Co-modality: Making Use of Public Transport to Carry Freight

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THE UNIVERSITY OF SYDNEY
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NSW GOVERNMENT
Transport for NSW

ITLS

iMOVE

Foreword

In an era with an ever-increasing demand and challenging service levels, planners and logisticians are consistently looking for initiatives for the safe, efficient, and reliable movement of goods into cities. A city's demand for goods is largely satisfied by road. However, these conventional delivery methods can contribute to congestion, disamenity and environmental impacts felt in cities. As a result of these concerns, this investigation has explored the use of public transport as an alternative channel for freight to, from and within cities. This approach is known as co-modality.

The Institute of Transport and Logistics Studies (ITLS) at the University of Sydney Business School, in partnership with Transport for NSW and with support from the iMOVE Cooperative Research Centre, have conducted a project to investigate the feasibility of adopting co-modality for deliveries to Sydney CBD. The project looks at the co-modality approaches taken around the globe, then gathered views and requirements of the concept from the various stakeholders that operate public transport networks and logistics services in our target area of Sydney CBD. Based on the lessons from existing examples of co-modality and inputs from stakeholders, the project analysed different scenarios for the adoption of co-modality and developed a business model detailing potential commercial and environmental benefits of the approach.

The project team would like to thank and acknowledge the assistance of the public transport operator in Sydney and the logistics industry who input data and insights to this project.

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Executive summary

Global investigations reveal several different approaches to co-modality, the use of public transport for freight, being applied in various circumstances. After reviewing these examples and consulting local public transport and logistics operators, the project investigated how this might apply to servicing Sydney CBD. The project sought to investigate the viability for co-modal freight service provision that would also generate social and economic benefits by reducing congestion. The following conclusions were reached:

- **There is latent capacity in the transport service network:** Throughout the middle of the day, there is capacity to move small freight consignments into the CBD. This is suited to same day consignments. While there is also public transport capacity in the early morning, freight at this time is most efficiently consolidated and moved via road.
- **The best role of co-modality is in the middle mile:** For a typical delivery from city outskirts to the downtown CBD area, there are few alternatives in the first mile to truck/van collection, and various options for the last mile to the customer. The greatest opportunity for co-modality is the middle mile where a cost-effective trip on public transport can outweigh despatching a road vehicle from the suburbs to the CBD.
- **Unaccompanied co-modality offers potential cost savings:** Truck/van movement in the middle mile necessitates equipment and labour costs while also creating congestion and environmental externality costs. Moving freight unaccompanied on public transport can generate revenues for the operator and cost savings for the logistics operator. It would require a management system to support it and an agreed division of responsibility for cargo movement onto and off the public transport.
- **Market size is ideal for the same day delivery:** Same day delivery comes with high expectations of punctuality and generally small amounts freight. The short delivery timeframe and smaller parcel quantity generally makes it costly for logistics service operators. Existing public transport services suit the same day market, as the smaller loads would mitigate disruption to the existing passenger transport while utilising services that generally have spare capacity outside peak hours.

Evaluation of market opportunities revealed the potential of co-modality to be:

- **Social-economics:** Many global co-modality schemes are motivated by social-economic objectives such as emission reduction and congestion alleviation. Adoption of co-modality for Sydney CBD could save 415 high cost delivery trips travelled by truck every day resulting in significant congestion and environmental benefits.
- **Commercial feasibility:** It is equally essential that the co-modal delivery scheme is commercially sustainable. Global examples of co-modality attempts reviewed in this paper highlighted the risk to concept feasibility where the business case was neglected. Recognising the importance of commercial feasibility, co-modality's commercial benefits were calculated to be approximately $2 million per year to service the CBD. It is suggested that these benefits be shared equitably between the logistics operator (in the form of reduced cost of delivering parcels) and the public transport service operator (in the form of a new revenue source). While it was not the focus of this project, several stakeholders were interested in the development of this concept for servicing regional customers with an expedited service. As public transport services are already scheduled, key costs would be the development of a track and trace system and ongoing service management.

Co-modality is a viable solution to address the challenges of delivering goods to dense urban centres such as Sydney CBD by utilising the latent capacity, particularly of the heavy rail network, to address the middle mile of freight trips. While unaccompanied travel of certain goods on public transport services affords the greatest potential, it also presents challenges around ensuring load and passenger security while mitigating impacts on passengers and the network. However, these challenges are not insurmountable. In utilising latent capacity on existing services to generate revenue, the approach can also reduce congestion impacts on metropolitan roads.

Contents

1 Introduction

1.1 What is co-modality?

City logistics plays an important role in supporting and shaping urban areas. In the last decade, social changes, especially technology advances, urbanisation, and e-commerce have led to a surge of freight activity in urban and suburban areas. This brings increased pollution and congestion, competition for parking, and a loss of 'livability' for residents and visitors alike (Savelsbergh and Van Woensel, 2016). One possible option aimed at addressing these challenges while meeting the demand for goods that keeps cities thriving is that of 'co-modality'.

Co-modality is a logistics concept whereby freight movement is integrated with the movement of passengers on public transport. Integration can occur at different levels, from the simultaneous movement of passengers and freight in shared vehicles to the scheduling of freight movement on shared transport network infrastructure. An example of integration is long-haul air transport, where passenger aircraft move freight within the "belly-hold" of the plane, therein generating additional revenue for airlines and maximising the use of latent capacity. In short-haul transport, people and freight generally share the same infrastructure (predominately road), however rarely share the same vehicle.

1.2 Problem statement

Safe, efficient, and reliable transport is crucial to supporting the productivity, liveability, and sustainability of large cities like Sydney. This applies to both the movement of people and goods. In congested urban areas like Sydney CBD, space is at a premium with competing demands for its use. A challenge is striking a balance between creating places for people and ensuring the delivery of goods and services essential for the place to function. Investment in additional transport infrastructure may not be sufficient to achieve this balance. One method may be to better integrate existing passenger transport networks with that of goods movement.

The movement of freight with passenger networks has the potential to reduce the number of vans and trucks required in urban and suburban environments, particularly alleviating traffic congestion, vehicle emissions and competition for scarce loading zones in Sydney's CBD. While taking on board the lessons learnt from other cities, the project anchors the concept in the specific composition, urbanity and functioning of Sydney CBD. The key objective is to **investigate the potential for moving freight into Sydney's CBD utilising latent capacity on the heavy rail network without disrupting passenger service levels.**

Given the various public transport options in Sydney, the project focused mainly on use of the Sydney Trains heavy rail network as the primary public transport network suited to a co-modal option. Sydney Trains is the public transport operator of the suburban rail network across metropolitan Sydney and sits within Transport for NSW. The suburban network has broad geographical reach to industrial areas across Sydney, regional NSW and other cities, compatible infrastructure, and connectivity to Sydney CBD.

1.3 Alignment with Transport for NSW strategy/goals

Transport for NSW's Future Transport 2056 strategy (TfNSW 2018) sets the vision of transport as an enabler of economic and social activity and contributor to long term goals of the NSW Government. The vision is built on six outcomes; customer focus; successful places; a strong economy; safety and performance; accessible services; and sustainability. The co-modality research aligns with the goals of:

- Successful places, as research into alternate modes into urban centres supports the balancing of the movement of goods with the amenity, quality and success of place making; and
- Sustainability, by exploring the best use of available public transport resources and assets for the movement of goods into centres and reducing emissions from vehicles in the 'middle mile'.

The Freight and Ports Plan 2018-2023 developed by Transport for NSW sits as a pillar underneath Future Transport 2056. The Plan sets objectives, goals, and initiatives for the safe, efficient, and reliable movement of goods. A goal within the efficiency improvement objective is to trial alternative delivery modes for deliveries in urban environments. This project supports this goal by examining the use of public transport as an alternative to conventional truck or van deliveries to Sydney's CBD, and its potential to bolster broader goals in the Plan by enhancing productivity, reducing travel times, and improving reliability and environmental outcomes.

1.4 Structure of the report

The structure of the report is outlined in Figure 1. Following the introduction, a review co-modality schemes worldwide is undertaken in Section 2, with a summary of the reasons for success or failure. In Section 3, we draw lessons learnt from global schemes and introduce the concept to local stakeholders and harness their views to design the key components for the application of the concept in a Sydney CBD context.

Section 4 then presents some viable options in both middle and last mile contexts and comparison with conventional truck deliveries. Section 5 defines a proof of concept of how co-modality could look for Sydney CBD with conclusions and next steps proposed in Section 5.4.5.

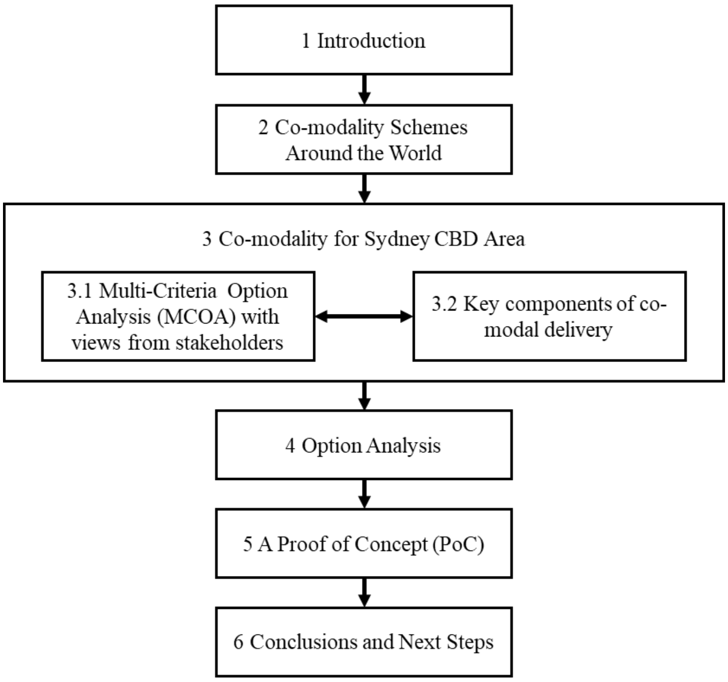

Figure 1 Report structure

2 Co-modality schemes around the world

Co-modality is not a new idea. Trentini and Mahléné (2010) discussed ‘passengers and goods cohabitation’, emphasising the importance of a management model as a basic framework to coordinate flows and the need for cost-benefit analysis. Arvidsson et al. (2016) explored last-mile synergies of sharing infrastructure and resources for passenger and freight transport. The authors identify the greatest synergy potential for co-modality in cities and assert that shifting from treating people and goods flows separately as two transport flows to one transport flow with different characteristics will open the window of opportunity to address last mile challenges. From a scenario analysis on ‘cargo hitching’ (utilising the unused capacity of public transport for city logistics), Van Duin et al. (2019) confirmed the necessity of integration on both institutional and business levels for co-modality to be a success, a sentiment shared by Arvidsson et al. (2016).

In this section, existing and historical co-modality examples are categorised and summarised by their coverage: Long, medium, and short haul (Figure 2). Examples of co-modality are commonly found in long haul interstate or intercontinental transportation and are historically widespread in medium haul inter-city transportation. Recently, a series of projects worldwide have emerged intending to revive medium haul co-modal transportation and explore its potential in short haul intra-city delivery. For example, the City of London is supporting a trial of parcel freight transport cooperating with a passenger rail operator (Parker, 2019).

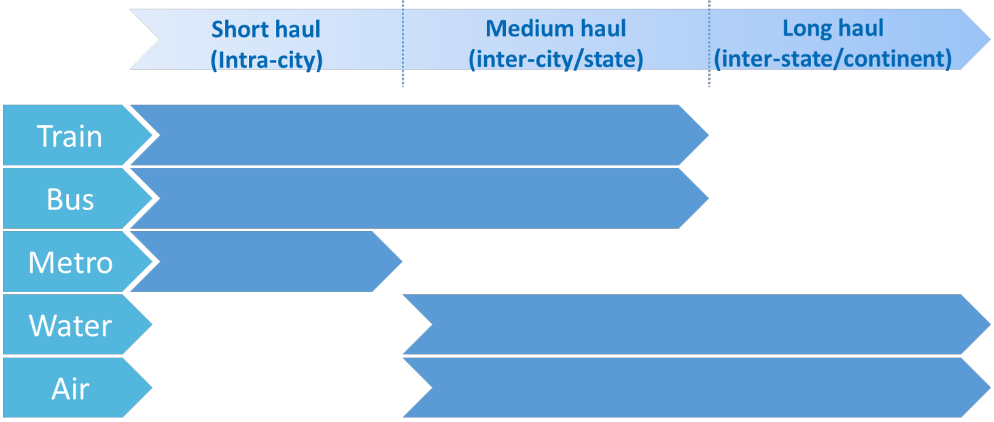

Figure 2 Co-modality in different levels

2.1 Long haul

2.1.1 Air transport

Airlines are long-standing and the most commonly recognised practitioners of co-modality. Passenger planes often carry freight at the same time. For most aircraft, cargo from different shippers is stored in the freight hold (“belly”) underneath the passenger cabin. Co-modality in air transport helps airlines maximise the revenue of operating routes. Approximately five percent of Qantas’ 2018 revenue was from freight movement (Qantas, 2019).

