focus is on guidance for existing model types and data. In addition, initial material is provided on tour-based models as a way of familiarising Australian practitioners with this emerging model type.

3.1 Existing practice

As discussed in section 2.3 of this report, most Australian cities currently use CV models that are either trip-based or commodity-flow models (i.e. the FMM). There are no tour-based freight models for HCVs in use in Australia at the time of writing this guidance (June 2021). It is also considered likely that most Australian jurisdictions are likely to continue to use trip-based and commodity follow models as their main urban freight modelling tools. The ensuing discussion focuses on trip-based and commodity-flow models.

The type of freight model in use is highly influenced by the availability (or lack thereof) of suitable data. Collecting freight data is notoriously difficult and is discussed in section 3.4 of this report. One of the most important issues that can restrict the amount of data that can be collected from private sector freight operators is the commercial sensitivity of the data. These organisations must be reassured that the data will not be shared with their competitors, that all data will be anonymised before use in modelling, and that the data will only be used for long-term strategic demand forecasting. Privacy legislation also means that the planned uses must be clearly explained to participants (although this generally has not been a reason for participants to refuse). In North America, some commercial operators have shared their electronic manifest data, anonymised so as to protect the identities of customers, suppliers and so on. However, although these data sets can offer substantial details, the need to integrate data sets from different operators into a common database can be prohibitively expensive.

The theoretical basis of our existing CV models is that if commercial vehicle trip productions and attractions can be estimated for the base year from land use data, then they can also be estimated for a future year, based on forecast future land use information. This is a sensible assumption as we need to build models which rely on data which are ‘forecastable’.

Our CV models rely on forecasts of population and employment data to forecast the number of light and heavy commercial vehicles for the base year and any future horizon year. The inherent assumption built into our commercial vehicles is therefore that growth in commercial vehicles is proportional to growth in population and employment, although not necessarily in equal proportions depending on an urban area’s demographic composition and its economic structure (e.g., a mining community will have different workforce and economic structures than, say, a capital city). Moreover, structural changes in the economy have a clear influence on the types and magnitudes of freight that are moved, and on the modes and vehicles used to move this. While growth in economic activity (as measured by GDP) also influence traffic growth, its influence is indirectly captured through the population and employment projects.

However, there is evidence to suggest that the commercial vehicle fleet grows more rapidly than either population, employment or GDP. For example, in NZ between 1970 and 1998, the growth in goods movement was about 2% higher than population growth. And in Western Australia, the average annual growth rate in the number of registered semi-trailers and prime movers between 1987-2010 was 5% per annum while population growth was in the range of 1.5%-2.0% per annum.

While this doesn’t necessarily change the data requirements for a CV survey, it needs to be considered when any new CV model is built in the future.

As noted, one of the most common CV model formulations in Australia today is the trip-based structure. The model follows a three-step formulation: trip generation, trip distribution and trip assignment, with the last step preferably integrated with the passenger auto vehicle trip assignment (see section 2.3.1. The urban freight model can be simplified by excluding the mode choice component. Mode choice is not an issue because all goods movement trips are assumed to be made by road vehicle (i.e. we are not concerned with forecasting goods movement demand by other modes) and, as experience elsewhere has shown, there are virtually no options to road-based vehicles (i.e. drivers have limited choice as to vehicle type). This simplifies the model calibration effort significantly and also reduces the minimum data requirements.

The other common CV model in use in Australia is the Freight Movement Model. The first FMM was developed in 2006 and its production rates (tonnes per employee per weekday) were estimated from freight survey data comprised of 602 samples collected for Melbourne, Brisbane and Sydney from 2006 to 2008. Since this time, there have been three major updates in 2009, 2012, and 2016.

3.2 Context and principles for best practice

The context for the design of urban freight models is, in general, the same as for the modelling of urban passenger movements, as outlined in ATAP T1 Travel Demand Modelling. The key aspects are:

- Data collection;
- Model design (incorporating trip generation, trip distribution and assignment in the case of a trip-based CV model);
- Model calibration and validation; and
- Documentation.

Some key differences include:

- Freight trips and tours involve the surveying of establishments and ports and intermodal terminals rather than households
- The selection of purposes is different, and is typically not differentiated due to a lack of data and the fact that the purposes are more homogeneous
- Freight travel typically has a different impedance[2] associated with the trip than does passenger travel; and

[2] ‘Impedance’ is a measure of the ‘cost’ of a trip, which can be defined as a function of one of more of journey time, path distance and out-of-pocket cost. Passengers and commercial drivers both have a desire to minimise the ‘costs’ of a trip, which is reflected in how models assign traffic (i.e. Wardrop’s first principle). However, the components of the impedance function, their relative importance and the underlying unit costs (values of times, CV route prohibitions, etc.) can differ between the assignment of passenger vehicles and commercial vehicle.

- The value of time of generalised cost equations for freight in multi-class (vehicle) traffic assignment would generally be expected to be higher for urban freight classifications than for passenger vehicles (Refer to ATAP guidance PV2 for values of time. Note PV2 provides separate value of time for the driver and the freight carried. See also King and Wallis (2020) for recent research in New Zealand).

The model development of passenger travel demand models is covered in Section 5 of T1 Travel Demand Modelling Guidelines. Similar approaches apply to the development for freight models but with some key considerations that are specific to freight modelling:

- Freight almost always comprises a minority component of total road traffic. However, on a per vehicle basis, it represents higher value (in terms of travel time savings, operating costs, impacts on road operation and maintenance, etc.) than passenger traffic, and
- For the freight carrier industry, a general axiom is that “time equals money.” This means that transporters will tend to favour the shortest route, timewise, which can entail travelling longer distances if necessary, to avoid congestion and delay. By comparison, although passengers also value their time, for freight carriers delays result in direct out-of-pocket expenditures (e.g., additional driver salaries) that must be recouped through increased tariffs or other means, or they must absorb the costs, which directly impacts their economic viability. Although passengers also incur the impacts of delays (e.g., someone is late for a meeting), but not always without incurring a corresponding out-of-pocket cost.

Recommended calibration requirements are shown in section 3.6. It should be noted (as per the discussion in T1) that these should be considered as guidance only rather than as rigid standards.

3.3 Key assumptions

3.3.1 Trip-based models

This section discusses important assumptions common to most Australian trip-based CV models. An overall description of the trip-based approach can be found in Appendix A.1.

It must be noted that the focus here is on *urban* or metropolitan freight models, as opposed to state-wide trip-based models. The latter do exist elsewhere (e.g., in North America), but separate models that focus on key urban areas are often developed in order to provide the necessary spatial detail within urban or metropolitan areas compatible with the areas’ passenger travel models. The state-wide models thus estimate trips that are external to the urban area – that is, the trips that start and/or end outside the urban / metropolitan area – which can then be incorporated into the urban model’s CV origin-destination matrices.

The urban / metropolitan area and state-wide freight model formulations are mainly similar in concept, although with some important distinctions. One key distinction is that mode choice is not typically a factor in urban formulations, given that virtually all urban freight movement is by road-based vehicle (CV). This means that the urban trip-based freight model typically has three steps: generation, distribution and assignment. Another distinction is that urban models commonly focus on a single day’s vehicular activity commensurate with the corresponding passenger travel model, while state-wide models can be based on annual commodity flows that must be translated to vehicles (Comi et al. 2014, Beagan et al. 2019).

CV trips are generally categorised into light (LCV) and heavy (HCV), based on the Austroads vehicle classification system shown in Appendix E. Classes 1 and 2 comprise LCVs and classes 3 through 12 comprise HCVs. However, there is a desire to move towards a more disaggregated definition of CVs which may include additional categories as follows:

- Class 1 & 2 (light commercial vehicles)
- Class 3, 4 and 5 (medium commercial vehicles)
- Class 6, 7, 8 & 9 (articulated heavy vehicles), and
- Class 10, 11 & 12 (long vehicles and road trains).

Adopting this type of disaggregated CV model will depend largely on the availability of data to calibrate each different segment.

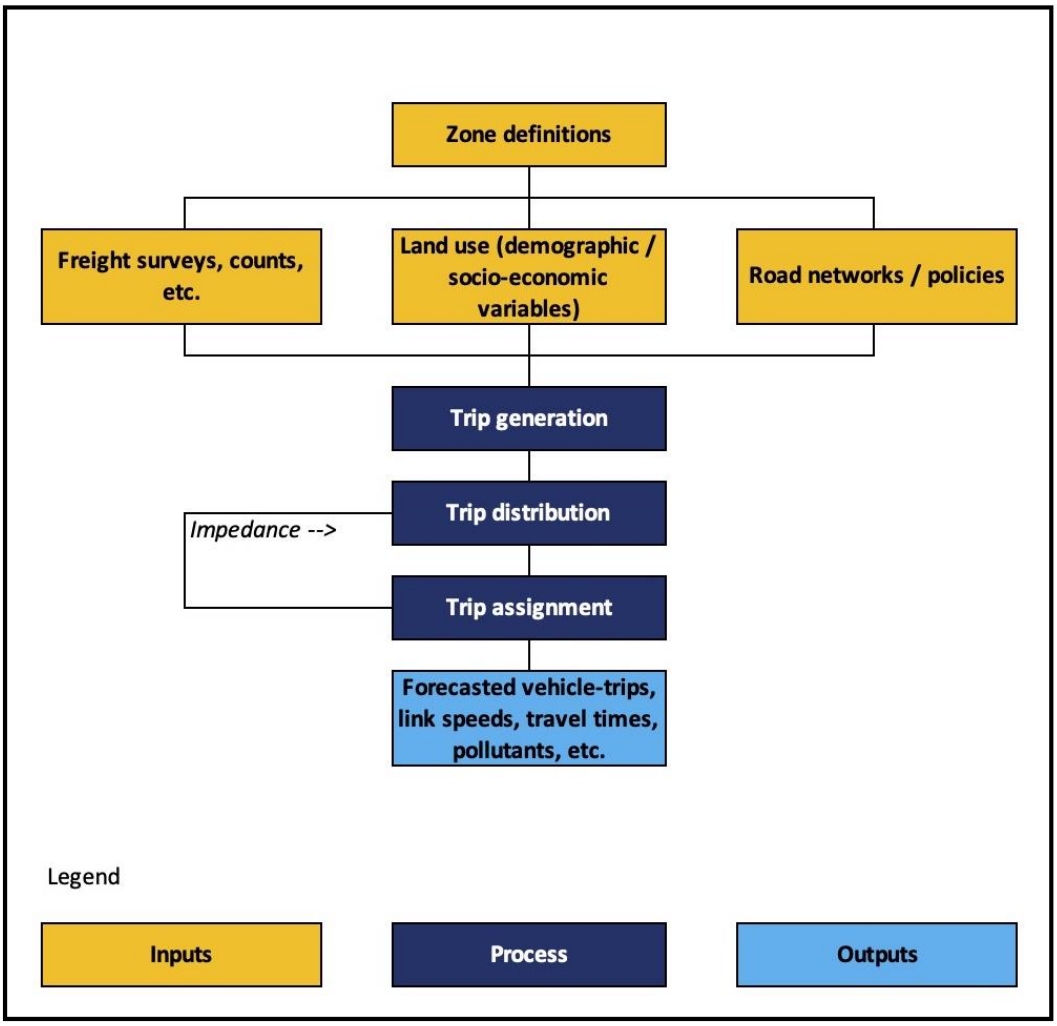
General model structure

The general structure for a CV trip model is displayed in Figure 3-1. The figure has three components:

- Inputs, shown in orange
- The three steps of the modelling process, shown in dark blue
- Outputs, shown in light blue.

Each component is discussed below.

Figure 3-1: Structure of trip-based model



Inputs

Figure 3-1 shows the four main inputs. These comprise:

- Zone definition, which are small spatial geographies generally known as transportation analysis zones (TAZs). They are defined by:
  - Homogeneous land uses such as residential neighbourhoods or employment areas.
  - Major traffic generators such as shopping centres and universities.
  - Natural or human-made geographic boundaries such as rivers or railroads.
- Land use (demographic) and socio-economic variables. These are the parameters upon which trip generation is based. These parameters must be available at the TAZ level, and they must also be forecastable: both considerations are key to selecting the parameters that are to be used for CV trip generation. Common parameters are:
  - Employment – that is, jobs categorised ideally at the two-digit ANZSIC subdivision level. These data commonly serve as a proxy for the establishments that generate and receive CV trips.
  - Population or households – that is, an indication that growth in CV trips is tied, in part, to demographic growth as well as being a destination in its own right (e.g., due to e-commerce).
  - Commercial / industrial space – some formulations have attempted to use floor space by industry type as a basis for CV trip generation.
  - Other parameters for special generators – for example, the container capacity at an intermodal rail terminal or port.
- Transportation network. This is the link-node road and highway network that comprises the metropolitan region, including links (gateways) to external areas. Volume-delay functions for trip assignment are allocated to each type of link, where type refers to road function, capacity, posted speed or other factors. Related to this input are policies on how the network can be used such as tolls and, especially, the definition of permitted and restricted CV routes.
- Freight surveys, counts, etc. These are data that profile CV activity on the urban road and highway network. These are discussed further in Section 3.4.

Assuming that an urban passenger travel model already exists, many of these inputs will already be available for developing the trip-based CV model. By implication, it is essential that the CV model's zone system and transportation networks are compatible with those used with the urban passenger travel model. Nonetheless, some modifications might be needed, especially:

- The creation of new TAZs that are specific to key freight generators such as marine ports or intermodal rail terminals, if these do not already exist as separate TAZs in the passenger model.
- Tagging the road / highway links with CV route restrictions. This ensures that CV trips are not assigned to prohibited routes during trip assignment, even if passenger vehicles are permitted on these links.

Trip generation

This first step calculates the total numbers of CV trips that start or end each TAZ. The trips are calculated as function of the land use and socio-economic inputs. Regression models and cross-classification analyses are commonly used to develop the trip generation equations. Some models feature separate trip generation equations by CV type – a common breakdown is for LCVs and HCVs. However, this depends on the availability of data that are sufficiently robust to describe the activities of the individual classes.

Keeping in mind the need to use forecastable land use variables as the basis, the trip generation equations commonly are based on different combinations of employment by type and population. The breakdown of employment by type, if available, can be used as a proxy for commodities hence for vehicle type as well, at least in some cases: for example, LCVs are not typically used to carry construction materials such as cement or steel hence it would be unlikely that the LCV trip generation equation would include construction employment as an independent variable. In this way, CV trips vary according to the land use variables and values associated with each TAZ, akin to the way urban passenger trips are generated.

Separate trip generation equations can also be developed for special generators such as marine ports, where CV activity is more reliably estimated as a function of, say, the tonnages or volumes of containers that pass through the port rather than by site employment.

It is common for trip generation equations to be conducted at the 24-hour level. The 24-hour basis reflects the relative paucity of data against which to calibrate a sub-daily model, meaning that there may not be sufficient data with which to calibrate a (commuter) peak hour or peak period matrix. As well, although the commuter peak hour typically reflects the time of maximum loading on the urban transport network, the times of peak CV activity often occur outside the commuter peaks. This reflects the preference of dispatchers and operators prefer to avoid the congested commuter peaks and the ensuing costs. It also can reflect requirements for pick-up and delivery, which are often dictated by customers, and available delivery windows at factories and assembly plants. As a result, peak conditions at key freight generators and terminals might not be captured if only the commuter peaks are modelled. The availability of 24-hour LCV or HCV matrices allows the modeller to analyse other times of day if and as desired.