The primary concern about co-modality in the air is physical safety. An example is Boeing’s “combi” aircraft, which had more flexibility in the cabin to store a combination of passengers and freight. However, the SAA Flight 295 disaster in 1987 raised concern for fire resistance in cargo compartments and dampened enthusiasm for the “combi” design on major commercial routes. Air cargo and passengers are now mostly separately stored and processed in different terminals, respectively.

2.2 Medium haul

2.2.1 British Rail - Red Star Parcels

Originating as British Rail's express registered parcel delivery service in 1963, Red Star Parcels is a good example of inter-city co-modality. It provided parcel transportation services between passenger railway stations throughout the United Kingdom to better utilise the railway capacity. Senders drop off parcels at selected stations. The parcel is carried in the luggage carriage of passenger services and stored at the nominated destination train station for pick-up by the recipient. As the service used scheduled trains, it was one of the fastest methods to transport packages over long distances in the United Kingdom.

During the privatisation of British Rail and the reduction in staff on passenger services, guards were no longer available to handle parcels on trains. Parcel movement by rail was no longer financially viable, as it required more dedicated staff on trains and in stations. Consequently, the Red Star business was sold in the mid-1990s and the service was finally closed in 1999 (Wikipedia, 2020, Hotten, 1995).

2.2.2 Indian Railways - Amazon

Indian Railways embarked on a pilot project with Amazon to transport parcels during non-peak hours (Nandi, 2020). For Indian Railways, the objective was to increase revenue by utilising off-peak capacity. Amazon valued the reach and speed of Indian Railways and believed it could help them better meet their customers' requirement for fast and reliable delivery. The project was at the pilot stage at the end of 2019 (Nandi, 2019).

2.2.3 Japanese rail operators - Yamato/Sagawa

Japan's two major couriers, Yamato Transport and Sagawa Express, are active participants in co-modal solutions. They have both launched a series of cooperative initiatives with public transport operators to provide co-modal delivery by inter-city trains. These projects are located in rural areas, where passenger demand is low. The benefit for couriers is to lower costs by switching from local van drivers to scheduled public transport services. For public transport operators, the benefit is a better use of the space on low patronage services and extra revenue.

Freight is stored in the couriers' branded roll cages and secured to the side of the carriage, as shown in Figure 3. The rail operator loads and unloads the roll cages, which travel unsupervised, while Yamato and Sagawa handle the first and last-mile deliveries at either end for their final customers.

These projects have been running since 2015. An increasing number of local public transport operators have expressed their interest to get involved in similar co-modality projects. [1]

[1] See: https://www.travel.co.jp/guide/article/9309/

*Figure 3 Sagawa cargo containers fixed in the accessible area of a regional train (Source: **Response**)*

2.2.4 Rural bus operators

Just like airlines, many long-distance rural bus operators are practitioners of co-modality by carrying freight alongside passengers. To fully utilise their network capacity, Greyhound Lines provide their package delivery services in United States, Canada, and Australia. The service was initially station-to-station, with cargo carried in passenger coaches or trailers (Figure 4). In Australia, Greyhound has expanded their services to door-to-door delivery, with deployment of a box trailer.

Figure 4 Grayhound freight delivery
*(Left: Greyhound Print Ad in 1973, Source: **Amazon**; Right: Greyhound trailer in Australia, Source: **Travelrat's Travels**)*

In Germany, bus operator Uckermark provides "KombiBus" services to deliver goods to shops, restaurants, and companies in sparsely populated regions alongside their public transport network (Kempers, 2018). Another example is the MultiBus project in Heinsberg, where the operator primarily provides on-demand bus services for local communities, but also conducts parcel delivery to improve cost efficiency (ELTIS, 2014b).

2.3 Short haul

2.3.1 Tramfret

The French Tramfret project (Figure 5) aimed to demonstrate the possibilities of delivering goods on a passenger transportation system. The project was driven by the replacement of a large number of trams in 2017 providing an opportunity to use retired passenger trams to convey freight. Two supermarket replenishment trials were conducted in June and July 2017 in Saint-Etienne using the converted trams on the passenger network. The tram cars were refurbished to handle roll cages with similar storage capacity of a 10-15 tonne truck. Six deliveries were made to the two supermarkets per day during the six-day trial, 17 tonnes of goods in total passed through the railway network without disruption to passenger traffic. However, the project was stopped by the city government and their supermarket partner in 2018 due to concerns about the economic viability of the project and technical difficulties (Tramfret, 2016, Antkowiak, 2018).

Figure 5 Tramfret cargo handling (Source: the Guardian)

2.3.2 Logistiktram

A similar project to Tramfret is running in Frankfurt, Germany. In this Logistiktram project, a "tram + cargo bike" concept is proposed to combine the advantages of using trams and cargo bikes as methods of delivery. The trams provide fast long-distance line haul, while the cargo bikes provide flexibility and agility for last-mile delivery. The trams are used in off-peak times to transport cargo boxes between micro-hubs for delivery by local cargo bikes. The cargo boxes are designed to fit both the tram and the cargo bike. At the pilot stage, the trams were reserved for cargo and had to be slightly modified to handle these boxes. At the time of writing, it is unclear if the pilot project is successful and whether passenger and freight would share the tram in future phases of the project (Meldner, 2018).

2.3.3 CarGoTram

CarGoTram is a logistics concept connecting Volkswagen (VW) factory in Dresden with its warehouse 5km away on the city fringe. Dedicated cargo trams are used for just-in-time deliveries of car components from a logistics centre by Dresden central station through the city centre to the car factory. CarGoTram share the tracks with passenger trams, however they are timetabled to fit around the passenger services. Each tram trip could avoid three conventional truck trips in the congested city centre, which fits well with the transport operator's philosophy of contributing to increased quality of life and the city's attractiveness and sustainable development (ELTIS, 2014a). The logistics concept has been in operation since 2011 and is planned to cease after 2020, due to the decreased demand for car parts in VW's new manufacturing plan (Tag24, 2020).

2.3.4 Cargo-Tram and E-Tram

Cargo-Tram and E-Tram were introduced in 2003 and 2006 to remove bulky and electrical/electronic waste in Zurich. Supported by the city government, the service is free of charge. Local residents bring their waste to one of the nine pick-up points. The tram used in service has two freight carriages. In the evening off-peak time, the waste at the pick-up points will be loaded onto the two adapted carriages and run to an incineration power plant for disposal or recycling. The project is still in operation as of December 2020.

2.4 Lessons learned

As passenger transport is generally a reliable and scheduled service, integrating freight movement with passenger transport services can provide logistics operators and customers a reliable and sometimes faster delivery option. The international review shows that co-modal freight operations mainly function in the medium to long distance market. The short distance urban and suburban application is more challenging, with issues yet to be resolved for the short distance model around technology and the business model. Of the several ongoing experiments in the short distance market, most involve the use of trams.

Co-modal freight services have the potential to alleviate traffic congestion and pollution in downtown areas. The costs of professional drivers and delivery personnel also incentivise the exploration of co-modality possibilities. Despite this, few city co-modality projects have proved sustainable in the longer term. Some city tram co-modality projects are worth noting, with Cargo-Tram and E-Tram still in operation. Logistiktram is ongoing in the pilot stage, but CarGoTram and Tramfret are stopped (or planned to be stopped) due to low demand.

The main lessons from these projects are:

1. Adding dedicated freight vehicles to an existing public transport system require a high degree of coordination at the operational level, including scheduling, handling, storage, etc. It would be costly in terms of procuring, operating, and maintaining dedicated equipment.
2. When freight and passengers use the same vehicle, it places a higher requirement on handling efficiency. A dedicated container (Unit Load Device, or ULD) proves highly useful to facilitate the whole service. The ULD size and weight should suit ease of movement by public transport for the middle mile and transition to cargo bike or hand cart for last mile delivery. Unlike medium and long haul carriers, who have sufficient time to handle the cargo at the destination of terminating services, short haul carriers are challenged with limited time windows to load/unload freight without impacting schedule integrity.
3. The market size for city logistics should be large enough to support co-modality. Cargo-Tram and E-Tram in Zurich operate well as they are supporting public service with stable demand. Meanwhile, the French Tramfret project's downfall is partly due to the small population of Saint-Etienne, making the entire project reliant on one local supermarket partner. If the partner is not satisfied with the trial results, there is no other local business taking over.
4. If the freight will share the same vehicle with passengers, the safety for passengers and the security for goods are important issues, especially when the ULDs travel unattended.

With the lessons learnt from global schemes, co-modality can potentially save cost, reduce emissions and congestion, and better utilise spare capacity in the public transport system. However, realising these opportunities without significant disruption to passengers needs consideration. Previous successful pilot projects suggest sustainable co-modality projects need moderate up-front investment and involve starting small, with freight sharing the same vehicle alongside passengers advisable. The project also needs to have a stable demand and ensure the safety and security for both freight and passengers.

While understanding global best practice is helpful, it is crucial to understand the concept context and the application through a Sydney CBD lens. The views of local stakeholders that manage the public transport network and those who operate logistics services are needed to construct and assess a viable business model.

3 Co-modality for Sydney CBD area

With the understanding of global co-modality schemes, the project conducted a workshop to investigate local challenges and opportunities for co-modality in Sydney CBD. Public transport service operators and logistics business stakeholders were invited to attend. The input from stakeholders, combined with lessons learnt from abroad, define the key components of a co-modal journey for Sydney CBD and are used as a basis for detailed analyses (in Section 4 and 5).

3.1 Multi-Criteria Option Analysis (MCOA) with views from stakeholders

Workshop participants included those with roles in Transport for NSW with expertise in infrastructure management, network operations management, network strategy, freight operations, human factors, security and safety, place making, and innovation. A few large logistics operators conducting last-mile deliveries in Sydney CBD also attended to provide an operational perspective.

Participants were first asked to consider the challenges and essential requirements across four areas of co-modality interest, for both attended and unattended journeys. The four areas were informed by challenges noted in global schemes and clustered into two topics.

The challenges and essential requirements identified helped formulate '*how might we*' (HMW) questions to get participants to flip problems to opportunities to progress the concept. Interestingly, there was no strong opposition to the concept by any of the stakeholders. The value of the concept and way of operating was seen across the various perspectives, with focus spent on what needs to happen to maximise the potential and sustainability of the approach.

The workshop process and key takeaways are summarised in Figure 6, with explanation in Sections 3.1.1 and 3.1.2 and detailed HMW outcomes in 6.4Appendix A.

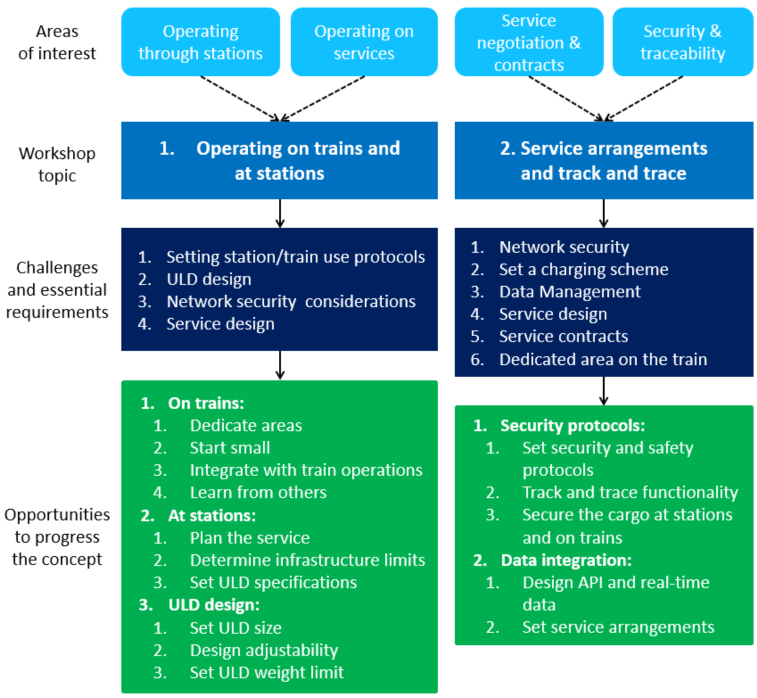

Figure 6 Workshop process and key takeaways

3.1.1 Operation on the train and at stations

The key challenges and essential requirements of a co-modal journey passing through the station and travelling on public transport include:

3.1.1.1 Setting station/train use protocols

- Dwell times on platforms, the concourse, service delays from loading/unloading, and acceptance by customers of use of space need to be considered. Designated storage areas both in the station and on the train were important.
- If the ULD is unaccompanied, resources should be allocated to load and unload the cargo. Decisions should be made regarding who provides the resource (public transport operator/logistics operator/third party) and how cooperation could be arranged (which will likely require agreements on data, equipment use, liability, etc).

3.1.1.2 ULD design

- The ULD should be designed with wheels and brakes to keep stable during the journey and be designed to fit the dimensions and capacities of public transport infrastructure, such as station lifts, ramps, gates, escalators and gaps between train and platform.
- Designing a stable and secure ULD was also raised as important for the unaccompanied cargo journey.

3.1.1.3 Network security considerations

- Limits on the types, weight and dimensions of goods should be set. A check-in procedure is recommended with monitoring and security checks.
- For the unaccompanied journey, network security concerns were raised, with methods to track, secure and ensure ULD loads both on public transport and in stations discussed. Possible solutions include locking to the vehicle and station posts and real-time CCTV monitoring.

3.1.1.4 Service design

- Co-modality should utilise off-peak capacity. The potential for overnight service is for next day delivery was discussed, noting that a larger volume of goods could then be conveyed. Simultaneously, there would be a higher requirement for a guaranteed storage area and security in the station and on the train.

3.1.1.5 Opportunities to progress the concept

The details of the last two takeaways—network security and service design—are more relevant to the second topic cluster and were incorporated into the HMW statements of the second topic accordingly.

Three HMW statements were devised for this topic with participants' ideas for each statement collected. Each idea was ranked in terms of how valuable participants felt it was to advance the concept and how complex it would be to implement on a scale of very low, low, moderate, high, and very high. The discussion outcomes are presented in Table 1 and explained further in Appendix A:

Table 1 Summary of 'how might we' statements for the topic of "Operating on trains and at stations"

	Value	Complexity
HMW1: Storage location on the train		
Dedicate areas for co-modality	Moderate	High
Start small	Very high	Moderate
Integration with train operations	High	Very high
Learn from others	Very high	Very low
HMW2: Handling at stations		
Planning the service	Very high	Very high
Determine infrastructure limits	Very high	Moderate
Set ULD specifications	High	High
HMW3: ULD design		
ULD size	High	Very low
ULD adjustability	High	Moderate/Easy
ULD weight	Very high	Moderate

3.1.2 Service arrangement and track and trace

The key challenges and essential requirements the service arrangements and track and trace functionality that support the co-modal journey include:

3.1.2.1 Network security

- The entire network should be safeguarded by regulating the types of goods transported. Cargo manifests should be provided to mitigate misuse and security risks for unattended ULDs.

3.1.2.2 Set a charging scheme

- Goods on a service should be charged differently to passengers or with a special Opal card.

3.1.2.3 Data management

- Several issues need to be considered on data handling, including reportability, privacy, integration with Opal data, and train run information.

3.1.2.4 Service design

- Protocols should be designed to handle disruption such as late running, cancelled services, or unclaimed goods.

3.1.2.5 Service contracts

- The exact service contract should be designed to explore if the service is open to all logistics operators or dedicated to a single operator, perhaps by competitive tender. The liability of facilities and workload between the transport service operator and logistics operator(s) should be appropriately assigned; the exact lines, stations, carriage types and time of the co-modal delivery service should be investigated.

3.1.2.6 Dedicated area on the train

- Dedicated areas on carriages to avoid security and fire incidents. Certain logistics operators are interested in dedicated freight carriages to meet high-volume requirements.

3.1.2.7 Opportunities to progress the concept

Similar to the first topic cluster (Section 3.1.1.5), HMW questions are posed for further discussion. As the first three takeaways are about network security and data management, our first HMW question in this topic cluster is about the security protocols, and the second is about data integration (Table 2 and explained further in Appendix A). Topics on service design and contract are discussed in Section 5.

Table 2 Summary of 'how might we' statements for the second topic cluster

	Value	Complexity
HMW4: Security protocols		
Set security and safety protocols	Very high	Very high
Track and trace functionality	Very high	Very high
Secure the cargo at stations and on trains	High	Low
HMW5: Data integration		
Design API and real-time data	Very high	High
Set service arrangements	Very high	Moderate

3.2 Key components of co-modal delivery

The lessons learnt from the global examples and topics discussed in the workshop have been incorporated to identify the components of a typical co-modal delivery journey. Using Sydney Trains as an example, a typical co-modal journey has been categorised into seven key stages, with options for each stage listed (Figure 7). This categorisation helps us understand the different options and decisions available at each stage, and what the co-modal journey may look like:

- Components 1 (service time), 6 (ULD related issues) and 7 (track & trace and security & safety) straddle the entire door to door journey.
- Component 2 (service area) represents the area of coverage for both the first mile and the last mile.
- Components 3 (liability transfer), 4 (boarding/alighting), and 5 (on the train) construct the middle mile. This could be the real crux of co-modality and options chosen within these components have a strong influence on the viability of the concept.

Each component has interdependencies with the other components. A decision to have the ULD travel unaccompanied, for example, gives rise to the need for personnel waiting at stations to receive the ULDs and transfer them to staging points within the station. The availability of storage locations within stations may then limit the stations where co-modality could operate on the network.

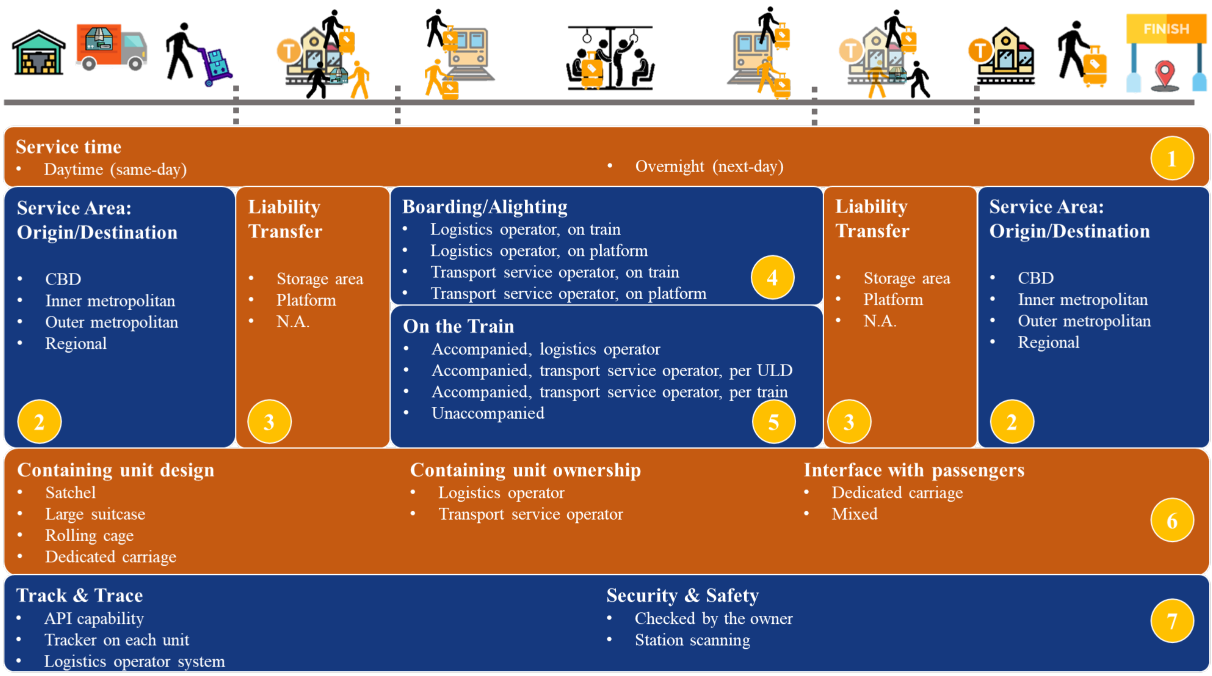

Figure 7 Key components of co-modal delivery

1. **Service time:** A co-modality service could operate in the daytime to provide same day delivery and/or overnight to perform a next day delivery. The choice of service time by the logistics operator largely stems from their business model and influences the nature of the co-modal journey. For example, an overnight (next day) service tends to be larger in volume and may suit a larger ULD design, which may require assistance to board/alight and dedicated stowage locations on the train. However, the same day services are generally more on-demand and smaller in volume, likely lending itself to a smaller and more manageable ULD size that requires no intervention to load/unload and can be mixed with passengers.

2. **Service area:** The project has focused initially on the service from outer metropolitan warehouses to the CBD area, but recognises that other options, particularly regional areas, are also worth investigating for co-modality. In determining service areas, there would need to be a detailed understanding of what specific stations could work for the other components of the journey. For example, a dedicated carriage of cargo could only be unloaded at a 'turn back' station due to the time required to unload and the need for adequate storage space to receive the cargo away from passenger flows.

3. **Liability transfer:** Depending on decisions in the adjoining journey components, there could be a point where the custody of goods is transferred between actors. The transfer may have a temporal element, meaning a ULD may need to be stored somewhere before/after the journey. Liability and processes at transfer points need to be ironed out with actors in the journey based on their service arrangement.

4. **Boarding/alighting:** If the logistics operator accompanies the ULD during the journey, then intuitively the transfer of ULDs on and off trains would be handled by them. However, should liability transfer to the transport service operator at the station, or the ULD travel unaccompanied, the transport service operator may have a role in facilitating loading/unloading of the ULD. Potential options could be the transport service operator personnel at stations or a dedicated 'freight porter' (explained below) facilitating the load/unload.

5. **On the train:** There are effectively two options for how goods could travel on a service; unaccompanied or accompanied. Within accompanied journeys, the actor supervising the goods in transit can range from the transport service operator or the logistics operator side or be a dedicated 'freight porter' resource. The 'freight porter' concept was raised during the workshop as a means to have ULDs accompanied and supervised on service, with the operating cost shared amongst logistics operators using the service. Unaccompanied ULD journeys were favoured by the logistics operators in the workshop. However, which actors are required to load/unload the ULDs at either end of the journey (component 4) and the liability transfer points (component 3) need to be defined. An unaccompanied journey would steer towards requiring a dedicated space on a train and introduce greater track and trace, safety and security concerns that would need to be addressed, again highlighting the interdependency between the components in the design of a co-modal journey.

6. **ULD:** The choice of ULD has a significant influence on the design of a co-modal journey. Its ownership would impact the service arrangement; if the logistics operator owns the devices, they could load the ULDs at their warehouses or distribution centres and then send them to the train stations. If the transport service operator has the ownership, the ULDs would be loaded within the stations. Regardless of the ownership, an acceptable balance between logistics and transport service operators' requirements on the network would need to be struck. The size of the ULD influences, and is influenced by, other components in the journey. It can range from a hand-held satchel, through to a more cumbersome large luggage-sized device, to a roll cage. Smaller ULDs can better integrate with the regular operation of the public transport network, with little intervention or disruption at stations or on services. In contrast, a large ULD may introduce complexity to other components in the journey. For example, rolling cages may require storage within the station or platform, which requires space and storage capacity. A roll cage would require a ramp to load on and off the train, introducing questions as to who performs that task, the potential risk to timetable integrity and which service areas this could happen (for example, only at turn back stations?).

7. **Track & trace and security & safety:** The scale of track and trace, and security and safety, required for a journey is influenced by the other components and the requirements of operators. For unaccompanied journeys, a greater degree of assurance and coordination is required to ensure the cargo passes on and through the network safely. Accompanied journeys may have a lesser degree of track and trace or security & safety requirements. However, there will still be a need for logistics providers (and potentially also the rail operator) to have visibility of what is travelling where.

Co-modality is comprised of a series of co-existing and interdependent components. A decision on one component will influence the shape of upstream and downstream components and broader components that straddle the entire journey (service time, ULD design, and traceability and security). This section introduced the components and options that could exist within them. These options were derived primarily from stakeholder input. However, due to the intricacies and interplays between components, no one structure of what co-modality would look like for Sydney CBD was landed upon.

The next section focuses on what a viable co-modality structure could look like by drilling down and quantifying options within the legs of the journey. The quantification will focus on the last and middle mile, due to the potential advantages of co-modal solutions to mitigate externalities as compared to conventional forms of delivery by truck and van. The first mile will be excluded from quantification, as it will likely be conducted by a truck or van in both conventional and co-modal approaches (a truck/van would be required to deliver the cargo or ULDs the first mile to a station location).

4 Option analysis

Numerical analysis was carried out to estimate the commercial feasibility of co-modal journey options. Although assessing triple bottom line benefits is more of the aim of this research, it is recognised that the journey must make commercial sense in order to be taken up by industry. If co-modality cannot produce commercial benefits, logistics operators may be less inclined to invest in the concept and continue conventional deliveries by truck or van. As such, this section focuses on commercial feasibility. Triple bottom line benefits are explored in Sections 5.4 and 6.2.

For the last mile delivery in CBD area, a virtual simulation was undertaken to compare the travel time and distance of co-modal option and the conventional truck/van delivery option. Sensitivity testing was then performed to understand the relationship between unit delivery cost and the total number of delivery consignments and congestion in the CBD area. The middle mile delivery is explored with sensitivity testing on how the unit cost changes with travel distance and delivery capacity.

4.1 Last mile delivery

4.1.1 Desktop assessment of co-modality in Sydney CBD

Using Google Maps, a desktop simulation was set up to compare the efficiency of co-modal deliveries in Sydney CBD against standard commercial truck deliveries. Public transport options for both train and tram are used in the co-modal delivery. The same ten delivery points were selected from a study in 2016, with the starting point being the Transport Management Centre in Eveleigh (Figure 8).

The commercial truck's delivery time and route information were taken from a 2016 study conducted by Transport for NSW focused on comparing driving and cycling times taken to complete ten deliveries in the CBD. The virtual co-modal simulation used public transport and walking to complete the deliveries.