More sophisticated model formulations are possible, depending on the urban area's economic composition. An example of how to achieve this is described by a recent formulation in Vancouver, Canada's key Pacific Ocean port and an important border crossing with the United States. The model develops CV trips according to four distinct markets, each of which uses econometric models and variables to develop equations for HCVs and LCVs that are appropriate to the specific market (TransLink 2015):

- Inter-regional sector, which reflects trips made by CV between Vancouver and the rest of Canada. Much of this activity reflects trade within the same province (British Columbia). As one example, it was found that the provincial employment by sector (six categories) and fuel prices are the best determinants of CV activity, although to different formulations for LCVs and HCVs. The econometric formulation also permits an analysis of seasonal variation: the importance is peak inter-regional HCV traffic occurs during the third quarter (summer in Canada) and then dip in the fourth quarter (autumn), which is the time of year captured in the urban travel model (because school is in session, vacations are over and travel behaviour has not yet been impeded by winter conditions). Hence, to more fully incorporate the impact of CVs into urban infrastructure planning, there may be a need to substitute CV matrices from a different quarter into the modelling suite.
- Regional sector, which reflects CV trips made within the metropolitan region. These CV trips reflect the composition of the local economy hence population and nine types of economic employment are used to generate CV trips, again varying between LCVs and HCVs and also according to four sub-areas within the metropolitan region.
- Asia-Pacific sector, which reflects HCV movements of containers that are transferred to and from Vancouver's Pacific ports – i.e., the independent variable for these equations are container volumes handled by the ports. Of note, CV trips are generated for all four markets for a 24-hour period, the availability of hour-by-hour counts of CVs entering and exiting the ports enable the development of precise time-of-day factors for developing slices.

- Cascade Border sector, which corresponds to CV trips moving across the US border that bounds the Vancouver metropolitan area. This formulation is based on an economic model of commodity flows in each direction. These flows are then converted vehicles and, according to border-crossing counts, factored to account for empty vehicles.

Trip distribution

The trip distribution phase distributes the generated CV trips among the TAZs. The gravity model and growth factor (Fratar) model formulations are commonly used. The gravity model relies on impedances that are output through the trip assignment, ideally those specific to the CV assignment or, if these are unavailable, for all vehicles taken together. In an urban model, these are commonly based on generalised inter-zonal travel costs, which can be a function of congested travel times and out-of-pocket costs such as tolls, as well as the CV trip ends generated at each TAZ. For 24-hour distribution models, generalised cost impedances could be derived from mid-day trip assignments if available - i.e., the times of day that avoid the extremes of the congested times and paths associated with the commuter peak periods and the free-flow conditions that typically represent only the sparsely travelled overnight period. If mid-day trip assignments are not available, then an average of commuter peak period and free-flow generalised costs could be used as a reasonable substitute. Models can be developed by vehicle class.

The growth factor model apportions CV trips according to the magnitude of land uses at each trip end but does not consider inter-zonal impedances. Models can be developed by vehicle class.

The Vancouver example cited above uses a combination of gravity and growth factors models. For the port-generated trips (the Asia-Pacific sector model) the HCV trip matrix is derived from GPS CV traces that determined that the large majority of port trips originate in or are destined to a small number of TAZs that represent certain heavy industries, distribution centres, warehouses, transload facilities and intermodal rail terminals. As a result, the observed distribution is used for this market without any mathematical procedure (TransLink 2015).

Trip assignment

The trip distribution process yields matrices of CVs – that is, flows of commercial vehicle-trips between TAZs. To be applied in transport planning studies, these trips must now be allocated - or assigned - to the urban road and highway network. Typically, the CV matrices are assigned together with auto vehicle-trip matrices.

Prior to trip assignment, the following must take place:

- CV trips for different markets or geographies must be combined by vehicle class. For example, intra-urban CV trips, external (long-haul) CV trips and special generator CV trips must be integrated into a single CV matrix for each vehicle class.
- The 24-hour CV trip matrices must be factored to represent the time period(s) that will be used for the trip assignment(s). In an urban model, these periods commonly represent the AM and/or PM peak hours and, in some models, a mid-day hour. Factors are typically drawn from observed ground counts. For modelling purposes, it is common to use single, matrix-wide factors for each class, although more specificity could be added for special generators or external O-Ds if so desired.
- PCE (passenger-car equivalent) factors are commonly applied to the CV trip matrices. The PCE factors account for the operational capacity taken up by CVs hence they can influence the selection of paths in trip assignment. For LCVs, these factors commonly range from 1.0 (for utes) to 1.5 (for rigids). For HCVs, these factors commonly range from 2.0 to 2.5, and even 3.0 to represent B-trains.

- If matrices by vehicle class have not been developed, one approach is to apply factors from ground counts to apportion matrices according to LCVs and HCVs. The factors can be specific to the time period(s) for which trips are to be assigned. For modelling purposes, it is common to use single, matrix-wide factors for each class, although more specificity could be added for special generators or external trip O-Ds if so desired.

There are different algorithms for assigning vehicle trips. Many models use the “equilibrium assignment” technique. This process allocates traffic to links so as to minimise the generalised cost of the vehicle trip between origin and destination. These relationships are quantified as volume-delay functions (VDFs), which determine a link’s traffic volume, typically expressed in vehicles per hour, as a function of travel time, cost (i.e., tolls converted to time equivalents through value of time factors) and capacity, where capacity is expressed commonly as number of lanes per direction times lane capacity in PCUs. The VDFs should be calibrated to local conditions, in order to reflect local throughputs.

The process also adheres to turn penalties (delays at intersections that reflect the type of intersection control), turning restrictions (prohibited turns) or link restrictions such as those that prohibit CV use of a particular link. The process allocates traffic over several iterations. The mathematical objective of the assignment process is to minimise total generalised cost. “Equilibrium” is achieved when, between the current and previous iterations, on average no driver (i.e., no vehicle-trip) can improve his/her travel cost by switching routes. This equilibrium optimises travel conditions for the users of the road system—hence it is known as a user-optimal equilibrium. The achievement of equilibrium also achieves the lowest overall impedances between zones – i.e., the lowest congested times and generalised costs summed across the entire network. To achieve equilibrium, the model can be allowed to run for a set number of iterations (e.g., upwards of 100 iterations for a congested urban network) or when the difference in the total network impedance between the current and previous iterations has been reduced to a specified absolute or percentage difference (e.g., less than 0.5%). The assignment stops whenever any one of the criteria is reached. The analyst has the option of running additional iterations if needed – e.g., in a highly congested network, the maximum number of iterations can be reached while the differences are still relatively large.

It is common for CV trip matrices to be assigned together with auto vehicle-trip matrices as part of a multi-class assignment. This ensures that the assigned paths account for all traffic on the network while also recognising the CVs on equal terms (that is, as PCUs). However, it must be noted that because auto vehicle-trips typically dominate the traffic mix in an urban network, especially during the commuter peak periods, the modelled paths might not necessarily be those that the CVs would use in reality. This could be problematic when considering urban corridors that are particularly important for freight movement, toll roads on which CVs are charged a different rate, or on accesses to key freight generators or intermodal terminals and ports. To address this, it may be necessary to calculate separate goodness-of-fit factors for CVs and then adjust the assignment accordingly. Commonly used goodness-of-fit factors, such as GEH statistic, serve the purpose provided sufficient data points are available: this also means that the GEH thresholds for CV assignments might necessitate more relaxed tolerances than those that are used for auto vehicle-trip assignments, if CV data are sparse.

The impedances generated from the multi-class assignment can be used as input to the trip distribution model, as described above.

The all-or-nothing assignment is another technique that can be useful under certain conditions. The all-or-nothing assigns all vehicle-trips irrespective of volume to the fastest route under free-flow conditions (or at posted speed). The all-or-nothing technique is appropriate for sparse networks – typically for small-volume CV matrices that use a network for which there are few or no alternative routes and no congestion – or for the assignment of 24-hour volumes, in which hourly capacity does not apply.

Outputs

Outputs of urban freight models are similar to those associated with passenger travel models. These comprise:

- Matrices of commercial vehicles by class and time of day. These can be used as the basis for subsequent analysis, e.g. as inputs to network micro-simulation models.
- Impedances (matrices of generalised costs), as described above.
- Assigned CV volumes for each link in the network, by class if the CV trip matrices have been categorised into LCV and HCV matrices as part of the multi-class assignment. These assignment results are expressed as vehicles (PCUs) according to the time period of the assignment: i.e., typically per hour or per 24-hour. Factors can then be applied according to available ground counts, to expand hourly volumes up to 24 hours (or to some part of the day) or to develop AADT volumes.
- Plots of the assigned CV volumes can be generated in addition to the aforementioned numerical results (i.e., they use the same data). Follow-on analyses for plan assessment and other needs can be generated – e.g. select link analysis can be used to understand the origins and destinations of the CVs that use a planned bridge, and comparisons can be made of the CV assignment results with and without a proposed link in place.
- Travel times and speeds for individual links under congestion or free-flow, depending on the trip assignment method. These outputs can be used to discern blockages along the network – e.g. due to an actual capacity constraint or potentially a network coding error.
- Path distances and travel times – i.e., matrices of the distances and assigned travel times between each origin and destination TAZ used by the CVs. These matrices are output from the trip assignment process.
- Vehicle-hours travelled (VHT) and vehicle-kilometres travelled (VKT) by vehicle class. These can be developed as the sum of individual link attributes (link CV volumes * link travel times or * link length) or generated as matrices according to user preference: the key is to be consistent with how VHT and VKT are tabulated for the passenger-vehicle model.
- Fuel, GHGs and air pollutants associated with CV usage on the network. These can be calculated by vehicle type (LCV and HCV) by speed or by distance, by link or for the overall matrix (VHT or VKT) according to the user’s preferences, needs available data and desired method.
- Vehicle operating costs associated with CV usage on the network. These costs are not necessarily the same as those used to calculate generalised costs, because they monetise several other metrics. The vehicle operating costs can be calculated by vehicle type and can account for driver salary, cargo value, out-of-pocket costs such as tolls, insurance and other built-in costs, and monetised values for fuel consumption, GHGs and air pollutants.
- Tonnages can be estimated by factoring the vehicle-trips by average (or assumed) loading factors, derived from surveys and field data.
- Screenline volume-capacity ratios for all vehicles combined, including all CV classes.

3.3.2 Commodity flow

This section describes assumptions made in the most commonly used commodity flow model in Australia (the FMM). As an example, the following assumptions were used in the Sydney FMM (AECOM 2017, 2018, 2020):

- A concordance was estimated to allocate each imported commodity to selected FMM industry classes.
- Expansion parameters were based on estimated mode shares to convert data for articulated vehicle tonnage movements to total heavy CV (i.e. rigid and articulated) movements.
- Imports from external country regions and interstate for future years are based on the estimated growth in employment in particular industry classes for each region. The growth in regional and interstate employment is estimated based on historical growth in 1-digit ANZSIC employment (from ABS) and applied to the respective 2-digit industry classes.

The primary assumptions involved in estimating the base and future year sea and air imports were as follows:

- A concordance was estimated to allocate each commodity imported to selected FMM industry classes
- Conversion parameters were estimated to convert yearly commodity imports to weekly imports (i.e. 12/52)
- Parameters were estimated to apportion the estimated sea imports to tonnage moved by road as rail freight is not considered in the FMM. Through discussion with personnel at the various ports, the following rail proportions were assumed:
  - 100% of Other Mining (i.e. coal and coke) trade through the Newcastle Port
  - 65% of Other Mining trade through Port Kembla, and
  - 20% of all trade through the Port of Sydney and Port Botany.
- Tonnage data obtained for trade through Sydney seaports did not specify port of destination. Therefore, parameters were estimated to apportion the estimated base and future year imports to/from Sydney to Port Botany and the Port of Sydney.
- Forecasts of the economic variable Gross State Product (GSP) through to 2015 were provided separately. Forecasts beyond 2015 were estimated by IMIS and assumed to be compounding (in line with Port estimates of compounding growth).
- To estimate the trade through ports in future years for the immediate strategic level application of the FMM, it has been assumed that the relationship between trade and GSP will remain constant.

The primary assumptions underlying the estimation of distribution to freight areas in the FMM are as follows:

- The estimated accessibility parameter is assumed to accurately reflect the relative attractiveness of freight areas in the Greater Sydney Region (GSR) for commodities produced in a particular freight area, based on travel time and employment opportunities, and
- The travel times between internal freight areas are taken from a ‘travel time skim’ from a 2003 Cube network and are used for base year and future year estimates.
- The estimated travel times between regional freight areas and internal GSR freight areas are based on freight movement data collected from ABS, which report tonnes and tonne-kilometres between these freight areas. The ABS data were used to estimate the average travel distance between freight areas (i.e. tonne-kilometres/tonnes) and an average travel speed of 80 kilometres/hour was assumed to estimate the average travel time between freight areas.

The primary assumptions underlying the estimation of mode share are as follows:

- Similar to the distribution models, these estimated probabilities reflect the current mode share of commodities for the base year.

- For the immediate strategic level application of the FMM it has been assumed that the estimated mode share probabilities in future years will remain the same as the base year, however the framework exists to reflect a shift in mode share over time.

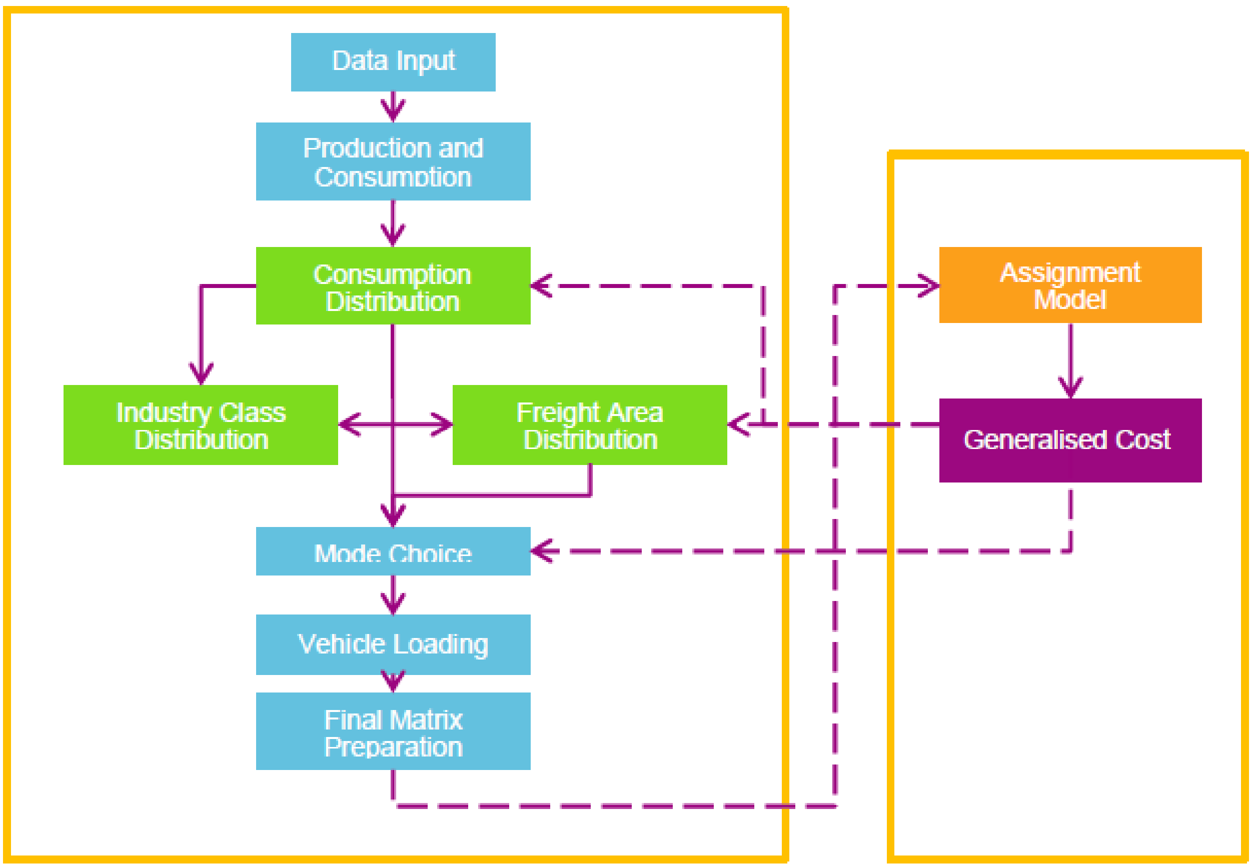
The primary assumptions involved in the application of the internal commodity production models were as follows:

- The 2-digit ANZSIC employment for freight areas in the GSR were supplied by TfNSW's Transport Data Centre (now known as TPA). The creators of the FMM were required to make assumptions to estimate industry class employment across freight areas for a few selected 3-digit FMM industry classes such as horticulture and fruits.
- The general quantity production model for an average month is converted to a production model for an average week using an expansion parameter (i.e. 12/52).
- Internal commodity productions for future years are estimated based on the growth in employment (forecasts supplied by TDC) and growth in the production rates for each industry class. The growth in productivity was estimated from the growth in turnover per employee for each industry class. These data were collected from ABS.
- The production models estimated from the business survey sample are representative of the business population in the GSR within an acceptable level of variance.