The desktop assessment recorded:

1. Travel routes (actual routes from the 2016 assessment, Google Maps routes for the virtual co-modal simulation).
2. Time spent walking, driving, and being transported, further categorised by:
    - Driving or travelling on public transport
    - Searching for parking
    - Travelling between parking/public transport/delivery locations
    - Getting back to the car or public transport after delivering a parcel
3. Distance travelled by walking, driving and public transport.

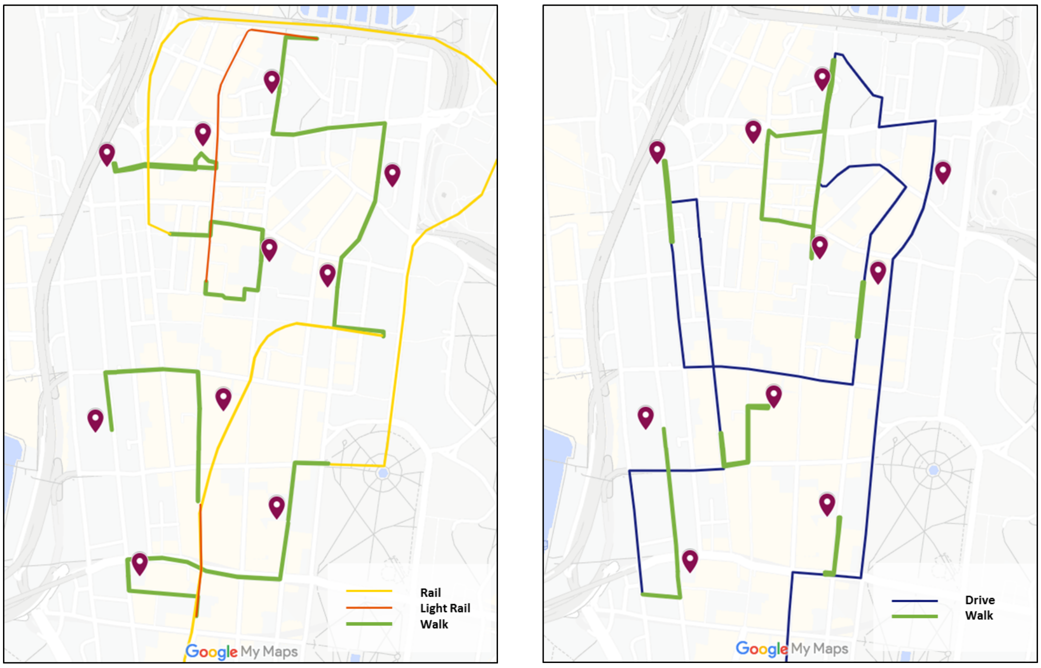

Figure 8 Routes of truck and Co-modality deliveries

Figure 9 shows that both scenarios had a similar walking distance, while co-modality involved slightly less distance on public transport than the distance driven by truck/van. In total, co-modality involves much less time travelling than the truck/van alternative.

Truck deliveries are more time consuming than the co-modal option as:

1. Drivers suffer road congestion and therefore spend more time driving; and
2. Loading and parking areas in the CBD are scarce, and availability is unpredictable. This forces the driver to find alternative, sub-optimal parking places that are further away from their destinations, contributing to longer delivery times.

The assessment concluded that the longer time taken to deliver the ten items pushed the total cost for truck delivery to $90, compared to the total cost of co-modal delivery at $50. [2]

[2] Driver+truck: $38/hour; Co-modality delivery personnel: $30/hour; Fuel cost: negligible; Public transport cost: retrieved from https://transportnsw.info/ti.ckets-opal/opal/fares-payments/adult-fares

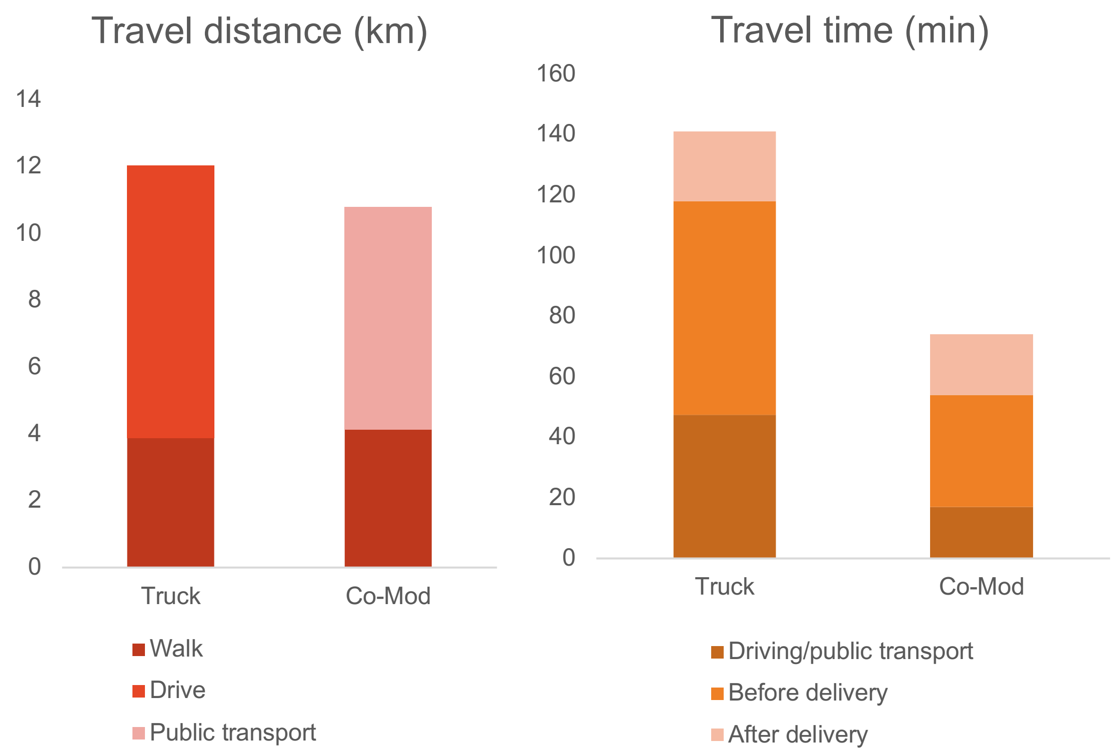

Figure 9 Comparison between the truck and co-modality deliveries at Sydney CBD area

The desktop assessment indicates that co-modality could save a significant amount of delivery time in congested urban environments, particularly as traditional truck/van drivers tend to spend a considerable amount of time finding a parking place and walking to/from delivery addresses. Whilst in reality the co-modality travel time could be higher, owing to waiting for public transport services, it is reasonable to assume that the total travel time would still be less than the truck option. For logistics operators, the saving in time could equate to reductions in the cost of conducting deliveries, particularly the labour cost.

4.1.2 Cost analysis of co-modality in Sydney CBD

The desktop analysis is further expanded into a series of quantitative sensitivity tests to investigate the cost impacts of the total number of parcels and traffic situation between the two delivery options. Detailed parameter setup information can be found in Appendix B.

There are several basic assumptions in the following sensitivity tests:

- In the truck (and van) delivery option, the courier could make multiple deliveries from each parking stop. The higher the number of consignments, the greater chance the addresses are close to each other, and the courier could deliver more parcels from one parking space. The traffic situation is modelled in a probabilistic way. The truck would face a probability to be caught in congestion between two consecutive parking spaces. Therefore, the costs related to truck delivery are expected values.
- For co-modality, the total time between every two consecutive deliveries is assumed to negatively relate to the total number of consignments. The rationale is similar to the assumption in truck (and van) delivery: With more parcels to deliver, there will be a higher chance to have destinations closer to each other and hence less time for each delivery. Though each delivery time is assumed to be fixed, the courier can make ad hoc decisions in the CBD on whether to use public transport, which is defined as a probability variable. The network is assumed to be operating at normal service levels

(i.e., not degraded mode). The adult ticket fare is used to calculate the ULD fare on public transport, as the ULD would be accompanied for the final mile.

- The co-modal approach is accompanied (goods do not travel without accompaniment on the public transport service, with a corresponding labour cost factored in)
- It is assumed that there are ten parcels for delivery, consistent with the desktop assessment.
- The truck (and van) has a 50% probability of being impacted by road network congested between each two parking spaces.

Figure 10 illustrates the relationship between the number of parcels and the last mile delivery cost per unit. Both options enjoy the economies of scale — the more parcels, the less the average unit cost. The truck delivery cost declines after a plateau because of the assumed function to define the number of deliveries per parking space. Consistent with the desktop assessment, where only ten parcels are considered for delivery, co-modality has an advantage in unit cost. When the number of consignments increases beyond 20, it is assumed that the economy of scale appears as the truck courier could do multiple deliveries after parking. The analysis demonstrates the advantage of the co-modal option for last-mile delivery cost when the total number of consignments is low. When the total number is high, co-modality does not have a clear advantage over the traditional delivery option. Practically speaking, the handling of a 'truck size' volume of parcels would also present challenges in handling between stops and on/off public transport services, supporting the notion that a lower volume suits a co-modal approach.

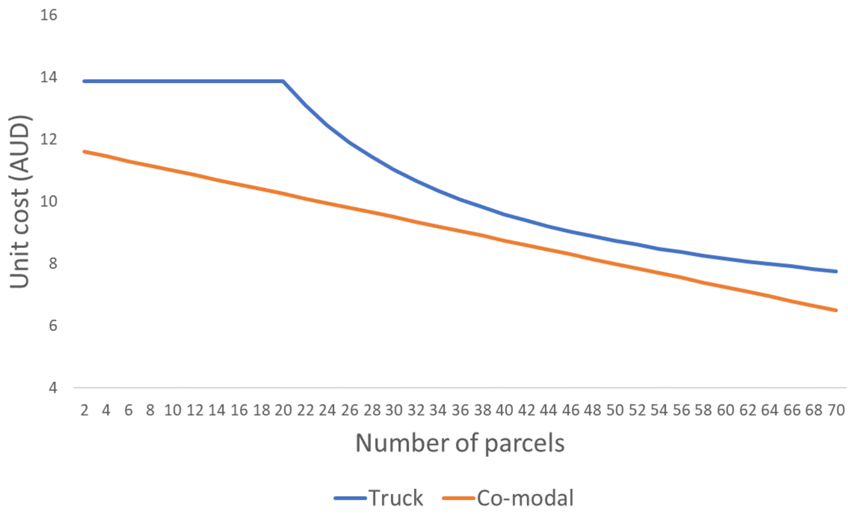

Figure 10 Sensitivity analysis (unit cost vs. number of parcels)

The second sensitivity analysis shows how the traffic situation would impact unit cost (see Figure 11). Intuitively, a higher expected congestion time increase a truck delivery's unit cost due to the longer total delivery time. As public transport systems (heavy rail based) are generally separated from the road network and less susceptible to disruption from traffic, congestion is deemed to be a factor with little influence in co-modal cost calculation, compared to the conventional truck delivery mode.

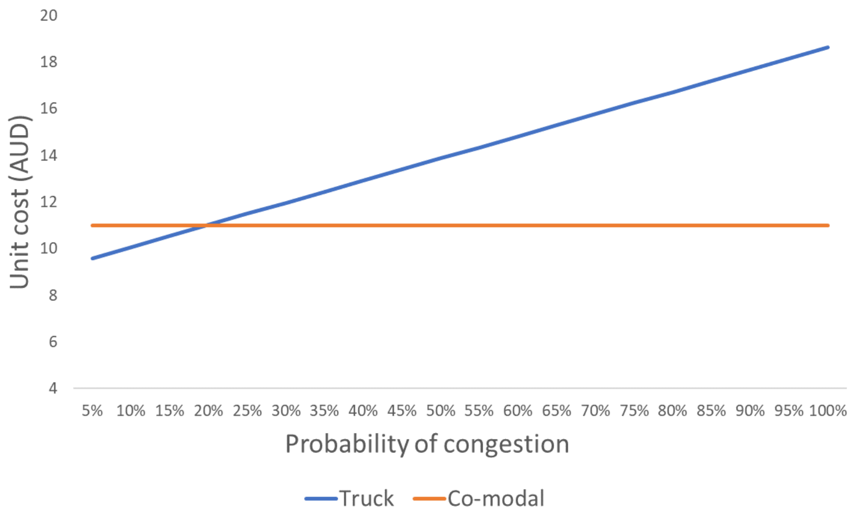

Figure 11 Sensitivity analysis (unit cost vs. probability of road congestion)

4.1.3 Summary

Co-modality, in this case a combination of walking and opportunistic public transport use, affords time and cost advantages over conventional truck (and van) delivery for the last mile, but only when dealing with a smaller number of consignments. As the number of consignments increases, the cost advantage of co-modality over truck delivery dissipates as the truck/van acts as a mobile warehouse. However, the co-modality option faces less congestion associated costs than conventional truck delivery, as the heavy rail network operates separately from the road network. For urban congested environments, such as Sydney CBD, with competition for the road network and kerbside capacity, it is reasonable to suggest that the probability of experiencing congestion to the point where co-modality affords an advantage over conventional delivery methods.

While the sensitivity assessment demonstrates the value of co-modality approaches in the last mile, its benefit opportunity should be tempered with the practicality of handling a large ULD, or multiple ULDs in stations, on city streets and in CBD buildings, compared to a truck, which for all intents and purposes acts like a mobile warehouse. As such, co-modality is an option for the last mile, alongside conventional delivery by truck, vans, and cargo-cycles.

4.2 Middle mile delivery

4.2.1 Capacity of the Sydney Trains network

A desktop analysis on the capacity of the heavy rail network was undertaken to understand when co-modality could exist alongside passenger movements without creating an unacceptable level of congestion or risk to the performance of the transport service. Train occupancy data was sourced from Open Data Hub[3] for 12 February 2019 and a few heavy rail stations (see Yennora at Figure 12 as an example, for more stations, see Appendix C). The data identified high patronage windows relating to conventional passenger peaks. The window of opportunity for co-modality to integrate with passenger services is during the inter-peak, roughly from 11 AM to 3 PM. The window of opportunity on the network aligns with the same-day market, where parcels are picked up from the origin in the morning and delivered that afternoon.

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[3] https://opendata.transport.nsw.gov.au/dataset/train-occupancy-nov-2018-feb-2019/resource/ba443167-84d2-4366-beaa-ed3b83ac4132

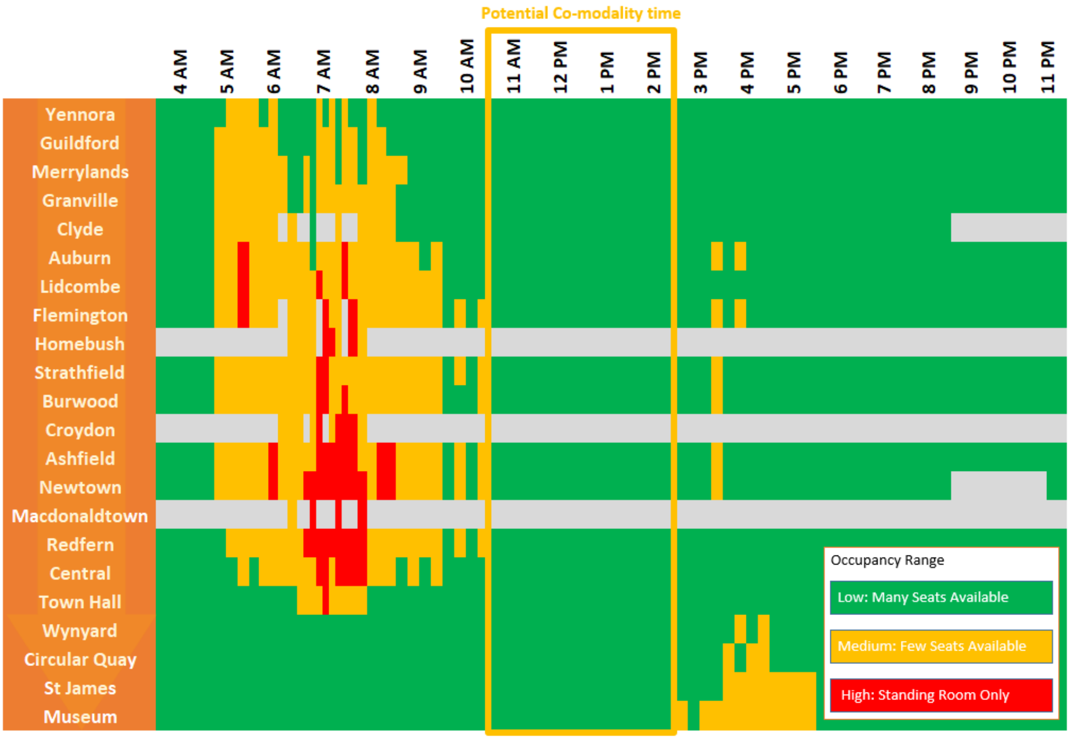

Figure 12 Capacity analysis—Yennora

4.2.2 Cost analysis of co-modality in middle mile delivery

Sydney Trains was chosen as the public transport network for the co-modal option due to its broad geographical reach to industrial areas across Sydney, regional NSW and other cities, suitable station infrastructure and connectivity to Sydney CBD.

The components considered to impact unit delivery cost directly are the total number of parcels and distance travelled. Co-modality is compared with truck only delivery, distinguishing between the co-modal options, namely where the ULDs on the trains are accompanied by the logistics provider or travel unaccompanied. Default parameter values are consistent with Section 4.1.2 and detailed in Appendix B.

The first sensitivity test considers the number of parcels for delivery (Figure 13). The unaccompanied delivery option has cost advantages when there are fewer consignments. Truck and accompanied co-modality start with a high cost because the operating costs are averaged to only a few consignments. The graph demonstrates that when the number of consignments is large enough, the economy of scale is realised, and costs reach a plateau. The sensitivity analysis echoes sentiments discussed in the workshop, where a greater number of parcels best suits conventional (road) forms of delivery, whereas delivering a small quantity same day is not economical for a logistics provider.

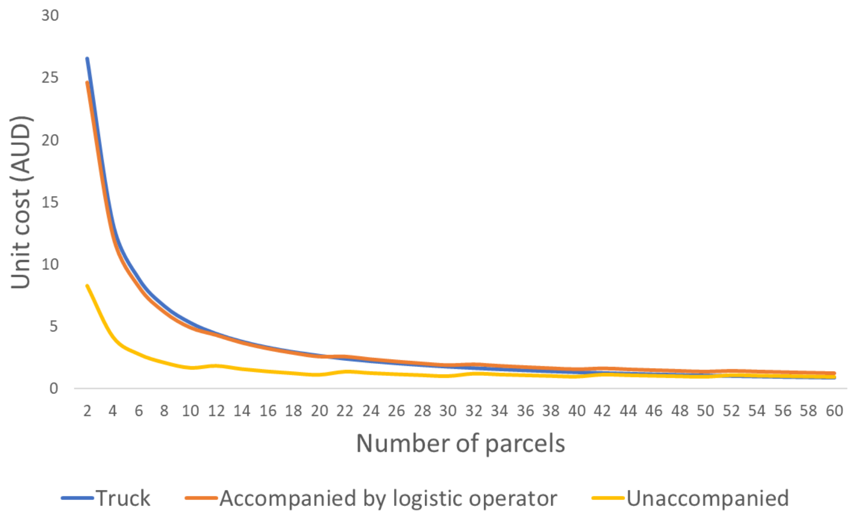

Figure 13 Sensitivity analysis (unit cost vs. number of parcels)

The second sensitivity analysis explores how cost changes along with distance (Figure 14). Unaccompanied cost is almost unchanged, as ULD ticket fare is assumed to increase very moderately with travel distance and shared by all the parcels. The other two options' unit costs are positively impacted by the distance, due to the operating cost to accompany the ULDs. When the middle mile is beyond 10 km, unaccompanied delivery gains cost advantage. For shorter journeys, less than 10km to the CBD, the truck option affords the lowest unit cost for parcel delivery.

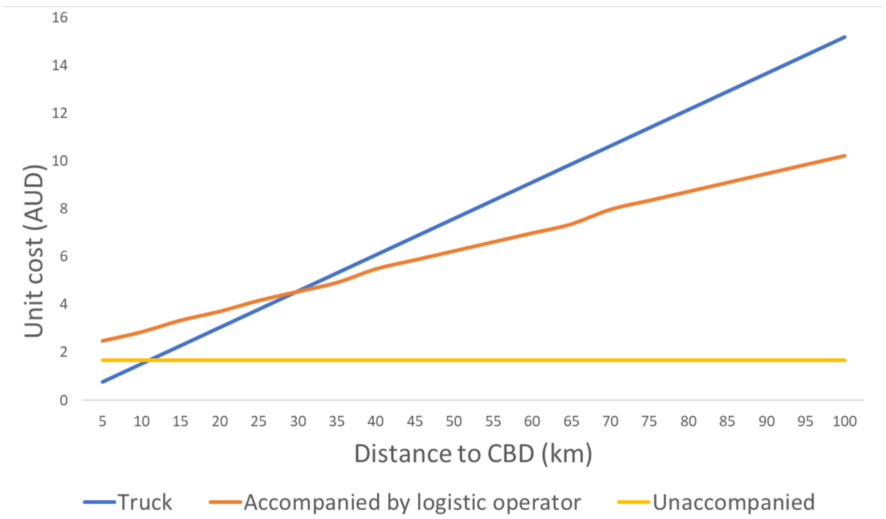

Figure 14 Sensitivity analysis (unit cost vs. distance to CBD)

4.2.3 Summary

The above analysis leads to the following conclusions:

- A small quantity of parcels sent unaccompanied on a train is more cost effective than sending the same quantity via truck.
- With relatively flat costs as distance increases, sending freight unaccompanied via train is significantly more cost effective than sending the same modest quantity via truck or with accompanied labour.

Consistent with the insights from stakeholder workshops, co-modal delivery is found to be an attractive option where a small consignment quantity needs to be sent a longer distance on an urgent timescale. This points towards serving the unaccompanied middle mile for same day delivery.

5 Proof of Concept (PoC)

This section seeks to advance and test the same day unaccompanied middle mile delivery option as a Proof of Concept (PoC). The PoC will also address some concerns about this option identified in the workshop.

A description of the delivery process is first presented as a proposal of the service arrangement. A brief architecture of the management system and data flow is then introduced to map out and address traceability and security concerns raised in the workshop. We then present a market size evaluation to estimate the potential benefits of co-modality and use data from the logistics industry to test assumptions in the PoC.

5.1 Examination of the delivery process

The process of a same day unaccompanied co-modal delivery (Figure 15) is detailed in the Supply Chain Operations Reference (SCOR) level 3—Process Element Level. On this level, specific information about element definitions and information inputs/outputs are presented for the different actors in the chain to understand the key business activities, and data transmission needs to occur in a viable co-modality model.

The chart comprises two parts: physical delivery flow on the right and the information management processes on the left. The transport operator (for example, Sydney Trains) and logistics operator's responsibilities are indicated by their respective coloured columns in the physical delivery flow. The information flow shows the documents or data updates corresponding to every physical delivery step. Different colours of the entries are used to record the data sources to construct the co-modal delivery management database, accessible by both stakeholders. The management database has three primary data sources: 1) Available data from the transport service operator, 2) Available data from the logistics operator, and 3) New entries specifically required for co-modality. For completeness, processes during the first and last mile are sketched out, despite co-modality being focused on the middle mile in the PoC.

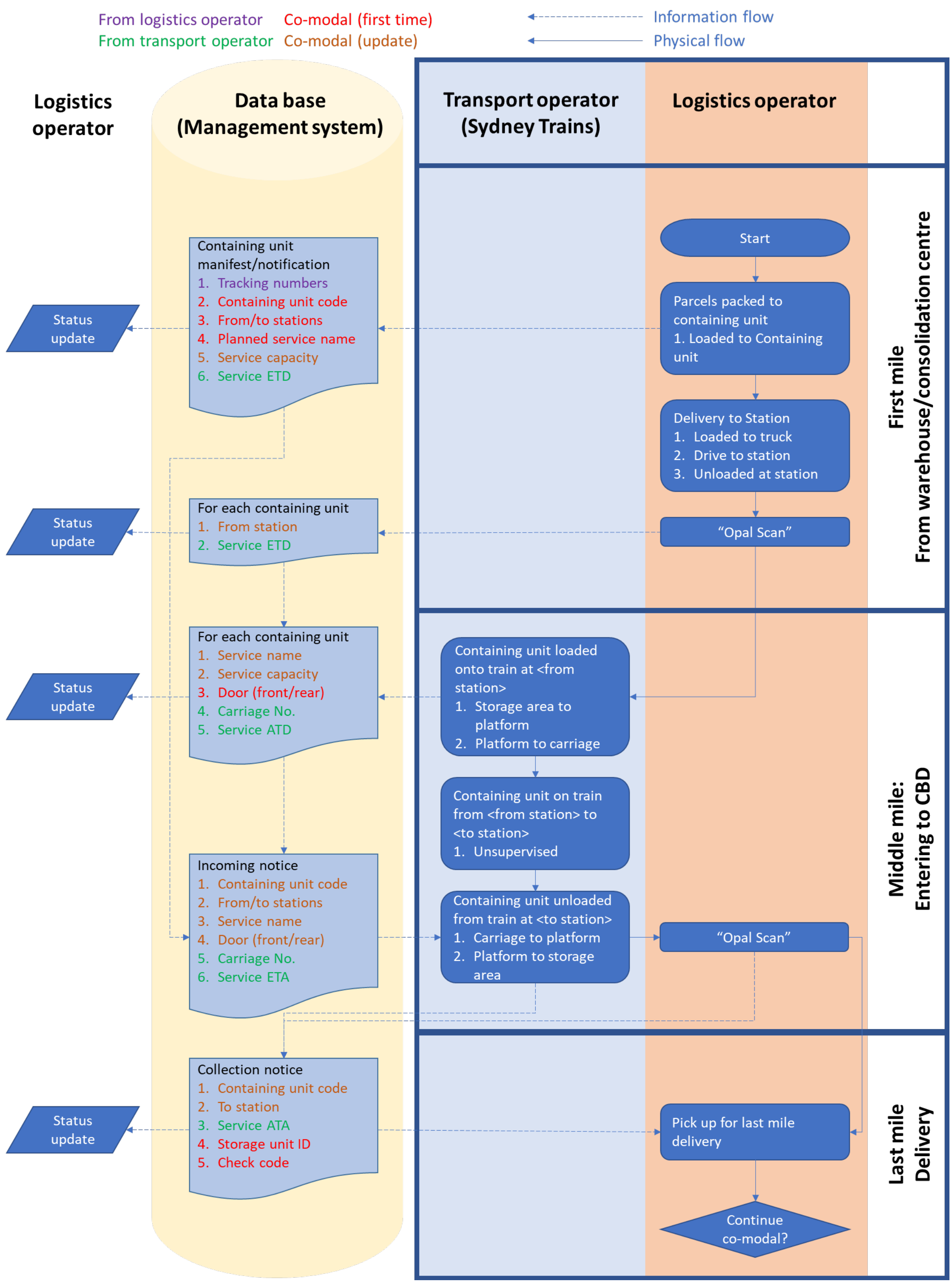

Figure 15 The delivery process of co-modality

5.1.1 First mile: From the warehouse to the origin station

- The process starts with the logistics operator's warehouse. Instead of being packed directly into trucks, the parcels are packed into specially designed ULDs for co-modal delivery.
- The logistics operator would generate a ULD specific manifest with its unique ID, scheduled stations to use and train service to catch. The parcels stored in this ULD

would be linked to the ULD manifest with their tracking numbers in the management database. The manifest could be treated as a notification to the transport service operator for their upcoming arrival.
- After the ULD is conveyed to the scheduled train station, it checks in to the transport service operator like an "opal scan", updates its status in the database and gets updated information on the scheduled train service.