General model structure

The general structure for a commodity flow model is displayed in Figure 3-2.

Figure 3-2: Structure of commodity flow model



Model data input

The following table outlines the data inputs that are typically required to build a commodity flow model.

Data	Description
Industry Class (IC)	Industry classes are divided into three main types to be considered for different modelling processes: • Production and Consumption. This includes the industries involved with both production and consumption processes. This type includes Agriculture, Forestry and Fishing, Mining, and Manufacturing • Redistribution. This includes Wholesale Trade, Retail Trade, and Transport, Postal and Warehousing • Consumption. This includes the remaining industries involved only in the consumption of freight.
Freight Area (FA)	Similar to travel zones, these represent main areas of freight activity, and used for the generation, consumption and distribution of freight. Typically, there are internal, external and special generator FAs
Employment	Employment is required as input by FA and industry class, divided by blue collar and white collar categories.
Travel time	Travel times (or a form of generalised cost) between all FAs for use in the distribution components of the commodity flow model, as well as mode choice if incorporated.
Production rates	Production rates are defined for production based ICs, and internal FAs. Production is also explicitly defined as an input in terms of total production tonnes for production ICs, and external and special generator FAs.
Consumption rates	Similar to production, consumption rates are input in terms of total tonnes per IC (for production/ consumption ICs), external and special generator FAs. This input also contains proportions to split the consumption tonnes into direct and staged components.
Impedance parameters	The impedance parameters are used in the consumption distribution and FA distribution subgroups. This data is required ICs (production and redistribution) and between freight area groups
Observed/Estimated Matrices	The observed matrices are provided for defining movements known or estimated outside of the Commodity Flow Model. Typically, these are defined as movements to and from the port terminals or intermodal terminals.
Distribution rates	The distribution rates are used in the IC Distribution subgroup to distribute tonnes between ICs
Mode choice road and rail delivery data	Delivery data such as road and rail travel time and delivery charge between internal FAs and any ports and vice versa. They are used in the mode choice model
Mode choice model coefficient data	This file contains the coefficients used to calculate utilities for road and rail mode choice by ICs
Vehicle loading data	This input contains the road mode share to split road modes into three separate vehicle classes: rigid, articulated and other. The mode shares are segmented by ICs and FA groups. This input also contains vehicle trip loading information such as the average vehicle loads, percentage of dead runs, and trip chaining which are used to convert vehicle tonnage into vehicle trips.
Time period multipliers	These are time period factors to convert the daily demand into one-hour peak period vehicle trips for AM, IP, PM and OP time periods. They are segmented by ICs and vehicle modes
Time period length	Length of each time period to convert trips to full time period lengths or combine to a daily level
PCU factors	To convert vehicle trips into PCUs
FA to travel zone concordance	This contains origin and destination factors to disaggregate vehicle matrices from FA into a traffic zone level

Production and consumption

The purpose of the Production and Consumption process is to estimate the tonnes produced and consumed for each freight area and industry class. This utilises employment data and production and consumption rates defined for all freight areas and industry classes.

Direct consumption distribution

This process involves the distribution of freight from production location direct to consumption (or export) in external regions and special generators. The purpose is to estimate the production locations for all direct consumption tonnes estimated. This is estimated using accessibility calculated based on travel time, the production tonnes estimated in all areas and impedance parameters defined by area and industry class. Calculations are typically undertaken for each industry class separately.

Industry class distribution

The purpose of the Industry Class Distribution process is to estimate the distribution of net production tonnes (i.e. the production tonnes remaining after being distributed direct to consumption locations) to each industry class.

Freight area distribution

The purpose of the Freight Area Distribution process is to calculate the distribution of tonnes from each freight area and industry class to every other freight area and industry class based upon a freight area to freight area attraction. This attraction is estimated based on employment within the receiving industry class, the travel time between the freight areas and the travel impedance. During this process, the remaining staged consumption tonnes are also distributed to special generating freight areas.

At the completion of this Freight Area Distribution process, the tonnes distributed to all redistribution industry classes (e.g. wholesale and storage) in each freight area are then used as the amount of redistribution tonnes to move from those areas in the next iteration of the Industry Class Distribution step.

Mode choice

The purpose of the Mode Choice process is to use a utility model to estimate the mode choice between road and rail. This process also splits the road component into different road modes defined by the user (such as Rigid, Articulated and other).

Vehicle loading

The purpose of the Vehicle Loading process is to take the tonnes between all freight areas and for each industry class estimated over all previous processes and convert this to vehicle trips. This is done by utilising input data such as average load, trip chaining and dead run parameters by freight area group and industry class provided as input.

Final matrix preparation

The Final Matrix Preparation process performs all final manipulations to matrices in preparation for assignment within the travel demand model. After all these processes described above, the heavy vehicle matrices are ready to be linked and integrated into the main travel demand model operational loop and to be assigned to the urban road network with all other personal vehicles.

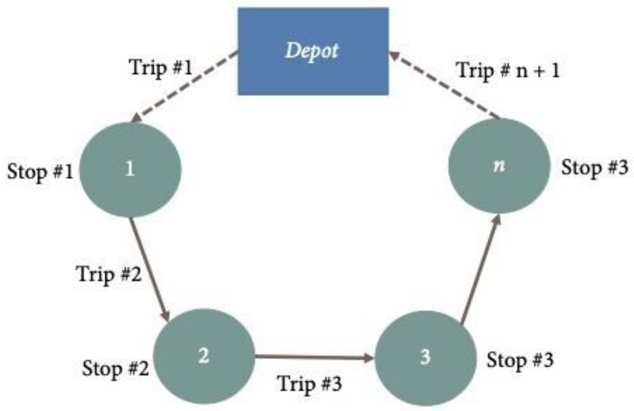
3.3.3 Tour-based

Tour-based urban freight models represent a key methodological advancement. Although they are relatively new, their application has driven much of the advancement in the state-of-practice in North America which may soon become the case in Australia. As noted above, these and other developments parallel similar approaches in urban passenger models but are expressed in significantly different ways in the freight formulation.

Researchers have long recognised that commercial vehicles tend to make long tours composed of multiple trips (legs), and that the sequence of trips is a function of logistics decisions made by the actors involved. The actors can include drivers, dispatchers, shippers, receivers and government. The logistics decisions include route choice in the face of congestion, required delivery or pick-up time at a stop, and the type of vehicle that is best suited for the commodity being carried, among others. This contrasts with the trip-based modelling assumption that each trip is independent and that trips between an origin and destination are related only to the zonal attributes and the travel impedance between the origin and destination. Whereas the trip-based model generates individual trips, the tour-based model starts by generating the tour, within which the sequence of stops along the tour are then determined.

The tour-based approach replicates the itinerary, or sequence of stops, made by a commercial vehicle in its daily rounds. As shown in Figure 3-3, typically the tour begins and ends at the vehicle's garage or depot (i.e., the location where the vehicle is normally based). A tour consists of multiple trips, each of which corresponds to the movement of the vehicle from one stop to the next. A commercial vehicle can have more than one tour in a day. The itinerary also can differ by tour, depending on the needs.

Figure 3-3: Components of a tour



Source: You and Ritchie (2019).

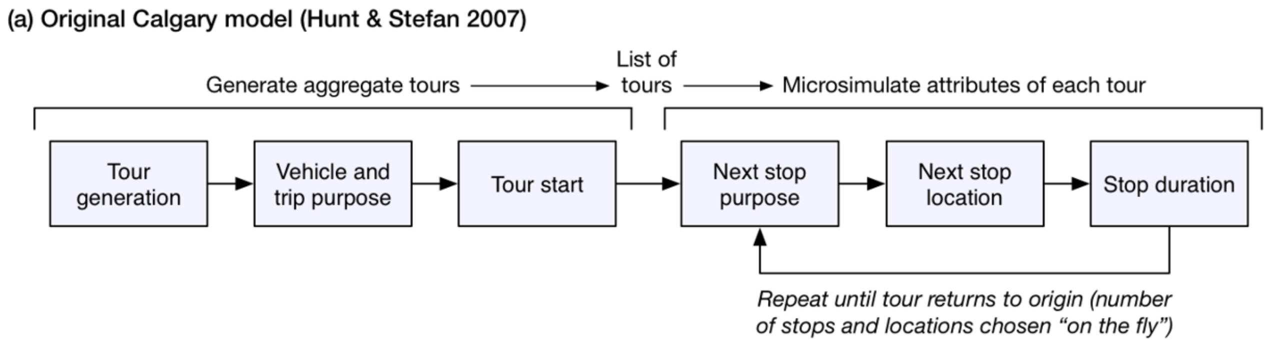
Although some trip-based model formulations do capture tours the impedances are based on the tour as a whole. As a result, the sequential characteristics that define the tour are lost, although they can subsequently be added into a trip-based formulation. The time spent at the stop also must be considered because it is integral to the path. However, this is not considered in a trip-based analysis and must be added.

The development of tour-based disaggregate modelling approaches addresses these limitations. This allows the tour-based formulation to forecast pick-ups and deliveries by modelling the type of tour (out-and-back or multi-stop), the type of vehicle that serves the tour, the number of stops, their sequence and duration, and the time of day when stops are made.

General model structure

An early structure for a truck tour-based model is displayed in Figure 3-4. This structure forms the basic tenets of current tour-based models.

Figure 3-4: Structure of truck tour-based model



The tour-based approach is still evolving, and much of the approach is tied to the general evolution in modelling to the microsimulation of trip and socio-demographic attributes. Accordingly, step-by-step guidance is scarce. Nonetheless, for the purposes of this guidance practitioners can note the following points from the structure. More details can be found in Appendix A.2.

- The approach begins with the generation of tours, as opposed to the generation of trips. This means that the need for a tour is the basic building block. The tour aims to replicate observed itineraries, a key premise of which is that the type of vehicle can be tied to the commodities and consignees (the stops) along the tour. For example, a supplier might deliver foods to series of restaurants every morning or on demand, which would require a refrigerated rigid CV. The characteristics of this tour indicate the time of day in which the tour must take place (i.e., prior to the restaurants' opening hours). The relatively small quantities of foods to be delivered at each stop describe the type of vehicle that can best serve the needs: rigid and refrigerated. Moreover, given the relatively small individual quantities, it is most cost-effective to serve the restaurants as part of a tour rather than a single out-and-back trip for each customer. This also means that the driver may require a rest break or refuelling stop along the way, rather than going back to the depot. At some stops, the driver might be asked to pick up certain goods (e.g., empty food containers for re-use) – i.e., the activity or purpose at each stop must be known. For practitioners, this means having available sufficient data that describe these tours: the nature of the commodities carried, the stop sequence, the actual routing, the industry at each stop, the activity performed at each stop, the type of vehicle used and the time of day.
- Once a list of the tours and the associated vehicle type is generated, each tour can be populated with the associated intermediate stops. The formulation models the sequence of stops within the tour. In some cases, this reflects a fixed itinerary (e.g., waste pick-up), but in many cases the itinerary will vary.

As a result, the choice of where to go for the next stop can depend on the stop's purpose (type of stop and the reason for the stop) as well as its proximity (location) relative to the current stop. Related to both purpose and proximity is the duration of the vehicle at the stop. For practitioners, this echoes the need to have appropriate data to support the development of the model.

- From Figure 3-4 it can be noted that the modelling of the tour sequence and its attributes can be conducted using micro-simulation techniques. For practitioners, this is akin to the micro-simulation of households in activity-based passenger travel models.
- Once the stop patterns have been generated, each leg can be transformed into a CV origin-destination, which serves as the basis for the CV matrix for trip assignment.

3.4 Data requirements for describing CV activity

Various types of input data requirements have been described in the preceding sections. This discussion focuses on data that describe the travel patterns of CVs in urban areas. These data serve as the basis for trip- and tour-based models and many of the inputs required for commodity-flow models, described in Section 3.3.2, are derived from these surveys. All of these data describe or lead to the quantitative description of CV trip origins, destinations, tours, stops, stop duration, stop activity, commodity carried, vehicle type and more. Four types of data are described below. (Allen et al. 2012, Piotrowski et al. 2015, Jacobs 2016). More information is available in Appendix A.3.

- Establishment survey: This survey provides characteristics about the establishment (public or private business) that generates commodities flows and commercial vehicle trips. These characteristics include the industry type, number of employees, general information about the types of commodities shipped and received, the modes used and, finally, the number of commercial vehicles that are at the establishment's disposal. As a result, the establishment survey also serves as the basis for sampling vehicles as part of the trip diary survey. Key guidelines for practitioners are:
  - Sampling for many establishment surveys in North America commonly uses three strata: the industry type (equivalent to the ANZICS subdivision level, thereby capturing all establishments, including those in the public sector), the number of employees (a proxy of freight-generating activity) and geographical location within the metropolitan region (in part to ensure adequate distribution of the sample across the metropolitan area and in part to ensure that CBD, urban and suburban activities can be captured). The distinctions between employee categories can be based on judgement: the object is to capture a broad range of activity. Similarly, some of the subdivision-level industry types can be aggregated, especially if their presence in the urban area is relatively small (e.g., agriculture and mining might not be present in large numbers in some urban areas). Judgement is required, and the experience of recent surveys in the United States offers insights.
  - The data captured in the establishment survey provides a reference point against which its commodity-generating activities can be determined. These data also can be used to support trip generation relationships. Of specific interest is the need to understand the type and level of CV activity that is being generated: in some cases, an establishment might rely heavily on rail to move freight, and so – even though it is a key freight generator – its CV trip generation could be very small.
  - The establishment survey also is used to determine whether an in-house CV fleet exists, as the basis for conducting a follow-on trip diary. In this way, the sampling can also be used to ensure that a representative range of vehicle types is surveyed (going back to the relationship between vehicle types and commodities carried for many types of tours). As a result, the ability to recruit establishments for the follow-on CV trip-diary survey is paramount and can influence the design and content of the establishment survey.

- Trip diary survey: This survey allows vehicle drivers to record the stops made on their tours: stop location, stop land use (activity), arrival and departure time or duration, activity (loading, unloading, etc.), type of commodity carried, and the fullness of the load. The vehicle is selected from the surveyed establishment's fleet. The sample can be categorised by vehicle type, establishment industry type, establishment size and location within the urban area. Trip diary surveys can be conducted over the course of a single day or over several consecutive days (typically up to one week). A key point for practitioners is the need to capture the full characteristics of the day's activity is fundamental to the development of trip- and tour-based models. This means that the survey form must be made as intuitive as possible for the vehicle's driver to complete, and for the survey administrator to be able to validate and, if necessary, impute missing data. New developments in the use of GPS loggers and apps show promise for ensuring accuracy and precision, although many drivers prefer the use of paper forms for convenience.
- Roadside interview (intercept) survey: In this survey a sample of vehicles is stopped along the side of the road and information is gathered regarding the vehicle's origin, destination, previous and next stop, activity, type of commodity carried and the fullness of the load. Vehicle characteristics (body type, etc.) can also be gathered. Whereas the trip diary survey captures several trips over one day (or more), the roadside interview captures only the characteristics of a single trip. The roadside interview is thus appropriate for long-haul transport on highways, or at accesses to a key freight generator such as a port, airport or intermodal terminal that serves as the origin or destination for all trips in question. Among the four types of data described here, the roadside interview has been in common use around the world for many years, although practitioners should note that its success in capturing all trips of interest means that the survey must be situated strategically on the road network so as to avoid 'leakage' or detouring around the site by CVs. Safety and privacy are also fundamental considerations. Practitioners should note that classified counts will be needed at each survey location, for use in expanding the sample, recognising that the sample will vary according to traffic conditions at different times of day.
- GPS survey: In this survey a GPS unit is mounted on the vehicle and records passively the route used, stop locations and times at every point along the route. This also can include a GPS used in combination with a logger or smartphone app, which allows drivers to enter additional information quickly and easily (e.g., choose among several pre-specified categories of commodity type). The growing use of commercial GPS CV tracing services by fleet managers means that 24/7 coverage of a given area can be made available. However, GPS fleet traces are still largely used by fleet owners for heavy vehicles that serve long-haul routes, meaning that independent operators (whose numbers are growing) and LCVs and some medium CVs that operate entirely in urban areas tend not to be well captured. In some urban areas in North America, authorities have used GPS fleet traces to develop 'starter' models, recognising that data gaps remain, and some model capabilities are missing as a result (i.e., capturing HCV activity). These can then be supplemented by establishment / trip diary surveys to capture LCV activity, augment trip generation and more.

At a minimum, to develop a trip-based model the following data are required:

- Vehicle type (typically characterising vehicles as LCV or HCV).
- Location where the vehicle is garaged (start and end of the trip) and characteristics of the owner (establishment) including the industry type, number of employees and the size and characteristics of its vehicle fleet.
- Locations of stops (trip origins and destinations).
- Arrival and departure times at the stops, which also give durations.
- Characteristics of the stops, typically land use.

Tour-based models require these data and also, for the purpose of generating tours, benefit from data on the commodity carried, the activity at each stop and the vehicle fulness after each stop. As described, however, in section 2.4, in the absence of surveys some overseas models have relied on GPS traces to develop 'first generation' tour-based models whose capabilities will be augmented with follow-on establishment and trip diary surveys.

3.5 Choosing the right type of model

3.5.1 Decision process and factors for model selection

There are many factors that must be considered when deciding on the most appropriate form of a CV model for an urban area. These include:

- Purpose of the model
- City size (i.e., population as a proxy for economic activity)
- Availability of data
- Financial resources to collect data and build the model
- Timeframe, and
- The availability of skilled resources needed to build and operate the model.

Table 3-1 shows a decision process for the selection of the most appropriate form of CV model according to city size – respectively, up to 100,000 population, 100,000 to 1 million and greater than 1,000,000.

Table 3-1: Structured decision process for selecting most appropriate model form

City Size (Population)	Case 1: New Infrastructure Investment Need Assessment	Case 2: Project Appraisal (Benefit Enumeration)	Case 3: Advanced Uses (Policy Assessment)
Less than 100k	• Trip-based sufficient	• Trip-based sufficient	• Trip-based sufficient
100k to 1m	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended
Greater than 1m (No Special Generators (SG) such as Ports)	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended
Greater than 1m (With Special Generators (SG) such as Ports)	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended	• Trip-based sufficient • Commodity flow model preferred • Tour-based recommended	• Trip-based sufficient • Commodity flow or tour-based preferred • Commodity flow or tour-based with SG add-on recommended

Note that the FHWA (USA) provides some guidance for smaller cities through their Quick Response Freight Methods guidelines (Beagan 2019). Freight trip generation rates and trip distribution coefficients can be found here that can be used by agencies that have no access to freight generation data.

For each city size, the first decision point is the purpose of the model: assessing the need for new infrastructure, developing business cases for new infrastructure or policy development. Each of these decisions then asks whether or not a trip-based model (or a commodity flow model that provides the necessary outputs) already exists. If so, and if the model is satisfactory (in particular, if it is based on current data), then it should be retained. If a trip-based model does not exist, then the development of a trip-based model should be considered. Depending on city size and on the availability of funds to collect new data, then a tour-based model could be considered. It is worth noting that transport organisations typically need capability in all three areas. So, it may be more cost-effective in the long-run to develop models that can address advanced uses.

A trip-based approach is the most common model in practice and will be appropriate for smaller urban areas or cities that have constrained budgets for commercial vehicle data collection.

A tour-based approach will be the preferred approach for larger cities, especially as these cities develop tour-based passenger models. Many overseas cities (especially in North America) are now using tour-based CV models or are considering adopting the tour-based approach. As noted, this approach links the individual trips made by a CV into a chain of trips starting and ending at the vehicle’s depot, thereby providing a more complete profile of the vehicle’s daily activity.

The commodity flow approach is perhaps the most complex and difficult type of CV model to build and calibrate. It requires detailed data of commodity movements and is recommended only for the most complex freight movement tasks.

Another possible approach is the layered approach where a tour-based or commodity-flow model is paired with a special generator model add-on for special freight generators (such as ports, airports, etc).

Overall:

- In small cities (less than 100k population), trip-based models are considered sufficient mainly because of the expense required to collect adequate data to build a tour-based or (intra-urban) commodity flow model
- Cost and data availability are very important considerations that may dictate the type of commercial vehicle model to be built. If the data required to build a tour-based model are available, then a tour-based model is recommended rather than a trip-based model.
- In very large cities, where theoretically there are more resources available for better data collection and more complex urban freight systems, (intra-urban) commodity flow models can be considered.

Nonetheless, modellers should still keep in mind that unique circumstances and judgement may ultimately determine the choice of model, and even the evolution from one type of model to another. In support of this need, Table 3-2 compares the three modelling approaches, providing a summary assessment of their relative strengths and limitations, the underlying data requirements and sample applications.

Table 3-2: Comparison of modelling approaches by characteristics

Model Type	Strengths	Limitations	Data	Sample Applications
Commodity Flow	• Direct link to broader regional / national economy, so changes in economic structure can be seen in the urban area • Includes multi-modal supply chain flows, so changes in the modes can be seen in the urban area	• Must translate commodity flows to vehicles, meaning that the specific relationship between a vehicle trip and what is carrying are aggregated • Urban area geographies are typically very large and must be disaggregated for use in an urban model	• Establishment survey • CV trip diary • GPS and other economic activity indicators	• Impact of long-combination vehicles on urban network
Trip-based	• Simplest formulation of the three – relatively easier to implement and can use available TAZ data • Focus is on urban vehicle trips	• Treats the legs of a tour as independent trips • Focus on urban activity can over-simplify the link with the broader economic context	• Establishment survey • CV trip diary • Roadside trip diary • GPS traces • Traffic counts • TAZ land use variables	• Project benefits estimation • Identification of capacity needs
Tour-based	• Focus is on urban vehicle trips • Most accurate and realistic depiction of urban freight movement by all types of vehicles and the underlying choices, yielding greater sensitivity to policy and operational considerations • Enables agent-based modelling to better capture individual choices that impact the tour	• Focus on urban activity can over-simplify the link with the broader economic context, although new formulation attempt to link the two • Can require more data and specificity than other model types	• Establishment survey • CV trip diary • Roadside trip diary • GPS traces • Traffic counts • TAZ land use variables	• Impact assessment of CV operational policy (e.g. modelling of off-hours delivery)

3.5.2 Fitting the application to the need

Modellers also must consider whether the particular model fits the intended purpose. In aid of this, key points that help the modeller determine the suitability of the application to fit the specific needs are described below:

- Generally speaking, trip-based models are suitable for benefits estimation for project and plan evaluation but less so for policy evaluation (such as operating policies). Compared with commodity flow models, trip-based formulations can offer a more accurate depiction of vehicle trips for follow-on operational modelling, but tour-based models are considered superior to trip-based models because they offer a more precise depiction of the sequence of trips that comprise the tour, the routing used, the time-of-day travelled and so on.

- Commodity-flow models might be considered as top-down models in the sense that they estimate commodity flow *first* from which vehicle-trips must then be estimated. The basis of these models in economic activity and in multi-modal supply chains ties them directly to the dynamics of a region's (or the nation's) economy – e.g. a shift in a region's economic structure from manufacturing to services. The impacts of these fluctuations can be seen directly in the urban area's freight activity, even if a change occurs at some distance from urban area (e.g. a new rail line linking an inland urban area to a port can shift imports from another port because the overall transport costs of serving the inland urban area are now cheaper). In other words, urban freight activity is modelled within the broader economic context. On the other hand, purely localised activity – such as local shipments generated by a small business – are less easily depicted because, individually, their activity is small (even though collectively the activity of small urban businesses can be significant). As a result, commodity-flow models tend to lack the detail associated with purely urban movements made by light vehicles, all of which comprises a significant portion of urban freight activity.

- In contrast, trip- and tour-based models estimate vehicle-trips *first* from which commodities can then be estimated if needed. The source data, comprising establishment surveys, vehicle origin-destination surveys and GPS vehicle traces, are all aimed at depicting the actual movement of vehicles of all types (including light vehicles) and the relationship of these movements to local urban activities and conditions. That makes them more attune to the specific needs of transport planning and operations for urban areas. As a result, they are more sensitive to changes in the local urban transport network, congestion levels, traffic operations, land use activities, site access, parking and other characteristics that are specific to an urban area. With this focus, however, the relationship of urban freight activity with the broader context of the multi-modal, large area supply chain is less well characterised, meaning that remote changes in the supply chain might appear in the urban model only, for example, as changes in urban vehicle trip volumes to and from external gateways such as highways and intermodal rail terminals and thereby miss the impacts of these changes on the activities of the many individual establishments that make up an urban area. In other words, the transport planning and traffic operational precision is improved but there can be less cohesion with the broader supply chain and economic context. It can be noted, however, that recent developments in supply chain (logistics) models aim to better integrate these two perspectives. These are described in Appendix A.4.

- It should be noted that special generators may warrant attention. In urban freight models the most common special generators are intermodal terminals such as rail yards, airports and marine ports where goods are exchanged between commercial vehicles and other modes. Special generators can also be industrial complexes that generate significant volumes of CV trips or whose CV activity is unique – e.g. a large assembly plant that forms the centre of a cluster of complementary industries, or an agricultural producer whose activity varies significantly by season. In some cases, the typical TAZ attributes (such as employment) might not capture the freight activity and would warrant a special treatment – e.g. the CV traffic to and from a marine port can be quite large in volume and is driven by tonnage or containers moved rather than by the number of employees at the port, whereas the use of employment as the underlying variable might work well for nearby industrial TAZs that are served by the port.

3.5.3 Limitations

The preceding sections have described the factors that are used to determine the type of urban freight models that should be deployed in particular situations. The purpose of the preceding discussion is to provide a systematic means of assessing these choices. However, as can be seen from the overseas practices described in section 3.5, the choice of model formulations does not always follow a clear path, and can depend on how users balance their needs, capabilities, resources and time requirements against the desire for precision and accuracy (in effect, model purpose and desired outcomes). As an example, the FRETURB approach of applying the same parameters to cities of varying sizes within a common framework simplifies the modelling approach but relies on the inherent assumption that any differences do not matter (Toilier 2018) - whereas approaches in North America may posit that the differences can be critical.

3.6 Model Calibration and Validation Criteria

Table 3-3 shows criteria for freight model calibration acceptance and validation that should be considered by the modeller. The criteria apply to all three model types, except where noted. Note that some of the criteria reflect 'desirable' situations, meaning that judgement also must be applied.

Table 3-3: Recommended calibration and validation criteria for urban freight modelling

Survey Type	Definition
Calibration	• Any linear regression component of a freight model (e.g. a trip generation equation or a formulation that estimates commodity flows from economic inputs) should desirably be able to demonstrate an r^2 value comparator greater than 0.85; and • Any logit model (e.g. applied as part of a mode share formulation in a commodity flow model or as part of a tour decision chain in a tour-based model; logit formulations are not common in trip-based models) should desirably be able to demonstrate a pseudo-r^2 greater than 0.45 (Hensher et al., 2005).
Validation	• Screenline sum comparisons against observed flows should have a r^2 greater than 0.85 and individual freight flows on primary distributor roads (Highways and Freeways, including ramps) should have a GEH < 5 for 85% of count locations. This applies to the assignment of matrices developed in commodity flow models, trip-based models and tour-based models; and • Assigned link volumes in and out of special freight generators (e.g. Ports and Airports) specific to the freight movement should meet the GEH < 5 criteria in all instances. This applies to the assignment of matrices developed in commodity flow models, trip-based models and tour-based models.

Source: Wonnacott and Wonnacott (1990), Hensher et al. (2005), UK Highways Agency (1987).

One consideration will need to be whether these comparisons are done with the aggregation of all of the classes of commercial vehicle, or by individual class. Applications that involve a detailed understanding of individual CV classes, such as road pricing studies or road user cost allocation studies, may require the detailed breakdown. However, this need depends on the rigour to which the results will be used – e.g. infrastructure financing decisions may require the detailed scrutiny whereas aggregated results might suffice for a sketch planning exercise.

3.7 Light Commercial Vehicle Models

As mentioned in Table 2-3, LCVs arguably represent the 'weakest link' in our urban passenger forecasting models for several reasons.

While HCVs are generally fairly well-defined within most Australian CV models, there is much less information readily available about LCV movements. In fact, information regarding LCVs is often non-existent and for this reason, LCV models are often placed in the 'too hard' basket.

The huge growth in LCV trips – e.g., as generated by the rapid growth in e-commerce deliveries and the transition of many urban carriers to using smaller vehicles for urban itineraries - and their impact on the transport network means that we can no longer afford to ignore LCVs nor make overly simplified assumptions about their trip characteristics.

3.7.1 Defining LCVs

There is a 'grey area' regarding the definition of an LCV.

LCVs include vehicles from classes 1 and 2 from the Austroads classification system (see Appendix E) and are generally garaged at a depot or place of work overnight. This contrasts with company cars or which begin and end the day at a household. These vehicles are not considered LCVs and it is assumed that the trips made by these types of vehicles are picked up in household travel survey (HTS) data.

Data on the movement of LCVs can only be obtained through an establishment survey (see Table 4-1) or potentially by obtaining GPS data (if one is able to differentiate between LCVs and private vehicles). There is a concern that LCV movements may be double-counted both from non-home based (NHB) trips in the passenger model (based on information collected in the HTS) and by the light commercial vehicle models that exist within most of these models. Very little information is available that can be used to distinguish passenger and commercial uses of light vehicles.

4. Emerging approaches and future directions

4.1 Supply chain (logistics) models

Urban freight movement takes place within the broader context of supply chain logistics. The supply chain from the original source of raw inputs to the consumer of finished products can be confined entirely within the same urban area, or it can extend around the world. For self-contained urban supply chains, the modelling is straightforward in the sense that the flows are largely unimodal (road-based) and can be captured with the established urban freight modelling frameworks. However, in a modern economy, a full range of commodities is imported to and exported from large and small urban areas. The supply chain can use different modes to move goods up and down the chain depending on the type, size/quantity and frequency of the commodity being moved, the value of the commodity, origin, destination, modal/vehicle availability, speed and reliability, intermodal capacity, the costs of shipment and trans-shipment, and security among other factors.

As a result, the impacts of long-haul flows to, from and through an urban area must be captured and linked to the urban freight model. These flows can involve the movement of goods into and out of the urban area via intermodal terminals (airports, marine ports and rail terminals), which are then distributed to or collected from multiple sources within the urban area by commercial vehicle. Some long-haul flows can be moved entirely by commercial vehicle, moving between an external location and one or more locations within the urban area.

Intra-urban freight movements are also included in supply chain (logistics) models. However, supply chain (logistics) models allow for better modelling of freight movements that move outside of the urban area (intra-state and inter-state). International freight movements can also be captured through freight movements with origins or destinations at special generators such as ports and airports. (Shabani et al. 2018).

For more discussion on Supply Chain (logistics) models, see Appendix A.4.

4.2 Emerging model types

As with other forms of models, advancements in the formulation of urban freight models continue. Two key advancements in urban freight modelling are described in this section. Although they are in various stages of development and are not necessarily ready for widespread practical deployment, they potentially have broad implications for the understanding of urban freight movement and the underlying behavioural patterns and choices.