5.1.2 Middle mile: Point to point

- The point-to-point delivery starts from the transport operator staff sending the ULDs from the storage area to the platform and then the correct train service, according to the management database's scheduled service information.
- Details of the ULD's storage area on the train would be updated in the database, including the train service, carriage number and door location. The train's capacity information would also be updated.
- An arriving ULD notice would be generated for collection at the destination station. With the notice, the designated staff at the arrival station would know the expected time of the service arrival and location of the arriving ULD on the train.
- The ULD would check out from the destination station like an "opal scan" and be temporarily stored in a designated storage area for the last-mile delivery in CBD.

5.1.3 Last mile: Deliveries in the CBD

- The courier would receive a notice for collection at the start of their last-mile delivery.
- At this stage, there could be multiple ways to complete the final delivery, including traditional truck delivery, cargo bike delivery, foot delivery and co-modal options previously discussed.
- ULD status would be updated with the information of the courier who is responsible for the last-mile delivery.
- For the co-modal last-mile option, the courier needs to return the empty ULD to a designated location. The whole delivery is then concluded with a final status update of each parcel.

5.2 Technical process flow of ULD tracking

A primary concern raised by stakeholders in the workshop was the need to know where the ULD was at all times, and what was in it, throughout the journey to ensure integrity to the cargo and the broader transport network. Learnings are taken from the airfreight industry in the design of this process.

Another identified challenge is incorporating data from different sources and developing a proprietary management system to integrate them. This management system is used as a medium that allows the transport service operator, logistics operator, cargo owner and other stakeholders to lodge, view and share information to manage the service.

As unaccompanied co-modality leads to more complexity and data streams for assurance, we introduce a technical process flow to showcase the availability of the data origins. While geared towards a journey on the heavy rail system in line with project scope, this process flow could be applicable to other transport modes, such as light rail.

The proposed tracking system would compose three data streams; (1) train information from Transport for NSW; (2) parcel information from the logistics operator and; (3) the co-modality relevant information (Figure 16).

Train information could be obtained from Transport for NSW Open Data application programming interfaces (APIs). From the General Transit Feed Specification (GTFS), the co-modality service data base could access the scheduled train service information for each ULD. With the recorded "trips" information, the trip ID, timetable, and platform could be obtained. After the train service starts, its information would start updating with the real-time GTFS (GTFS-R). The status of a train service would be updated with any delay condition, vehicle IDs, real-time location and departure and arrival times.

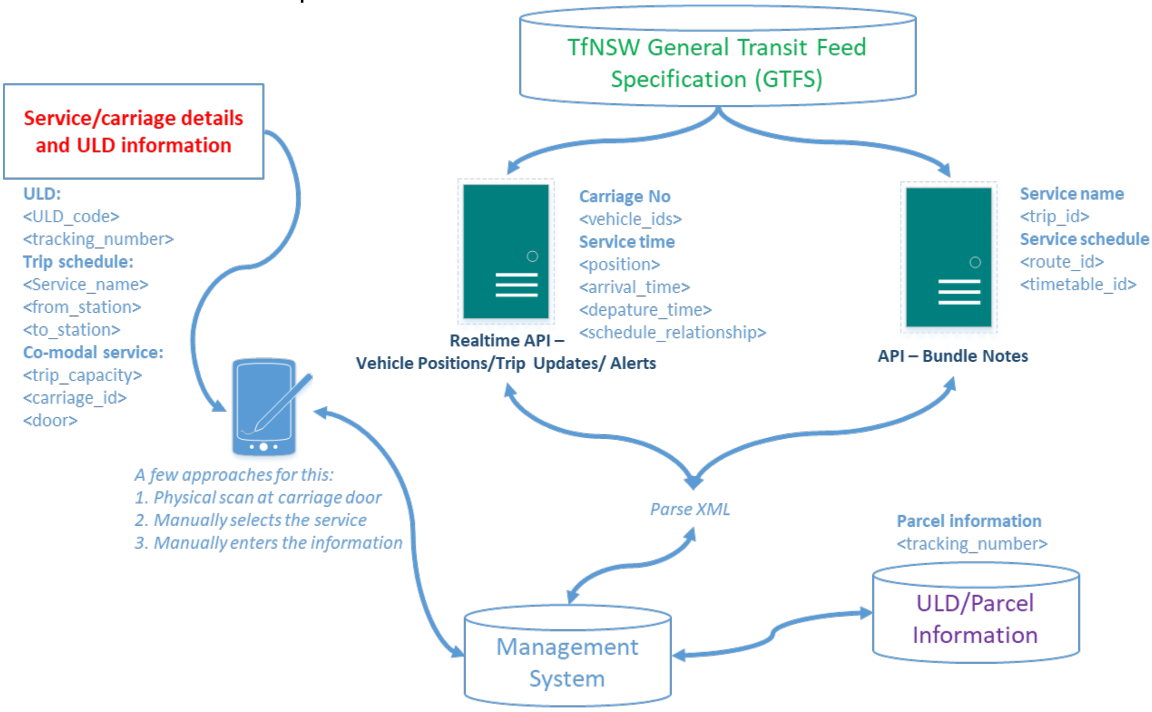

Figure 16 The technical process of co-modality

Each ULD would be assigned with a unique code. After being loaded in the warehouse, the ULD code should be connected with all loaded parcels' tracking numbers. Scheduled train service information needs to be assigned to the ULD code. Essential data to input is the storage position on the train, including service_name and carriage_id, door. This information would need to be recorded manually with the portable data terminal (PDT), although ideally, a bar/QR code to scan at the carriage door would overcome manual entry. Once this information is submitted, confirmation of the ULD's storage area on carriage would be uploaded to the database. This would update the train service's capacity status for both co-modality service and transport service operator.

5.3 Market size evaluation

To understand the scale of potential benefits, an estimation is first performed on the market opportunity of same day deliveries for Sydney CBD. This estimation is validated, so far as reasonably practical, by logistics operational data in order to land on an evaluation that is reliable and representative.

The logistics operational data is from the courier sector and is understood to have a greater portion of same day shipments than some other operations completing deliveries into Sydney CBD. As such, reliance on this data may skew conclusions of higher market size and therefore potential benefits. Data for one week worth of deliveries made in September 2019 and September 2020 was supplied. The September 2019 values were considered representational of 'normal demand' and used in the calculations performed below. The September 2020 data was during the Covid-19 pandemic. The pandemic saw travel and parcel delivery demands of

Sydney change and for the purposes of this project, were considered as less representational of 'normal demand'.

Where there is a significant difference between what is assumed to be a reliable value, and what the logistics operator data shows, a compromise value is proposed.

Parameters of the model and a detailed methodology of the evaluation approach are detailed in Appendix C.

5.3.1 Market size for same day deliveries in Sydney CBD

From the total number of parcel deliveries in Australia and the fraction of people working in Sydney's CBD, an estimate of the annual same day deliveries is made. This assumption is needed as the proportion of same day delivery in the parcel industry is not clearly recorded and its estimation varies across different sources. For example, BCG (2013) reported that 9% of all customers think the same day delivery would improve their shopping experience. McKinsey & Company (2016) surveyed that 23% of customers stated they would prefer same day delivery. However, these sources only recorded stated preference, which is likely to overestimate the market share of same day delivery. In 2019, the global same day delivery market size was 7.38 billion USD, which is about 1.7% of the whole delivery market (Marketwatch, 2021).

As the same day delivery market is estimated to grow, a conservative assumption of 5% market share for same day parcel delivery is proposed as the lower bound in the calculation. The logistics operator data for 2019 was analysed to determine the validity of this conservative assumption. The data revealed that 28% of all deliveries undertaken by the operator were for same day deliveries (explored further in Appendix C). This value represented the upper bound in the calculation. A middle ground of 15% is proposed to represent a more mature market, which calculates the potential for Sydney CBD to be a more reasonable 9,000 deliveries (Figure 17). This middle ground is taken forward in the calculations.

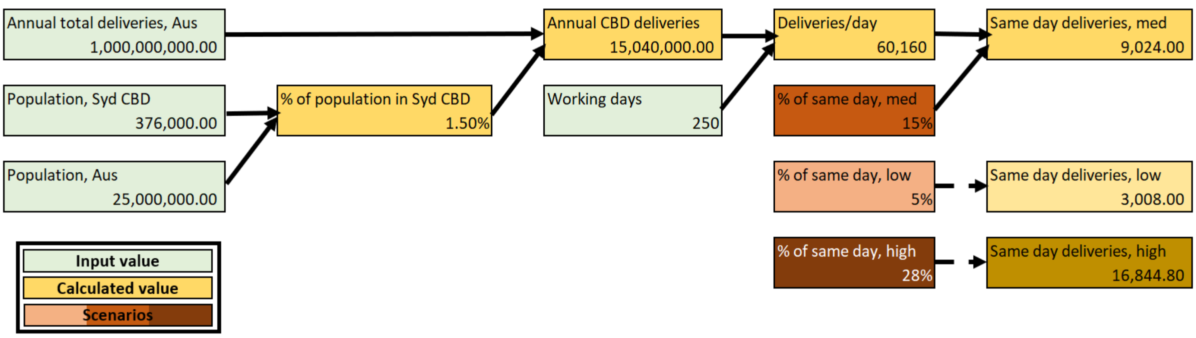

Figure 17 Market size estimation—same day deliveries in Sydney CBD

5.3.2 Market size for co-modality deliveries in Sydney CBD

Using the medium same day market size of Sydney CBD as a basis, the potential of the co-modality market is then calculated. Not all same day deliveries would make sense for co-modality and may best sit with conventional forms of delivery. For example, parcels with an origin far away from heavy rail stations or origin locations very close to the Sydney CBD (as demonstrated in Figure 13) may warrant delivery by conventional methods. Parcels that are very heavy may also best suit conventional delivery methods, as they may present safety risks when needing to be loaded and unloaded off passenger services.

A conservative estimate of the potential same day market size that could be performed with co-modal methods was assumed to be 10%, reflecting the notion of starting small (as discussed in Section 3.1.1) or a slower or lower interest from industry to partake. The logistics operator data were analysed to understand the potential of same day deliveries that could be performed by co-modal methods. The data suggests that 48% of the same day parcels could be performed by co-modality (explored further in Appendix C). This high value is considered the upper bound and assumes that parcels that are under a particular weight and within relative proximity to a heavy rail train station would be considered for co-modality. In reality, the cost of co-modality, any additional time taken to handle the parcels, what other deliveries are in the area, etc, would be factored in the decision-making process of the operator prior to sending a parcel onto the public transport network. This high value would also assume that systems and processes are in place across the broader Sydney Trains heavy rail network to enable a logistics operator to conduct co-modality from a variety of origins across the network. In reality, it may take time to iron out processes and procedures to enable the broader application of co-modality.

As a middle ground, analysis compared the time taken for parcels to be transported via conventional forms and via co-modality. Parcels that took up to 15 minutes longer to travel into the city with co-modality from the origin point were considered contestable. That is, the logistics operator may wish to run the middle mile using co-modality, despite it taking up to 15 minutes longer. The rationale for this is the logistics operator taking into account the additional costs of operating the vehicle and the cost of the driver. Analysis of the data presented a middle ground of 23% (Figure 18).