4.2.1 Agent-based freight modelling

Agent-based formulations provide the ability to model the behaviour and choices of the wide variety of actors in urban freight – shippers, carriers, intermediaries, consumers and third-party logistics firms - who have conflicting goals and different understandings of the supply chain and the choices they can make. Individual agents aim to maximise their own performance (e.g., to gain an economic benefit) in reaction to choices made by other agents. The approach enables a more complete and sensitive depiction of the choices that determine what is being moved, between whom and how. In particular, the choices are more sensitive to price signals in transport costs, commodity costs and so on. However, the approach is not yet fully developed. Most applications to date are for research applications and cover small areas and a limited number of agents (although the Chicago example cited below is an exception). (Nuzzolo et al. 2014)

Most research in behavioural freight modelling has focused on firms' mode choice decisions. Some other decisions are modelled, although not explicitly, including those concerning (defining) production, consumption and trade. More recent research has looked at other choices such as supplier choice, outsourcing, the use of distribution centres, shipment size choice, vehicle type choice and routing of flows. The aim is to use agent-based formulations to better model how decisions made by individual firms on these and other factors impact production and consumption, hence freight flows. (Tavasszy 2020)

For more discussion on Agent-based models, see Appendix A.5.

4.2.2 Changing purchasing and delivery practices

Profound changes in the supply chain are taking place. These changes arise from the rapid expansion in computing and communications capabilities over the past two decades that have greatly extended connectivity across all links in the supply chain, from the source of raw materials, manufacturers, brokers and transporters of all modes through distributors, retailers and the end purchaser. These changes – which collectively can be characterized as the digitalisation of the supply chain – have enabled e-commerce purchasing, advanced manufacturing processes such as 3D printing (additive manufacturing) and connected and autonomous vehicles, among a wide range of advancements. (Forger et al. 2019, Kriger 2019)

The impact of e-commerce on urban freight has become particularly apparent in recent years, as online shopping, home deliveries and instant deliveries have generated significant growth in urban delivery volumes, especially by light commercial vehicles and especially in residential areas where freight traffic traditionally has been minimal. More generally, shopping (i.e., trips for making purchase that result in the transfer of freight to the end-consumer), is not typically taken into account in urban freight models even though, by some estimates, this accounts for between 45 and 55% of total freight-related traffic. Consumer purchasing choices (where, when and what) are also related to the availability of products, and consumer demand in turn drives the need for stocks to be replenished. However, urban freight modelling has focused on the retail store as the final destination in the supply chain, as opposed to individual households or businesses whose purchases may bypass the bricks-and-mortar store altogether. (Comi et al. 2014)

An integrated freight modelling approach recognises three types of decisions that must be considered:

- Purchasing / shopping, which refers to travel decisions made by the consumer (households and businesses) regarding whether to shop in person or online, where to shop and how to receive the purchase (e.g., delivery or self-pick-up).
- Restocking, in which transport and logistics firms and retailers bring freight to shops, to ensure that consumer demands can be met.
- E-delivering, in which transport and logistics operators decide how and when to make deliveries.

The approach has developed a prototype model that generates purchases on the basis of consumer choices, including whether to make the purchase in person or online, the type of commodity to be purchased, purchaser demographic characteristics, vehicle availability, proximity to the store and so on. (Comi 2020)

Finally, the dynamics of private sector business and logistics decisions in reaction to business cycles and other factors, as well as the reaction of and adoption by supply chain participants to new freight policies and infrastructure, are also cited as an emerging research need for urban freight models. (Tavasszy 2020)

4.3 Steps to maintain and improve urban freight modelling in Australia

These guidelines have described the different algorithmic formulations of urban freight models from current and emerging practice. As noted previously, modellers may wish to use different combinations of the formulations. The three figures below show how the different formulations could fit together. Each figure shows the urban freight model in orange and the long-haul (commodity flow) model in blue. The urban freight model represents intra-urban; that is, internal-internal (I-I) trips. The commodity flow model develops intra-state, inter-state and international flows, from which vehicle trips that start and/or end external (E) to the urban area are derived: from the urban area (I-E), to the urban area (E-I) and through the urban area (E-E). Combined, all these flows impact the urban road network, as depicted by the trip assignment component (green).

Figure 4-1 shows the most common formulations in Australia today – namely, the trip-based urban freight model in combination with the commodity flow model. In many international formulations, the commercial vehicle (I-I) model is derived separately from the available commodity flow models. This is a function of several factors, including multiple jurisdictions and the differing applications of the two models. In this case, the commodity flow model provides only the externally based trips for insertion into the urban trip matrix, and the I-I trips are developed entirely by the trip-based model. (The new Toronto model, described in Appendix D, illustrates this approach.)

However, in the Australian context, the commercial vehicle (I-I) model can be informed directly by the commodity flow model (i.e., the Freight Movement Model, which also includes internal-internal flows). In this case, the I-I commodity flows are extracted from the FMM and then factored into vehicle trips using vehicle loading factors for trip assignment. This linkage is illustrated conceptually between the blue and orange boxes in the figure. While this approach ensures consistency with the broader (external) commodity flows, the trip-based model allows greater specificity on the urban (I-I) CV trip patterns, operations and so on.

Figure 4-2 shows how the urban formulation could be transformed to a tour-based model, and how the commodity flow model now becomes the input to a supply chain model. Finally, Figure 4-3 adds agent-based formulations to both modelling streams as well as extending the urban freight model by accounting for changing logistics practices (which, given their newness, are shown in a dashed line as mainly research endeavours). Again, as noted, different formulations could be combined – for example, a tour-based urban freight model combined with a commodity flow model (but without the supply chain formulation). Finally, practitioners may want to note that the pacing of this evolution is often linked to the parallel development of the urban area's passenger models.

Figure 4-1. Trip-based urban freight model / commodity flow model (conceptualisation)

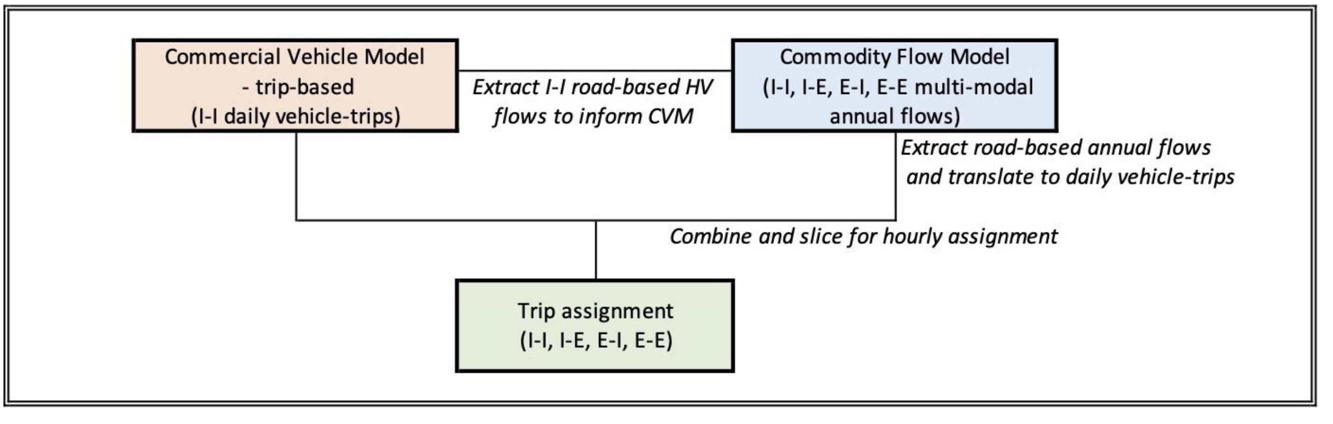


Figure 4-2. Tour-based urban freight model / supply chain model (conceptualisation)

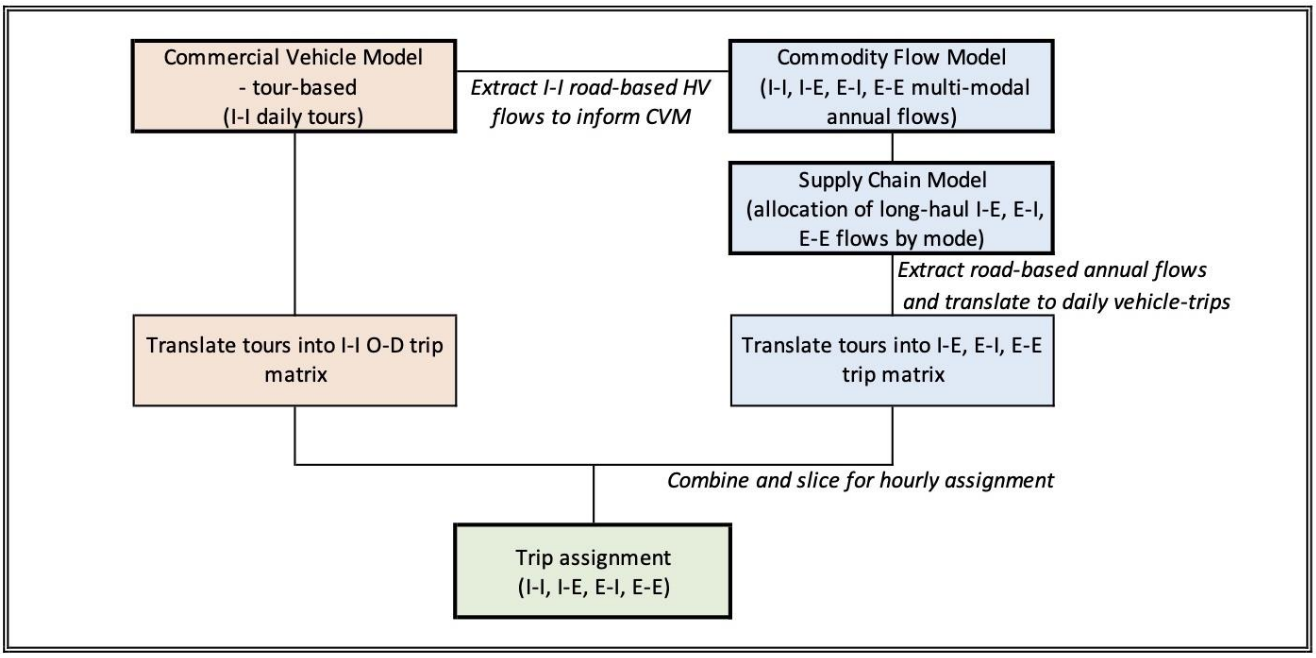
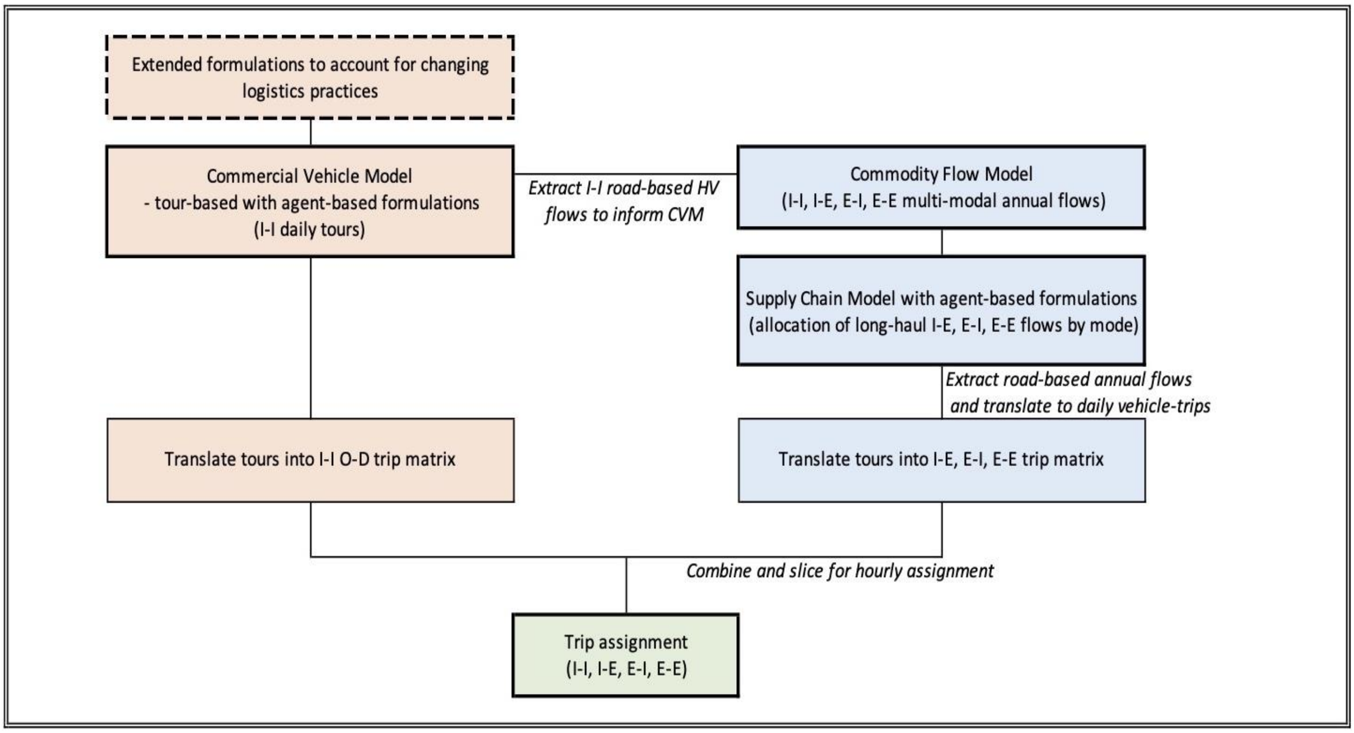


Figure 4-3. Tour-based urban freight model with extensions for changing practices / supply chain model, both with agent-based formulations (conceptualisation)



Appendix A Model type detail

A.1 Trip based models

Urban freight modelling has its basis in the approaches used to model urban passenger trips. As a result, the four-step trip-based paradigm that came into wide use in the 1960s and later was also applied to modelling urban freight (i.e. the modelling of commercial vehicles). The four-step paradigm is a sequential model, in which trip generation, trip distribution, mode choice and trip assignment are considered mainly as distinct sequential choices (Comi et al. 2014, D'Este 2008, Stephens et al. 1993):

- The production of goods by a firm, the consumption of these goods by a householder, and the exchange between the two are represented indirectly through trip generation and distribution models that are typically based on zonal demographic parameters such as employment and population and distribution models that are based mainly on auto impedances. Trip generation and distribution result in an origin-destination matrix, showing the number of fright trips between each origin-destination zone pair, for a given time period. Matrices are typically generated for a number of periods: peak hours, off-peak hours and 24 hours.
- Some trip generation and distribution models are developed by vehicle class (i.e. light, medium and heavy commercial vehicles). Some models estimate total commercial vehicle demand without distinction by class, and then use classification counts to factor the resultant matrix by vehicle class so as to enable the application of PCU or other factors before assignment.
- Mode choice is not typically used in the urban trip-based freight formulation, recognising that urban freight is moved predominantly by road-based transport.
- The last step is trip assignment of the road freight trip matrices to a given road network. They may be assigned with personal vehicle origin-destination matrices in a multi-class assignment, or following personal trip assignment.

Some general observations can be made:

- For earlier models, vehicle origin-destination surveys commonly served as the basis for estimating the models. The data were sourced from trip diaries maintained by a sample of vehicles (as derived from vehicle registry records) or from roadside surveys. This allowed for sample selection according to vehicle class and for calibration of the resultant models according to screenline classification counts. However, survey response rates were commonly quite low (less than 1%). To maximise the utility of the available data and recognising that much commercial vehicle activity occurs outside the commuter peak periods, some trip generation and distribution models were developed for the 24-hour period, from which hourly slices were derived for trip assignment.
- Other models used observed trip generation rates to develop hourly totals directly from site-specific trip generation studies, from which trip distribution models were developed. This had the advantage of accounting explicitly for variations in hourly distribution although the site-specific trip generation rates were not necessarily indicative of local conditions nor did they account for trip origin-destination. The US Federal Highway Administration's Quick Response Freight Methods (now in its third edition) is one source of commonly used factors, simplified approaches and transferable parameters that can be applied in the absence of local data.