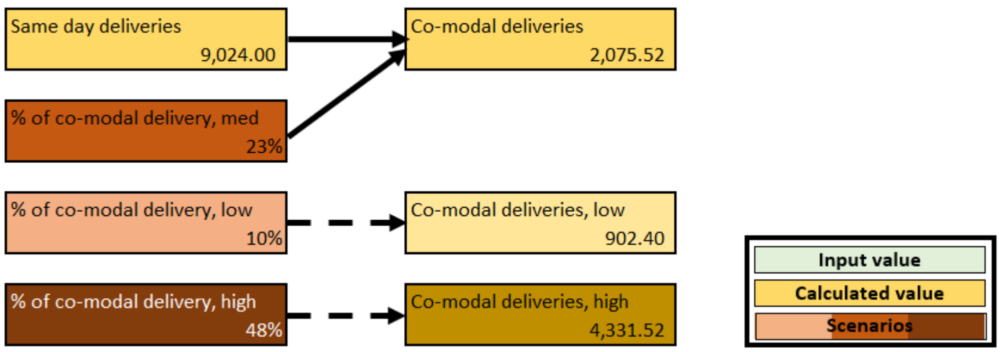

Figure 18 Market size estimation—same day co-modal deliveries in Sydney CBD

5.4 Potential benefits

The potential benefits of bringing co-modality to Sydney CBD is evaluated from environmental, congestion and commercial perspectives. A key parameter has been calculated based on the logistics operator's dataset to understand the ratio between potential co-modal trips and co-modal parcels. This ratio was applied to estimate benefits based on the potential truck trips replaced by the medium-medium co-modality scenario (see Table 3) presented thus far. The potential benefit under other scenarios is presented in Section 5.4.4.

The process to get to this ration is explained in Appendix C.2.1. For parcels that meet the weight, pick-up density and delivery time criteria of the day, the number of corresponding co-modal trips is calculated. The deliveries/trip is estimated to be larger than 4.5, and it is rounded up to 5 in the following analyses for simplicity.

With the 5 deliveries/trip ratio and middle ground scenarios of the same day (15%) and co-modality (23%) deliveries, it is estimated that more than 400 truck trips could be replaced by the co-modality option (Figure 19).

The saved truck distance per trip is averaged at 24.2 km/trip, which factors in the kilometres saved by picking up a parcel and sending it to the nearest train station, as opposed to picking up the parcel and driving into the CBD.

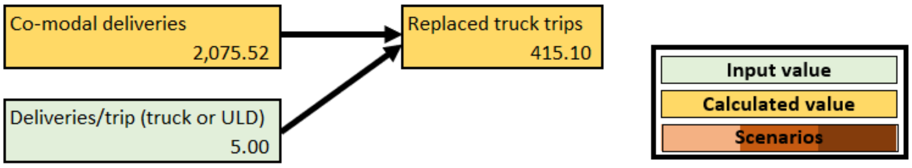

Figure 19 Market size estimation—daily replaced truck trips

5.4.1 Environmental benefits

The environmental externalities impact parameters are derived from the *Transport for NSW Economic Parameter Values*, (see Appendix C) consisting of air pollution, greenhouse gas (GHG) emissions, noise, water pollution, nature and landscape, urban separation, and upstream/downstream costs. Based on the medium scenario settings presented, co-modality could potentially contribute to a total environmental saving of above $2,200 per day (Figure 20).

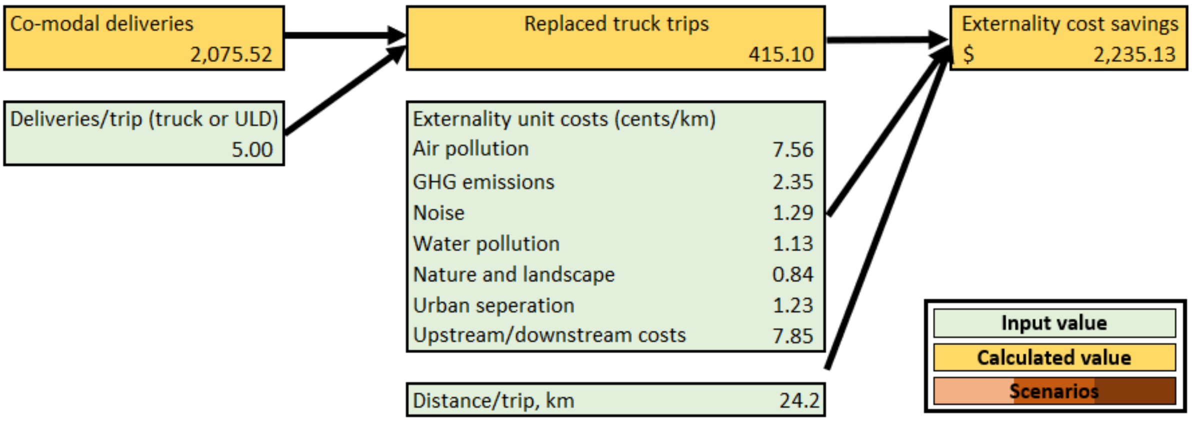

Figure 20 Potential benefits—environmental

5.4.2 Congestion reduction benefits

The congestion reduction parameters are also derived from the *Transport for NSW Economic Parameter Values*, where a $0.4488 congestion cost saving per vehicle kilometre travelled is applied for light commercial vehicles. Approximately $4,500 in congestion costs could be alleviated each day by using the co-modality option (Figure 21).

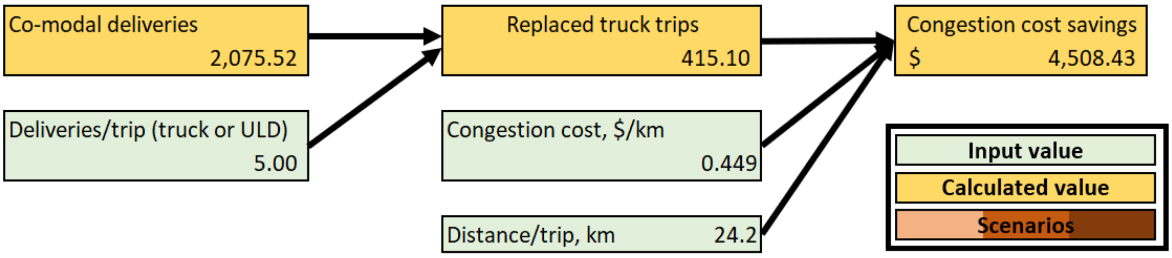

Figure 21 Potential benefits—congestion reduction

Whilst there is no economic parameter to quantify saving potential, it is recognised that the removal of truck trips into the Sydney CBD would also contribute to alleviating pressure and competition for loading zone space within the Sydney CBD.

5.4.3 Commercial benefits

The commercial benefits are based on the logistics operator's saved labour costs by applying co-modality. The costs are calculated as the difference in time between conventional truck delivery to Sydney CBD and the co-modality's time for the first mile delivery to the nearby heavy rail station and shuffling time to get parcels to and within the station. From the logistics operator's data, the average time saved per trip is 0.49 hour. The saved time is then converted to saved cost with a rate of $38/hour and the total cost saving is estimated to be $7,729 per day (Figure 22). This cost saving does not incorporate any service charge that the transport service operator may levy for the service to be conducted on the public transport network (explored further in Section 5.4.5).

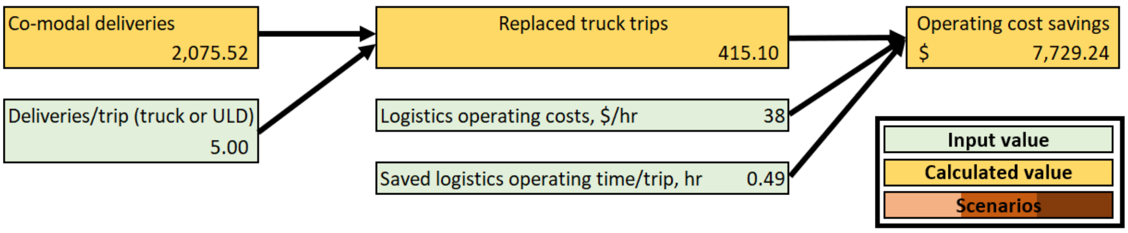

Figure 22 Potential benefits—commercial costs

5.4.4 Other scenarios

So far, the potential benefits of co-modality identified have been with assumptions of a medium market opportunity and medium industry uptake. The spectrum of scenario combinations is acknowledged and presented in Table 3. These calculations apply the assumption of 5 deliveries/trip.

Table 3 Potential daily benefits under different scenarios

% of co-modal		% of same day Low (5%)	Medium (15%)	High (28%)	
Low (10%)		$ 323.93	$ 971.79	$ 1,814.02	*Environmental benefits*
		$ 653.40	$ 1,960.19	$ 3,659.01	*Congestion benefits*
		$ 1,120.18	$ 3,360.54	$ 6,273.00	*Commercial benefits*
Medium (23%)		$ 745.04	$ 2,235.13	$ 4,172.24	
		$ 1,502.81	$ 4,508.43	$ 8,415.73	
		$ 2,576.41	$ 7,729.24	$ 14,427.91	
High (48%)		$ 1,554.87	$ 4,664.61	$ 8,707.28	
		$ 3,136.30	$ 9,408.89	$ 17,563.27	
		$ 5,376.86	$ 16,130.58	$ 30,110.42	

5.4.5 Summary and commentary

The calculations demonstrate that on a medium-medium scenario, moderate improvements to the cost incurred and externality cost created in the process of delivering parcels into congested urban environments can be improved.

The removal of a conventional truck/van for the middle mile presents opportunities to improve environmental and reduce congestion externality costs faced by cities. These benefits were calculated to be for the order of $2,200 and $4,500 respectively per day.

Co-modality also has the potential to reduce the cost of conducting deliveries, by improving the time taken to send in parcels from across metropolitan Sydney into the CBD. The potential cost saving for a medium-medium scenario is of the order of $7,700 per day. This saving is before any cost of conducting the co-modal service is levied by the transport service operator.

To ensure all stakeholders share part of the potential commercial benefits afforded in the operation of a co-modal service on the public transport network, a charging regime is necessary. A portion of the commercial cost savings could be allocated amongst stakeholders. For example, should the transport service operator charge $5 per ULD to operate on the public transport network, it has the potential to create a new revenue stream to the value of approximately $2,000 per day, or $500,000 per annum, to the transport service operator. For the logistics provider, the cost saving after a service charge is levied could still be of the order of $5,700 per day, or $1,425,000 per annum.

While a medium-medium scenario was the focus of this section, it is also acknowledged that a spectrum of potential combinations exists. This spectrum reflects the maturity of the same-day market and the potential take-up of the alternate middle mile mode amongst logistics industry players.

6 Conclusions and next steps

Co-modality can play a role in resolving a city's logistical challenges. Capturing the potential benefits of integration of goods with passenger movement requires a well-designed business model, the collaboration between the stakeholders within the supply chain and the integration of information management systems to provide journey assurance.

This white paper flags the opportunity of shaping co-modal freight delivery as an alternate transport mode into Sydney's CBD. In addition to reviewing existing co-modality schemes around the world, gathering stakeholder views, and conducting numerical tests, the project has consulted with key logistics operators to evaluate the concept. This section shows the viability of co-modality in the Sydney CBD along with its potential opportunities, risks, and how it could fit in the triple bottom line strategy. Finally, we present the next steps for this topic.

6.1 Opportunities

As an alternative to conventional truck delivery, co-modality has been demonstrated to positively contribute to city logistics by providing a delivery method that reduces emissions and congestion associated with deliveries into dense urban environments. It also has the potential to reduce commercial costs associated with conducting deliveries.

The analysis identified opportunities for co-modality for Sydney CBD for:

- **Utilising latent transport service capacity**: The heavy rail network has passenger peaks in the early morning and afternoon, reflecting general working hours. In between the passenger peaks, transport services often run with spare capacity. Co-modality offers an opportunity to maximise the value of running passenger services during the day by integrating the movement of certain types of goods. For the public transport service operator, it is a better utilisation of the asset and potential revenue generator. For the logistics provider, it enables opportunities to access a scheduled and reliable middle mile transport mode that is removed from road network congestion experienced by conventional delivery by van/truck.

- **Middle mile:** Co-modality best serves as a middle mile solution, due to its potential to remove the longer truck leg of the supply chain. The first mile and last mile are not deemed as most suitable at this stage: The first mile will not be changed by adopting co-modality as it will still be conducted by a truck or van. Co-modality could be one of many options in last mile delivery. However, it should be noted that traditional truck delivery has the upper hand for acting as a mobile warehouse in the CBD. Moreover, many last mile solutions have been developed in recent years ranging from Autonomous Mobile Lockers (Li et al., 2021) to drones.

  The removal of the truck/van middle leg produces moderate improvements to emissions and the cost of congestion. The time-saving potential of the co-modal option of the middle mile depends on the distance of the origin from the CBD and the road connections and rail connections from the origin location, as origin locations with good connections to the road network generally favour the truck over the co-modal option for the time taken for parcels to be run into the CBD. However, when factoring in the labour cost of this leg, co-modality has the potential to reduce the commercial cost of the middle mile, particularly should the middle mile be conducted unaccompanied on the public transport service.