- The peak hour selected commonly correspond to the peak commuter travel times. However, many transport companies avoid making trips during the commuter peaks, if possible, in order to minimise time spent in congestion, which impacts delivery schedules and increases costs. In other words, in practice the common application is to model peak network loadings, which do not necessarily correspond to the peak times of travel for commercial vehicles. For most applications, which aim to replicate peak network conditions, this should not be problematic. However, for access roads to key freight generators and intermodal terminals and ports, the overall peak conditions on the access might actually occur during the peak CV loading which might occur outside the commuter peak periods.
- The assignment routings necessarily follow those of passenger vehicles, which are dominant. Paths must also account for links from which commercial vehicles are prohibited (i.e., links on which passenger vehicles are permitted but not CVs). For most transport planning applications, which seek to understand network performance across the entire network, this likely is sufficient. However, these are not necessarily the paths taken by a commercial vehicle whose itineraries might depend on having to serve a customer within a specific delivery window at minimal cost to the carrier. In practice, CVs and passenger vehicles tend to be assigned together as part of a multi-class assignment although it is possible to assign the two classes sequentially, with the CV trip assignment iterations starting with congested travel times generated by the passenger vehicles. However, this means that the passenger vehicle trip assignment does not account for the extra CV volume: For most transport planning applications, it suffices to combine the two classes together. However, the analyst might wish to test the impacts of a sequential assignment in cases where the specifics of the CV assignment are important.
- Many trip generation and distribution models estimate vehicle trips directly, which avoids the need to translate commodity or tonnages into actual vehicle-trips hence provides a more precise base for operational modelling. However, some earlier formulations of stand-alone urban trip-based models estimated commodity flows (tonnage) that must be converted into vehicle trips before assignment. Conversion factors, estimated from observations, can vary by type of commodity, which in turn allows a distinction by vehicle type (i.e., the vehicle type is matched to the commodity that is carried). Nonetheless, the inherent imprecision of converting commodity flows to deliveries and then trips was an important motivation for the development of trip generation models that estimate vehicle trips directly.

Variations to the trip-based formulation include:

- Special generator add-on models – for example, a model in San Francisco, USA that accounts for commercial vehicle traffic moving to and from the region's ports.
- Synthetic matrix estimation used in lieu of trip generation and distribution. This approach uses ground counts to estimate a vehicle origin-destination matrix, thereby circumventing data gaps and out of date information. Because the matrix is used as the basis for forecasting using growth factor methods, the underlying assumption is that distributions will remain the same, modified only by proportional changes in zonal activity (e.g., projected growth in jobs). To account for forecasted new development in currently vacant zones, where no trips are recorded today, the matrix must be seeded. One recent formulation differentiates trip tables by retail markets served and for home deliveries. A second formulation differentiates trips by commodities carried, of which empty vehicles was modelled as distinct commodity. Other models account for multiple vehicle classes and incorporate techniques to dampen the impact on the seeding from small changes in the traffic count inputs.
- Entropy-maximisation models have been used to improve the modelling of trip productions and attractions, while also allowing for the modelling of commercial vehicle tours (described in section 3.4). These formulations used establishment – vehicle trip diary surveys as the basis, which provide detailed depictions of what the establishment produces, vehicle itineraries, land uses at each stop and so on. An early research effort used surveys from Denver, USA to develop a tour flow distribution model (i.e., modelling the vehicular movements along multiple chains of stops) from which a tour choice model (i.e., the set of tours that would best serve these stops). (Wang et al. 2009)

A.2 Tour based models

Tour-based urban freight models represent a key methodological improvement over the trip-based formulation (Transportation Research Board 2007). Their application has driven much of the advancement in the state of the practice. As noted above, these and other developments parallel similar approaches in urban passenger models but are expressed in significantly different ways in the freight formulation. The tour-based model formulation is considered to be the freight equivalent of the activity-based passenger model.

Researchers have long recognised that commercial vehicles tend to make long tours composed of multiple trips (legs), and that the sequence of trips is a function of logistics decisions made by the actors involved. The actors can include drivers, dispatchers, shippers, receivers and government. The logistics decisions include route choice in the face of congestion, required delivery or pick-up time at a stop, and the type of vehicle that is best suited for the commodity being carried, among others. This contrasts with the trip-based modelling assumption that each trip is independent and that trips between an origin and destination are related only to the zonal attributes and the travel impedance between the origin and destination. (Wang et al. 2009)

Many trip-based models rely on aggregate data, in which link and route flows are calculated as the sum of individual trips. However, researchers have noted that this aggregate-level depiction does not capture the logistics decisions made within the tour. In other words, the aforementioned nuances of individual logistics decisions that impact routing or stop sequencing choices along the itinerary are not captured. The approach also provides a more refined ability to model the characteristics of tours that are made by different vehicle types and to serve individual industries. (Moore 2017)

The tour-based approach replicates the itinerary, or sequence of stops, made by a commercial vehicle in its daily rounds. As shown in Figure 3-3, typically the tour begins and ends at the vehicle's garage or depot (i.e. the location where the vehicle is normally based) (You et al. 2019). A tour consists of multiple trips, each of which corresponds to the movement of the vehicle from one stop to the next. A commercial vehicle can have more than one tour in a day.

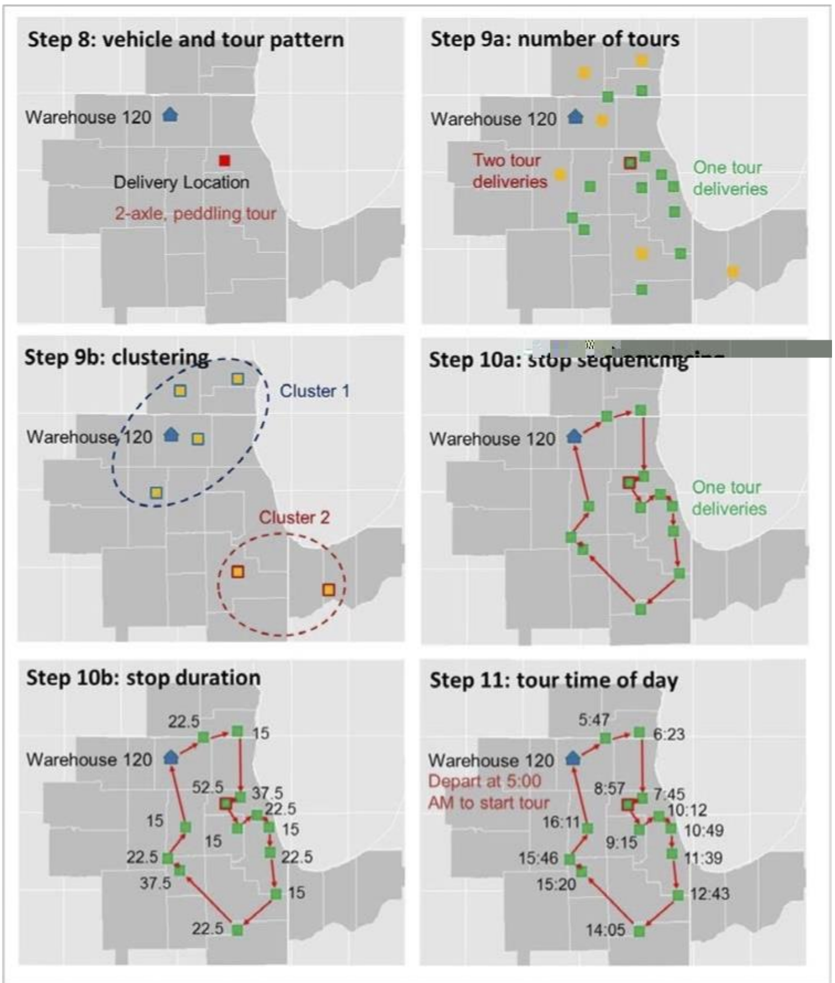
Although some trip-based model formulations do capture tours – for example, the entropy-maximisation example described in the previous section – the impedances are based on the tour as a whole. As a result, the sequential characteristics that define the tour are lost, although they can be added in a trip-based formulation. The time spent at the stop also must be considered because it is integral to the path. However, this is not considered in a trip-based analysis and must be added. (Shabani et al. 2018)

The development of disaggregate modelling approaches addresses these limitations. This allows the tour-based formulation to forecast pick-ups and deliveries through four modelling components:

- Vehicle and tour pattern choice. This model predicts the joint choice of whether a shipment is delivered on a direct (i.e., out-and-back) tour or a multi-stop tour and the size of the vehicle that makes the delivery.
- Number of tours and stops. This model predicts the number of multi-stop tours required to complete all deliveries and estimates the number of shipments the same vehicle can deliver.
- Stop sequence and duration. This model sequences the stops in a reasonably efficient sequence, although this does not necessarily represent the shortest path. The model predicts the amount of time taken at each stop, based on the size and commodity of the shipment.
- Delivery time of day. This model predicts the departure time of the vehicle at the beginning of the tour and for each subsequent trip on the tour.

Figure 4-4 presents a conceptual visualisation of the four modelling components. The visualisation shows how an individual delivery location (the red box) is eventually included in a tour. Note that Step 9b considers the clustering of stops, as part of the second component (number of tour and stops).

Figure 4-4: Steps in developing the tour



Note: The steps in the figure start at 8, being part of a broader discussion in the source document. Readers should interpret step 8 in the figure as being the first step for our purposes here.

Source: Smith (2018).

In other words, the formulation estimates the demand for tours and the itinerary by predicting the type of goods that must be moved, the size of the shipments, the time required at a stop to pick up or drop off the shipments, the types of vehicles that can carry these goods, and when the stops are made. The tours are modelled from observed data, such as establishment and vehicle origin-destination surveys and GPS vehicle traces. The outputs of a commercial vehicle tour model are converted to vehicle trip matrices, with intermediate stops treated as origins and destinations. The matrices can then be included with matrices of passenger vehicles in a multi-class assignment.

A formulation first applied in Calgary, Canada allows an increased ability to simulate the potential impacts of changes in demand, policies and infrastructure on tour choices, as opposed to replicating existing tours. Nested logit models are applied for each tour and are based on stop land use rather than economic activity. This means that tours do not have to be defined or optimised a priori. Instead, the formulation simulates a decision at each stop as to whether to continue to another stop or return to the home base. The probability is calculated as a function of the vehicle's current location, the distance from its origin and the location of the next stop (from a list of all available stops) among other factors. Potential stops that move the vehicle significantly away from its current location are rejected in favour of those that move it back towards the origin. (Hunt et al. 2007)

A.3 Data describing CV characteristics

Commercial vehicle surveys have been conducted for several decades in Australia and around the world. However, compared with passenger origin-destination surveys, the state of the practice is much less well established. One reason for this is that transport plans around the world have tended to focus on moving people, with less consideration on moving goods. However, an increased recognition of the linkage between efficient transport and economic well-being has generated renewed interest in understanding goods movement, and also in understanding the contribution of commercial vehicles on urban congestion (and vice versa).

Commercial vehicle surveys are difficult and expensive and for these reasons, they are not done very often. CV data are also considered commercially sensitive by many private sector operators which can make the data more difficult to collect.

Typical limitations of CV surveys include:

- Widely varying sample population and activities, whether defined by vehicles or businesses, or the commodities they are moving
- Fragmented sample population, with the majority of 'actors' being engaged in private sector, for-profit activities. As a result, these actors are often reluctant to share information that they may deem as proprietary for use in a transport planning application whose benefits might not be clear to them
- Difficulties in finding sampling frames that provide complete and up-to-date coverage
- Limited sample size
- Confidentiality concerns of companies of sharing GPS data
- Uneven sampling rates amongst different vehicle types and industries, and
- Lack of cooperation from drivers which results in a disappointing response rate.

Table 4-1 lists the four types of surveys of specific relevance to urban freight model development, and their strengths and weaknesses:

Some of the surveys are combined – notably, trip diary surveys are conducted as the next step of an establishment survey, GPS surveys have been used in conjunction with trip diary surveys, and roadside interview surveys at external cordons complement the trip diary or GPS surveys that depict urban trips. The combination of surveys addresses some of the key weaknesses identified for each type, while complementing their strengths. These strengths and weaknesses are summarised in Table 4-1.

Table 4-1: Summary of key strengths and weaknesses by survey type

Survey type	Key strengths (+), weaknesses (-) and neutral points (±)
Establishment survey. Used to collect data about total goods vehicle trips to/from surveyed establishments, and variation by time, day and month. Can also be used to capture data about type of goods delivered/collected. Also allows collection of information about the delivery/collection process but some respondents may not be very sure about certain issues including vehicle types, time taken to load/unload, where vehicles stop, method of goods movement from the vehicle, and origin of vehicle/goods trips.	+ Can provide both goods flow and vehicle activity data + Links goods flow and vehicle activity to business sector / land use / supply chain - Respondents often not very knowledgeable about goods vehicle type, loading / unloading locations and times - Relies on knowledge and recall of respondents - Response rates can be adversely affected if survey takes too long to complete - Does not provide insight into vehicle rounds - Surveying relatively expensive on a per establishment basis
Trip diary survey. Used to collect detailed information about the activities of a single vehicle throughout the course of its tour(s) over a single day or a few days. Involves driver or operator recording trip and activity data. Can provide data about exact locations served, route, arrival and departure times, time taken for delivery / collection / servicing, type of goods/service carried, fulness of the vehicle, activity at each stop and stop land use.	+ Can provide detailed information about vehicle trips and rounds - Driver may not be aware of the products carried especially if boxed or containerised - Can place a lot of work on the respondent and affect driver productivity, resulting in low response rates unless made compulsory ± Surveyor can travel in-vehicle with the driver to record trip data to reduce the survey work for the driver, but some companies are not keen on permitting this and can result in very high survey costs
Roadside interview survey. Normally involves working with the police or suitable law enforcement agency to pull over vehicles and interview drivers at the roadside about their current trip. Typically used to capture data about origin/destination, trip purpose, goods carried, and vehicle type. Usually a relatively brief survey so as not to disrupt drivers and avoid causing unnecessary traffic congestion.	+ Produces goods vehicle trip matrices for traffic modelling purposes - The practicalities and legalities of stopping goods vehicles on route can make this difficult to organise - Survey costs tend to be high - Given limited time available for interviews, drivers are usually only asked about previous and next stopping points rather than the entire round - Driver may not be aware of products carried especially if boxed or containerised and may not know about the type of land use served - Tend to take place on major roads only, so contains a bias against vehicles using minor roads
GPS survey. Many CV fleets subscribe to GPS tracing services, which monitor vehicle location at frequent intervals (thereby providing routing information), as well as vehicle travel times and speed. The spatial and temporal ubiquity of GPS traces means that large volumes of data can be available. The GPS traces also be used to record stops for loading / unloading / parking. Therefore, similar to vehicle trip diaries, with the key difference being that GPS traces cannot capture the vehicle content, its fullness, the activity at the stop or the stop's land use.	+ Can provide information about vehicle trips and itineraries without placing additional work on the driver or company—can give a detailed insight into speeds and travel times on different roads and routes + Can provide detailed routing information - Automatically captured data do not usually provide the same level of detail possible through vehicle trip diaries about type of goods, reason for stopping, quantity delivered and so on unless the driver manually inputs data ± Can be cheaper to analyse than data collected by a vehicle trip diary (as manual data input not required) but obtaining permission to access data (and potential purchase costs) can be problematic and prohibitive

Source: Allen et al. (2012)

A.4 Supply chain (logistics) models

Recent advances have improved the behavioural representation of supply chain models. Common components of advanced supply chain models now include firm synthesis (from which estimates of commodities produced and consumed by business establishments are derived), buyer-supplier matching (i.e., defining origins and destinations for allocating commodity flows), shipment size (units of commodities that must be moved), distribution channels (choosing among options for transporting commodities), vehicle choice and vehicle touring models.

Figure 4-5 illustrates the behavioural supply chain modelling process schematically. The process starts by understanding what business establishments (firms) produce and consume, taking into account input-output tables and other factors. It then estimates commodity flows, matching consumers and producers (buyers and sellers) as the basis for distributing (allocating) flows among origins and final destinations. From these flows, logistics chain models allocate flows by mode according to shipment size and frequency, available means of distribution (network supply, cost, etc.) and the availability of intermodal transfers. The resultant shipments by mode can then be assigned to individual modal networks. For urban freight models, it is the manifestation of these flows on the urban road network that is of interest, including road-based trips to and from intermodal terminals. (Shabani et al. 2018)

Methodologically, the supply chain's logistical form is determined by the utility of each modal link or trip within the change and the level of service (such as cost and time) at intermediate transfer points (intermodal terminals). For the purposes of forecasting, by definition the supply chain is assumed to move only the same type of cargo, which means that flows can be forecasted between the origin (shipper) and the destination (end receiver). In contrast to a trip-based model, the same origin-destination flow can change modes along the way. In this way, the linked trips across transfer points are similar to vehicle tour-based models, with the intermodal transfer points corresponding to the intermediate stops.

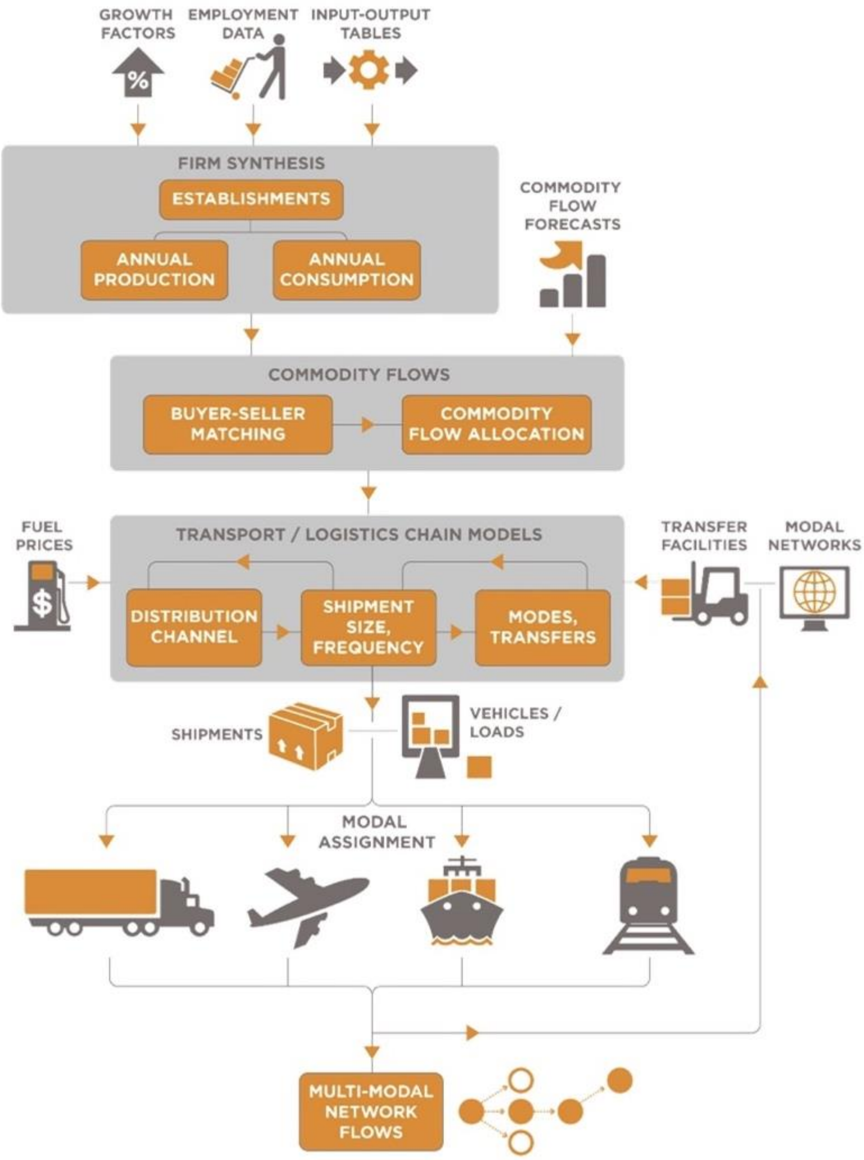
Supply chain freight models thus do not focus on a single mode but link multiple trips by different modes into the chain. The formulation takes into account all the available supply chains that can serve each origin-destination pair – for example, marine-railroad, air all the way, and so on. The formulation accounts for all possible modal combinations, sequences and routes, as well as choice models that allocate freight among the alternatives according to their utility. (Beagan et al. 2019)

The process has four main steps and inputs: (Shabani et al. 2018)

- Freight origin-destination flows by commodity, derived from national commodity flow data or freight movement surveys. The Australian equivalents are noted in Table 4-1. Some international sources are:
  - The Freight Analysis Framework (FAF) in the United States is a primary database of multi-modal freight flows among states and large metropolitan regions. Because the flows described in terms of origins and destinations, the FAF data can be used directly in supply chain models. (US Federal Highway Administration 2020b) FAF is based on several sources, notably the US Commodity Flow Survey (CFS), which captures data on shipments from business establishments in mining, manufacturing, wholesale trade and selected retail and service industrial sectors. Data are compiled at the state level and for large metropolitan areas. The CFS is conducted periodically across the country, most recently in 2017 (US Bureau of the Census 2020). The current FAF, version 4, is based on the 2012 CFS.

   - Canada does not have its own CFS. A bi-national continent-wide CFS was proposed to be conducted jointly with the United States so as to capture the extensive cross-border trade. The US CFS stops at the border; however, there are significant manufacturing supply chains that move back and forth across the border and are important to both countries, of which vehicle manufacturing is perhaps the most prominent (Kriger et al. 2010). This proposal was recently being considered, although the status of the discussions is unclear. In the meantime, Canada has started to compile a Canadian Freight Analysis Framework (CFAF) from available statistics (Statistics Canada 2020). However, CFAF lacks the key CFS component and is of limited use in developing freight origin-destination flows.
- Information about the travel times and costs of the competing modes is combined with freight origin-destination flows, from which a supply chain model allocates the flows to chains that are specific to the commodity.
- Different commodities follow different paths between origin and final destination. From this, modal use and transfer points can be discerned, and the resultant origin-destination shipping costs (impedances) can be derived to inform trip generation and distribution.

Figure 4-5: Behaviour supply chain modelling process



Source: Shabani et al. (2018)

- Finally, vehicle trips are extracted from the multi-modal chains. The intermodal transfer points (to and from commercial vehicle) represent the origins and destinations of individual vehicle trips for conversion to trip matrices for assignment.

To set up the supply chain model, a model of firms (shippers and receivers) must be developed or synthesised, from which their production and consumption are estimated and, ultimately, shipments and mode choices are replicated. The process uses employment data for the modelled region to develop a record of establishments that contains location, size (number of employees), industry type, production and consumption information (i.e., the commodity flows that are produced and consumed). Industry and commodity flows are grouped by standard industrial classifications (e.g., ANZSIC). Depending on the location, public or private data sources may be required.

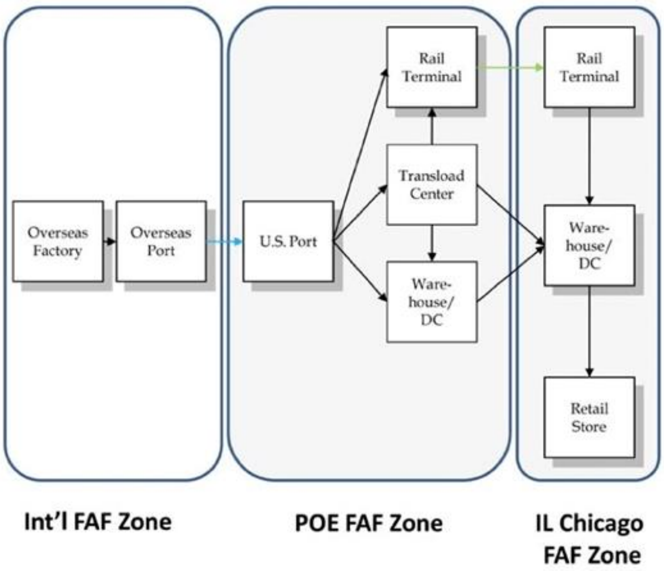
For micro-simulation demand modelling, records for individual establishments may be sought, as opposed to zonal totals. However, if only aggregate data are available, then firms can be synthesised by apportioning (distributing) the number of establishments in each geography according to ANZSIC codes and employee-size groups, allocate these according to the desired geographical levels, and then add production and consumption. The latter are derived from Make Tables (commodities produced by each industry) and Use Tables (commodities consumed by each industry) as derived from input-output accounts. (Shabani et al. 2018)

As an example, Figure 4-6 depicts a supply chain for consumer goods, moving from an overseas manufacturer (origin) to a retailer in Chicago, USA (destination). The figure shows three zones, using FAF designations:

- The supply chain origin is the overseas zone.
- The Port of Entry (POE) zone is the port through which the goods enter the United States.
- The supply chain end destination is a retailer in Chicago.

Once the goods are shipped – by container in this example – to the Port of Entry, there are several options for onward shipment. One option is to move the container to a rail terminal for onward conveyance by rail to Chicago, where the container is opened, the contents are unpacked, and the goods are delivered by commercial vehicle to a warehouse and on to the retailer. A second option unpacks the container at the Port of Entry, from which the goods are stored in a local warehouse and shipped to a warehouse in Chicago via commercial vehicle or are transferred to rail for onward shipment to Chicago. It can be seen that other combinations between the Port of Entry and the final destination can be selected. From these combinations, the associated costs, number of vehicles or rail cars and so on can be determined. Once the goods are within the Chicago area, the local commercial vehicle trips between the rail terminal and/or the warehouse and the final destination can be incorporated into the urban freight model. Road-based exchanges at the Port of Entry can be incorporated into that location’s urban freight model as well – in this way, goods that are passing through the urban area but neither originate nor are destined to the area can be added into the model. (Beagan et al. 2019)

Figure 4-6: Supply chain for consumer goods – example using FAF



Source: Beagan et al. (2019)

A.5 Agent-based models

In the United States, agent-based formulations have been deployed in some recent supply chain models. A regional model for Chicago, which is commonly recognised as most important intermodal hub in the country, provides an example how an agent-based approach is used to estimate freight flows. The formulation uses an agent-based approach to synthesising potential trading partners and their exchanges as the basis for estimating freight flows. Buyers and sellers (consumers and producers) within the United States and those of its trading partners are synthesised. An agent-based approach is used to match buyers and sellers through an iterative procurement market game (simulation). This involves a pool of buyers who attempt to procure inputs from a pool of sellers in the market. Based on models of distribution channels, shipment sizes and available modes, buyers consider shipping times, unit costs (transport and non-transport) and risk minimisation (such as disruptions to the supply chain). Sellers, operating under production capacities, evaluate whether to trade with a buyer in the face of other potentially more lucrative offers. Through repeated bilateral games, agents can form preferences for specific trading partners based on past interactions and can adjust their tolerances for risk according to market constraints. The final (user-specified) iteration of the game indicates which agents have established trading relationships and the quantities of commodities bought and sold. From this, a set of spatially distributed freight flows between establishments is derived. Buyers can purchase commodities from multipole sellers, to account for risk minimisation or seller capacity. Non-US trading partners are also included, which yields import and export flows.

Nonetheless, despite these advancements, in practice the development of agent-based formulations is challenging because of the lack of data on the choices made by each actor. An empirical agent-based prototype for Rotterdam, The Netherlands illustrates the importance of the data, the complexities involved and the potential opportunity. The prototype was based on microdata from a detailed Statistics Netherlands database on road transport and transported shipments. The database contains 30,000 records from a survey of transport companies, both own-account firms and third-party logistics providers, whose participation in the survey once sampled was mandatory. The survey enabled participants to automatically upload GPS traces from their vehicle management systems. As a result, data on shipment size and type, tour itineraries, stop locations, stop arrival and departure times, firm type, location and size, and the flow of goods could be developed in great detail. The prototype comprised a shipment synthesiser, which simulates the formation of shipments, and a tour formation model, which simulates the routing and schedule of deliveries. The resultant freight tour patterns can be assigned to the urban road network. It can be noted that the prototype model details the agents and describes their behaviour empirically but does not yet model how they made their choices: the microdata were being used (in 2018) to develop two choice models, one for the tour formation and the other for combined shipment and vehicle time choice.

Other research applications have examined agents' behaviour under bans on heavy vehicles in certain areas, load consolidation (different shippers and carriers in the same vehicles), priority treatments for electric vehicles (e.g., reserved parking), introduction of urban distribution centres (where loads from different carriers can be consolidated before onward delivery by small or carbon-neutral vehicles), cordon pricing for all vehicles and for e-commerce specifically, road tolls and parking fees among others. All these research efforts are small scale 'tests' of different urban policies. The research generally involves small networks and a selection of agents who are making different types of choices (notably, routing but also scheduling and willingness to cooperate among other choices). (Comi et al. 2014, de Bok et al. 2018, Nuzzolo et al. 2018, Tavasszy 2020)

Appendix B Glossary

For the purposes of these guidelines, it is useful to begin by establishing working definitions of several key terms. The perspective is that of the inputs, processes and applications of urban freight models as used mainly although not exclusively in the Australian context (Table 4-2).

Table 4-2: Key terminology

Key terms	Definition	Notes
Commercial Vehicle (CV) Model, or Trip-based model, or Truck-trip model	A commonly used sub-model in Australian capital city strategic models based on the standard four-step trip-based modelling approach to estimate commercial vehicle-trips (usually classified as either 'light' or 'heavy').	The four-step paradigm is a sequential model in which trip generation, trip distribution, mode choice and trip assignment are considered mainly as distinct sequential choices. The movement of commercial vehicles is estimated through trip generation models that are typically based on zonal demographic parameters such as employment and population and trip distribution models that are based mainly on auto impedances. Some trip generation and distribution models are developed by vehicle class (i.e. light, medium and heavy commercial vehicles). The resultant commercial vehicle trip tables are assigned to the network along with autos and other vehicles. Typically, mode choice is not used in an urban context, since all modelled activity is by commercial vehicles.
Tour-based Models	An emerging CV model formulation not yet widely used in Australia but starting to come into broader use internationally, and in Australia commensurate with the deployment of passenger tour-based models.	The tour-based formulation recognises that CVs typically follow an itinerary or 'tour' of stops in making their deliveries and pick-ups, thereby incorporating the sequence of stops, land uses, commodities being transported and vehicle types directly into the definition of tours. The formulation can incorporate elements of the trip-based four-step paradigm.
Commodity Flow Model	A commodity flow model, a formulation commonly used in Australia, models the movement of goods or commodities across a state or across the country by various long-haul modes. From this, flows to, from and through urban areas are extracted. The flows are derived from forecasts of economic activity and are typically expressed as annual or monthly flows. These estimated commodity movements are subsequently converted into estimates of the number of daily commercial vehicle-trips required to transport these commodities within the urban area.	These flows can involve the movement of goods into and out of the urban area via intermodal terminals (airports, marine ports and rail terminals), which are then distributed to or collected from multiple sources within the urban area by commercial vehicle. Some long-haul flows can be moved entirely by commercial vehicle, moving between an external location and one or more locations within the urban area. Commodity flow models are not typically deployed to model intra-urban commodity flows.
Supply Chain Model	The 'supply chain' represents "the integration of key business processes from end user through original suppliers that providers products, services, and information that add value for customers and other stakeholders."	Individual components of the supply chain can be moved via different 'modes.' The choice of modes is driven largely by cost, which is a function of several factors such as availability, capacity, congestion, labour, fuel, vehicle operations, value and time sensitivity of the good, the quantity to be moved, security and more. Other factors such as regulations (e.g., time of day access restrictions), policy (e.g., the mandated use of low-sulphur fuels for marine shipping), urban form and so on also impact the choices of modes.

Key terms	Definition	Notes
	The supply chain can be entirely self-contained within an urban area or it can stretch across the country and around the world. Components can move forwards and backwards within the supply chain as new parts or functions are added along the way until the product is finalised. Supply chain models and commodity flow models can have some degree of overlap, especially in the depiction of long-haul multi-modal freight flows that are transported to, from and through an urban area. However, from the perspective of these guidelines, supply chain models add the ability to model the logistics choices that are made along the way, which in turn impact how goods are transported within an urban area. 'Logistics' refers to the 'management of material and information flows across the supply chain.' (Lambert 2001)	The business processes that are conducted along the way can also impact the choice of mode: for example, the components of an auto engine are small enough to be moved by commercial vehicle among several factories that each add a part, whereas the finished auto is commonly transported by rail.
Goods	The term 'goods' refers to physical commodities, ranging from bulk commodities, such as grains and fuel, that are used as inputs to manufacturing and other processes, to discrete finished products, such as furniture and parcels that are delivered to the final user. (US Federal Highway Administration 2020a)	
Services	Some urban freight models include 'services' within their scope. This is because services represent activities that generally use commercial vehicles and are not otherwise covered in passenger transport models. In other words, commercial vehicles are transporting people as part of their work activities but are not necessarily carrying goods. (US Federal Highway Administration 2020a)	Example: Appliance repair, in which the repair person might have several appointments at various homes or businesses over her workday, and these appointments can vary from day to day. Note that these activities refer to on-the-job activities, and for modelling purposes, these are distinct from the home-work commute and a business meeting outside the office, which are commonly captured in urban passenger models. Note also that some on-the-job activities that involve multiple stops at random locations, such as a home care nurse visiting patients in their homes, are more likely to be included in passenger travel demand models even though they more closely approximate service vehicle patterns.
Urban Freight	Refers to the 'movement of all types of goods and commercial services to, from, within and through an urban area.' Consists of intra-urban, plus those parts of intra-state, inter-state and international that occur within the urban area. (US Federal Highway Administration 2020a)	'Urban freight' and 'urban goods' are both found in the urban freight modelling literature and are used interchangeably here.
Intra-Urban	Freight movements made by commercial vehicles entirely within a specified urban area.	An urban freight model includes intra-urban freight movements as well the urban elements of intra-state, inter-state and international freight movement.
Intra-State	Freight movements made by commercial vehicles, rail, marine or air entirely within a specified state.	An urban freight model includes the urban legs of intra-state freight movement – e.g., the last-kilometre delivery of a container that arrived in the urban area by commercial vehicle from elsewhere in the state.

Key terms	Definition	Notes
Inter-State	Freight movements made by commercial vehicles, rail, marine or air from one Australian state to another.	An urban freight model includes the urban legs of inter-state freight movement - e.g., the last-kilometre delivery of a container that arrived in the urban area by transcontinental rail.
International	Freight movements made by marine or air between different countries.	An urban freight model includes the urban legs of international freight movement – e.g., the last-kilometre delivery of a container that arrived in the urban area through a marine port.

Appendix C National freight models

Several freight models have been developed to assess freight movements at a national level. Whilst these models are most useful for analysis at the national level, they nevertheless provide some insights for urban freight movement for various reasons:

- Much of this freight movement has origins or destinations (or both) in urban areas or is moving through urban areas, and
- Some urban model formulations (especially urban commodity flow models) are derived from the large-area model formulations, as are some of the data sources.

It should be noted that some of these models have had a narrower focus than traditional transport modelling applications.

FreightSim

FreightSim is described as a tool for projecting freight OD matrices for six transport modes, namely road, rail, sea, air, pipeline and conveyer. FreightSim has 132 zones which correspond to the 8-capital city Statistical Divisions and 123 ABS statistical sub-regions. The inter-regional freight demand projections are based on information from the FDF Pty Ltd Freight Info 1999 national database, with augmentation from the 2002 ABS Freight Movements Survey. Key characteristics include reliability, frequency and travel time. (FreightSim does not appear to be in use or under active development any longer.)

Transport Network Strategic Investment Tool (TraNSIT)

TraNSIT was developed by the CSIRO as a tool to evaluate the impact on transport logistics costs and benefits of changes in infrastructure and policy changes.

As part of the model development, analysis of survey data from 222,000 enterprises (predominantly farms) was undertaken to establish supply chain movements for the markets of Cotton, Dairy, Pigs, Sugar, Rice, Horticulture, Sheep / Goats, Chicken Meat and Buffalo.

Some 332,000 unique OD paths were used to assign over 5.5 million vehicle trips per annum to the strategic road network as well as 9,500 rail trips per annum. The model creates several outputs including travel costs and greenhouse gas emissions. (Higgins et al. 2017)

NZ Transport Outlook Freight Model

Last updated in 2019, this model was created in 2014 as part of the NZ Freight Demand Study. The study was completed to develop a comprehensive understanding of the freight industry, considering freight commodity (the model considers 19 different commodity groups), mode and region. This model is grounded on data gathered as part of the ‘Freight Information Gathering System’ and is built in Excel.

Appendix D Overseas practice

Table 4-3 presents a selection of international urban freight modelling examples. The selection is not meant to be an inventory of practice but instead is intended to bring out different aspects of the models described in Table 4-2 in more detail. The examples represent a mix of trip- and tour-based models for cities of different sizes and economic structures (e.g., some are port cities but others are not), based on varying data sources and formulations.

Table 4-3: International examples of urban freight models

Urban Area / Owner	Type of Model	Description
Chicago, USA / Chicago Metropolitan Agency for Planning (CMAP)	Multi-level model: intra-regional commercial vehicle touring model integrated within multi-modal supply chain model	As the dominant intermodal transfer point for freight in the United States, as well as being an important international trade hub, transport and logistics is an important part of the Chicago region's economy. CMAP, the regional transport planning agency, has incrementally been building a regional freight model since 2010. The model has multiple levels of resolution, which allow it to forecast freight flows between Chicago and the rest of the world (meso-scale), as well as an intra-regional vehicle touring model (micro-scale). Beginning with firm synthesis, supplier selection and mode choice, CMAP has incrementally added supply chain and logistics elements, vehicle touring models and, more recently, an extension to the meso-scale model for forecasting freight flows under different sets of investment, policy and macroeconomic scenarios. (Shabani et al. 2018) This integrated multi-level approach enables the use of data and models at levels of spatial and temporal resolution that are appropriate for each level, rather than forcing them to function at a single scale. (Comi et al. 2014)
France	Tour-based matrix scalable to cities of different sizes	The FRETURB model develops commercial vehicle matrices that can be applied generically to cites of varying sizes. The model is based on establishment and trip diary surveys that have been conducted in cities across France in several waves since 1993. A key finding from these surveys is that the primary relationships (trip rates by establishment type, parking duration and so on) were very similar among the surveyed cities and were largely stable over time, while other parameters that varied by city size and structure could be discerned (composition of establishments, urban form). Given details of a city's establishments and urban form, the model: • Categorises the establishments. • Estimates the number of operations (pick-ups and deliveries) for each category. • Assigns the operations to a logistical behaviour (tour, vehicle type, etc.). • Estimates parking duration at each stop. • Estimates the travelled distances for a tour. • Estimates origin-destination matrices for light, medium and heavy vehicle-trips. Users can then assign the matrix to their own model networks. The model has been applied to approximately 50 cities of varying sizes, mostly in France but including Paris, Lyon, Brussels and Zurich. FRETURB has three components: a delivery-pick-up model that describes the movement of freight among all the different types of establishments of a city, a town management model for construction and public services, and a purchasing trip model that simulates trips of consumers during their purchasing activities.

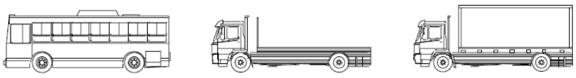
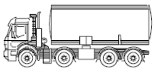
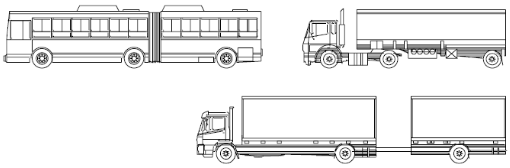
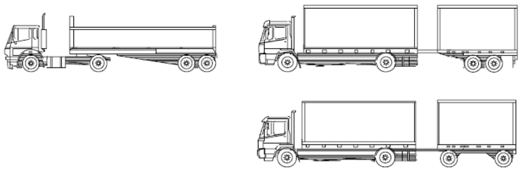
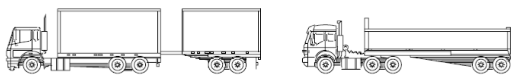
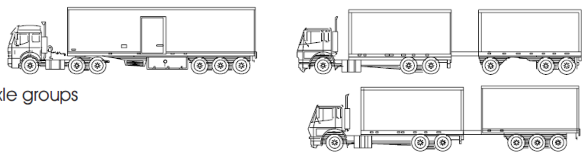
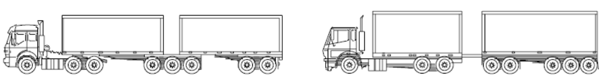
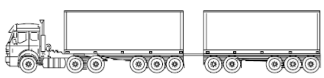
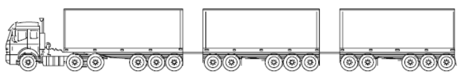
Urban Area / Owner	Type of Model	Description
		FRETURB was based on the original wave of surveys in the 1990s and has been updated periodically since then as new surveys become available. Recent research has focused on changes that have occurred through the increased use of light vehicles and e-commerce-generated deliveries, which are expected to change the formulation of the light vehicle matrix. (Toilier et al. 2018) The FRETURB model lacks precise details on actual movements and the specifics of individual cities, but utilises a history of dense surveys across several cities to develop key relationships that can be transferred among urban areas.
Phoenix, USA / Maricopa Association of Governments (MAG)	Supply-chain model	Phoenix is a key and fast-growing freight hub in the southwestern United States along the key trade corridors from southern California's ocean ports and close to the border with Mexico. As part of a Federal government-sponsored research initiative MAG, the regional MPO, developed a supply chain model for the Phoenix-centered mega-region. The model incorporates a firm synthesiser, supply chain and supplier-selection (producer-consumer matching) model, a transport, mode choice and path choice model, and a tour-based commercial vehicle model using GPS fleet traces. A logit vehicle-type choice model allocates trips between medium and heavy vehicles, based on data from a 2016 establishment and vehicle origin-destination survey. The supply chain model considers commercial vehicles, rail and air as well as courier (parcels). The modelling suite can output both annual commodity flows and vehicle trip matrices for assignment with other vehicles in the regional travel demand model. (Shabani et al. 2018)
Saskatoon, Canada / Saskatchewan Ministry of Highways and Infrastructure	Trip-based model based on GPS trip traces and counts	Saskatoon is a city of 220,000 that serves as a trading center for the surrounding agricultural, forestry and resource attraction communities. As part of a 2015 passenger model calibration, a commercial vehicle component was developed. The model primarily represents long-haul trips, given the lack of urban data. A heavy vehicle trip matrix was derived from GPS fleet traces, which primarily reflect long-haul travel. A light vehicle trip matrix was derived synthetically from ground counts. The combined 24-hour matrices were calibrated first against counts surrounding the urban area, then against available internal counts. A key challenge was the lack of classifications in the available counts, for which proxies from other similar cities were used to establish heavy and light vehicle proportions. The matrices were then factored to develop AM and PM peak hour matrices, for assignment with passenger vehicle matrices. (Saskatchewan Ministry of Highways and Infrastructure, 2015) Although lacking details on urban freight activity, this is an example of a trip-based model that uses available data to ensure that freight can be incorporated into the municipality's demand forecasts and long-range transport plans. Because it was developed as an adjunct to the trip-based passenger model, its development was relatively cost-efficient.

Urban Area / Owner	Type of Model	Description
Toronto, Canada / Ontario Ministry of Transportation	Tour-based model based on GPS trip traces and integrated with a large-area commodity flow model	The Toronto-centered mega-region is Canada's dominant economic hub, with a population of 7.5 million. As such, it is well integrated into the provincial, national and continental economy. A three-step truck trip model was added to a 2008 hybrid tour-based passenger model, based on Ontario's Commercial Vehicle Survey, a comprehensive roadside vehicle origin-destination survey that is conducted every 5-6 years on the province's highways. (A small establishment and vehicle trip diary survey was conducted in 2012 but has not been used for modelling.) In 2016, GPS fleet traces were used to develop an urban tour-based model, based on an adoption of the Calgary formulation and on a firm synthesiser model. A multi-modal province-wide passenger and freight model was developed at the same time. A macro-economic model of the provincial economy develops multi-modal flows (road, rail and marine), from which long-distance commercial vehicle trips are discerned, including intermodal transfers at rail terminals and marine ports. The long-distance formulation uses GPS fleet traces and includes the aforementioned firm synthesiser model and accounts for empty vehicle trips. The translation from commodity flows to long-distance commercial vehicle trips is aided by Ontario's Commercial Vehicle Survey. Trips that pass to, from and through the mega-region are extracted and integrated with the regional matrices for assignment. (Damodaran 2017, Duggal 2017) The Toronto formulation is Canada's first tour-based urban freight model and the first model that is integrated with a large-area multi-modal commodity flow and freight model. It uses available GPS data and, notably, a comprehensive and dense data set of long-haul and regional commercial vehicle characteristics.
Vancouver, Canada / TransLink	Trip-based model based on vehicle surveys, defined according to different freight markets	The Vancouver region is Canada's largest Pacific Ocean port. As such, inbound container traffic and outbound resources pass through the region by rail and commercial vehicle. Vancouver is also located close to the US border and serves as vehicular gateway between western Canada and the US West Coast. In 1999, the regional transportation planning agency (at the time, the Greater Vancouver Regional District), conducted a vehicle-based trip diary survey, which was used to calibrate trip-based generation, distribution and assignment models for light, medium and heavy commercial vehicles. In 2014, TransLink, the regional transportation authority, reformulated the model to better reflect. The original trip diary survey data were retained, augmented with more recent depictions of supply chain characteristics, up-to-date demographic and employment data, new classification counts and, notably, GPS data from vehicles that serve the Port of Vancouver and commercial vehicle surveys at the Canada – US border. The new model was restructured to represent four primary freight market sectors: inter-regional (internal and urban), regional (long-distance vehicular traffic between Vancouver and elsewhere in western Canada), Asia-Pacific (port traffic) and cross-border (between Canada and the United States). The forecasting models for each sector were re-estimated to use economic variables such as GDP, fuel price, monetary exchange rates (between Canada and the United States) and other factors that more closely depict commercial vehicle generation than zonal land use variables alone. The resultant matrices are combined and then assigned with passenger vehicle matrices as part of the regional travel demand modelling suite. (TransLink 2015) Although trip-based and ultimately relying on somewhat dated vehicle trip characteristics, the categorisation of different freight markets allows a more sensitive depiction of freight activity especially for the key port-related and cross-border traffic.

Appendix E Austroads Vehicle Classification

VEHICLE CLASSIFICATION SYSTEM

AUSTROADS

CLASS	LIGHT VEHICLES	
1	SHORT Car, Van, Wagon, 4WD, Utility, Bicycle, Motorcycle	
2	SHORT - TOWING Trailer, Caravan, Boat	
	HEAVY VEHICLES	
3	TWO AXLE TRUCK OR BUS *2 axles	
4	THREE AXLE TRUCK OR BUS *3 axles, 2 axle groups	
5	FOUR (or FIVE) AXLE TRUCK *4 (5) axles, 2 axle groups	
6	THREE AXLE ARTICULATED *3 axles, 3 axle groups	
7	FOUR AXLE ARTICULATED *4 axles, 3 or 4 axle groups	
8	FIVE AXLE ARTICULATED *5 axles, 3+ axle groups	
9	SIX AXLE ARTICULATED *6 axles, 3+ axle groups or 7+ axles, 3 axle groups	
	LONG VEHICLES AND ROAD TRAINS	
10	B DOUBLE or HEAVY TRUCK and TRAILER *7+ axles, 4 axle groups	
11	DOUBLE ROAD TRAIN *7+ axles, 5 or 6 axle groups	
12	TRIPLE ROAD TRAIN *7+ axles, 7+ axle groups	

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