- **Same day delivery:** The area of opportunity for co-modality centres around the same day delivery market, where quantities of parcels are generally small, customer expectations are high and the cost of conducting the delivery is high as there is little potential for the logistics provider to consolidate loads. Sensitivity analysis on the unit cost of the middle mile suggests that conventional forms of delivery (by truck or van) have a continued role in city logistics when the number of parcels is large enough per delivery trip. When the total number is smaller, an unaccompanied co-modal option has the ability to reduce the cost of the middle mile. On a practical level, seamless integration of goods movement on passenger services could be hampered if a large volume of consignments is required to be shuttled on or off a passenger service within short station dwell times, supporting the sensitivity analysis finding that co-modality has potential in the same day market space.

- **Unaccompanied journeys:** The greatest area of potential for co-modality centres around goods travelling unaccompanied on the public transport network. An unaccompanied co-modal journey reduces the operating cost associated with the middle mile by removing the need for a driver to travel to the CBD. While unaccompanied parcels afford the greatest commercial opportunity, it requires significant partnerships to be formed between the logistics operator(s) and the public transport service operator to ensure the movement of goods occurs in a safe, efficient, and reliable manner.

6.2 Triple bottom line and commercial benefits

Co-modality is designed to be a sustainable transport solution that utilises latent public transport capacity and reduces the negative externalities of logistics services. For TfNSW, co-modality can secure broader economic outcomes by improving network use efficiency and can unlock social and environmental benefits by reducing congestion and emissions. For logistics operators (and to a lesser degree, TfNSW), co-modality can deliver commercially efficient and viable outcomes.

- **Societal:** Co-modality, as a new service, would create new ways of working and has the potential to change the way delivery occurs for the middle and last mile. For urban congested societies, such as Sydney CBD, the potential of co-modality to replace conventional truck/van trips has the effect of alleviating congestions both on roads to from and within the CBD and can reduce the pressure placed on loading zone availability within the CBD, which would generally improve the liveability of surrounding areas.

- **Environmental:** This dimension evaluates co-modality's environmental performance potential. Co-modality utilises latent public transport capacity and reduces emission by replacing delivery truck trips. From our proof of concept (Section 5.4.1), adopting co-modality in Sydney could lead to environmental externality saving of above $2,200 per day.

- **Economic:** Co-modality could improve overall transport network efficiency and alleviate traffic congestion on the approaches to the Sydney CBD area. Co-modality would look to make the most of latent capacity on existing public transport services during the day, thereby generating greater value in the public transport asset. By replacing delivery trucks and vans with public transport, our proof of concept (Section 5.4.2) showed a potential daily saving of $4,500 for congestion reduction.

- **Commercial:** Cost analysis demonstrates that co-modality could be a viable delivery option under certain scenarios. It can reduce operating costs for logistics operators and be a potential revenue generation source for the transport service operator. For logistics providers, incorporating public transport in their delivery network could potentially save on truck and driver costs because of the unaccompanied middle mile transport, of the order of approximately $7,700 per day.

6.3 Co-modality in Operation

Co-modality on public transport has few successful precedents and it takes time for setting procedures, responsibilities and gaining public acceptance. Potential risks on the operational level were identified through the workshop with the public transport service operator and logistics providers. A key risk that was identified in the workshop centred on the ability to move and transfer co-modality loads on the network without impacting the movement of passengers and maintaining schedule integrity. In particular, the loading/unloading of ULDs on/off train services at stations within 15-20 second station dwell times on the heavy rail network was seen as a significant risk that could derail a co-modality scheme. Even with low freight volume, the short dwell time places a high requirement on alignment with the timetable and swiftly placing or retrieving ULDs on trains. This requirement is heightened in the unaccompanied case, where personnel would be required to board, load/unload and lash/unlash the ULD(s) and then leave the train before departure.

The workshop sentiment from public transport and logistics operators alike, was that these cargos handling related issues can be overcome, managed, or worked through by starting small, setting limits and specifications of the scheme (including on the ULD, infrastructure and track and trace systems) and then solving issues as they arise. Starting small could take the form of trialling the scheme with one logistics provider in partnership with the public transport operator, using small luggage sized ULDs and operating on parts of the heavy rail network that do not have station dwell time pressure. It would require significant time and resources from both parties to setup, learn, relearn, and adapt a co-modal approach. Given the suggestion is to work with one logistics provider, the unit cost for delivery in formative stages will be higher than if there was a broader application of the scheme. However, the opportunity is there to start small and establish processes, specifications, and procedures and then extend to stations under dwell time pressure, if there is interest from stakeholders. Ironing out issues by starting small will provide certainty and assurance that the co-modal approach will not impede passengers or passenger services and will create a pathway for further integration.

6.4 Next steps—realising co-modality

The next step would be to reach out to key interested stakeholders to tackle the potential challenges, opportunities and benefits explored in this paper and translate them into real-world application by starting small. Though starting small would temper the potential benefits of co-modality and require considerable cost and resourcing in the short-term, it is necessary to ensure that the integration of freight on public transport networks affords benefits and acceptable risks to all, and that the service can be scaled up without shifting the benefits or risks to an unacceptable level.

Though out of scope for this report, this project and engagement with stakeholders have identified some promising niches for co-modality worthy of future research:

- **Last mile potential:** While the report focused on the potential for co-modality in the middle mile, the desktop assessment and numerical tests indicated that co-modality could be a viable option for last mile delivery when dealing with a small amount of freight. It is recognised that the CBD context is very sophisticated and there exist barriers to overcome in the uncertainty of public transport timetables, crowding on public transport, difficulties/detours to access to stations and platforms, and ULD return. For the last mile, parcels may still be walked, cycled, or driven to the final customer destination.

  Figure 23 shows a whole day's delivery destinations in Sydney CBD for one logistics provider and indicates the proximity of these destinations to heavy rail, light rail, and ferry stations. In a co-modal future, these stations would play a role in deliveries.

However, the last mile from these stations has not received much attention in this report, in part because of rapid technological progress with delivery robots, drones and smart lockers. Last mile solutions should be the subject of further research.

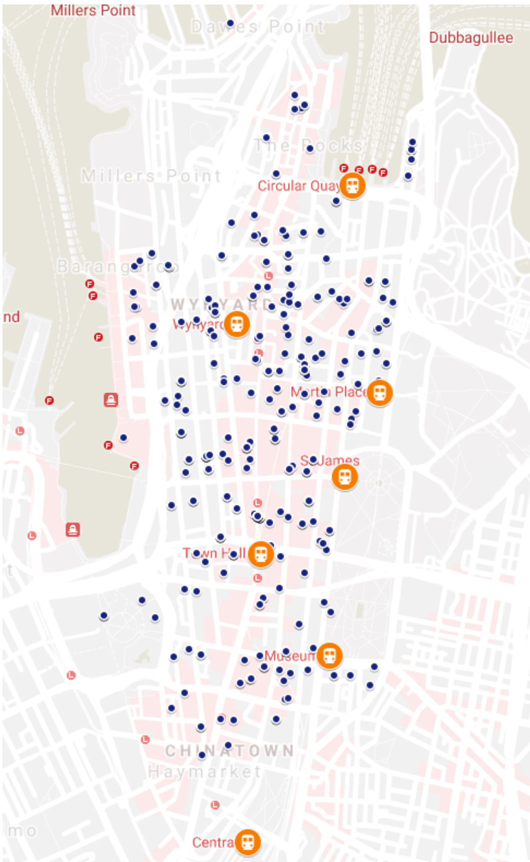

Figure 23 The logistics operator's delivery destinations in CBD, one day in March 2020

- **"Same day" intra-state deliveries.** With respect to Figure 14 that highlights the benefits of co-modality as distance increases, there is an opportunity of applying this process to trains travelling further afield than Sydney CBD. For example, consignments loaded on a train at Central station at 2:32 pm can be available for collection or local delivery in Newcastle after 5:10 pm. Initial discussions with logistics providers and the transport service operator show interest in developing an intra-state scenario. While this can be appealing to logistics and transport operators alike and potentially revenue-generating, it should be considered against the objectives of this project in that:

    - It is creating a new expedited logistics movement with orders that could have been efficiently consolidated to a truck and sent the next day.
    - In so doing it is not easing congestion or generating economic benefits unless the volume moved on the train was the tipping point necessitating the deployment of an extra vehicle.
    - This option would utilise the same management systems as explored in this CBD context. Given its appeal, it could be explored as a means to generate additional revenue that can support the development of CBD solutions focused on generating broader benefits.

- **Suburban areas:** One area of potential for co-modality is the same day delivery from metropolitan areas to suburban and regional areas. The consignments could be conveyed to suburban/regional stations and a local logistics provider would finish the last mile delivery. Feedback from logistics providers identified that same day delivery to regional areas, in particular, has low transport volumes yet requires frequent services, making it often costly for truck delivery but potentially feasible for public transport (as shown in Figure 13).

- **Synergy with limited mobility accessibility:** Sydney Trains is developing a data platform to enable public transport customers with mobility needs to notify station and network staff of accessibility requirements ahead of time via a mobile phone application. This shares some similarities with the technical process explored in Section 5.2, where the logistics operator inputs details on the ULDs and the co-modal journey that flow into the transport operator system to enable all stakeholders to know what is on the network, where and when. The development of new communication methods for customer accessibility could be harnessed or furthered to mature the technical flow of information for co-modality.

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Appendices

Appendix A 'How might we' questions and evaluations

A.1 HMW Question 1

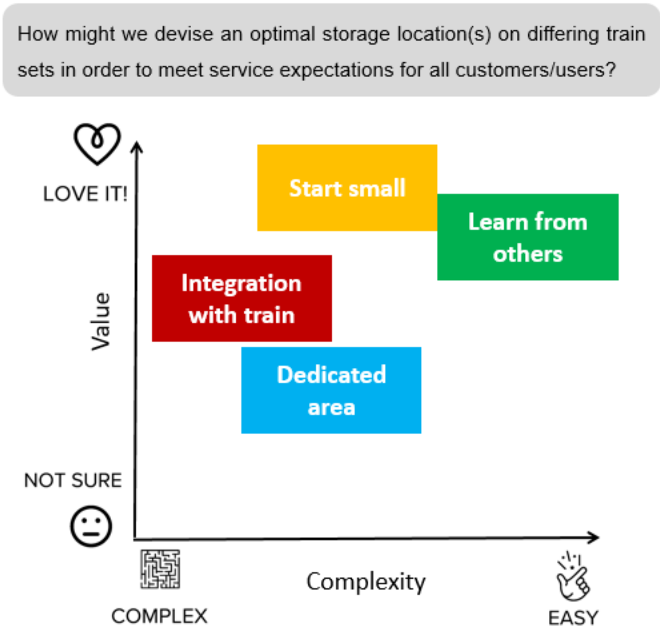

Figure 24 HMW question 1

The first HMW question (Figure 24) covering:

- Passengers – free movement on trains, seating (including accessibility areas) available, comfortable, and undisrupted journeys.
- Network operator (including security commands) – access to emergency equipment maintained, CCTV coverage.
- Logistics operator – safe and comfortable journey, access to help if needed, potential allocated/dedicated/partitioned-off area for ULD.

The key ideas include:

- **Dedicated areas on trains** (value: moderate | complexity: high): The idea centres around having a designated area like a 'freight zone' with seat adjustment on an existing carriage or an entire dedicated carriage on the train (depending on logistics operator demand). For larger ULD loads, train turn-back locations were suggested as ideal locations to commence or end a co-modal journey, as they reduced time pressure to load or unload the ULD within the standard station dwell time of a train on a timetabled service.
  Providing a dedicated area for a co-modal journey was rated as having moderate value, as it affords peace of mind to a logistics operator that space is available for their use. However, it is complex to implement, as reserving a space on a passenger carriage for the purposes of freight may introduce a change to a customer's service expectation or having a dedicated carriage at night for freight introduces procedural changes for the public transport operator.
- **Start small** (value: very high | complexity: moderate): Start small and work through the issues. A small load accompanied by a courier for the public transport journey that could be carried on and off quickly could occur right now on the network, meaning its

value to the concept was judged as very high. Its complexity was rated as moderate as it would require adjustment to the processes and procedures of a logistics operator. If the concept proved beneficial and/or feasible, and logistics operator demand increases (in terms of size of the load, number of runs per day or number of operators), participants flagged the potential of crowdsourced resourcing models or dedicated areas on public transport infrastructure for freight movements, which would increase the complexity of implementation.

- **Integration with train operations** (value: high | complexity: very high): Integration with current network operation and passenger movements. Potential opportunities to adapt train sets or utilise maintenance centres were discussed, subject to logistics operator demand and business case.
  Integration with the current network is rated as high value, as one objective of the co-modality concept is to fit in the current public transport network without introducing too many disruptions to the normal running of the network. The complexity of this is very high, as integration is likely to require new or additional operation procedures introduced to coordinate the freight flow within the current passenger traffic. More significant challenges may need to be addressed if the freight is unaccompanied on the carriages, or when ULDs are larger in size, to ensure the cargoes could be handled correctly to/from the vehicles.
- **Learn from others** (value: very high | complexity: very low): The idea refers to exploring existing examples and learnings from parts of the network where large luggage movements frequently occur. The example pointed to was looking at the design and management of people and luggage using the airport line on the Sydney Trains network.
  The complexity to engage and learn from similar projects was deemed as very low, as those connections can be facilitated between the project team and selected Transport for NSW employees. The value of learning was deemed very high, as the issues, problems to resolve and solutions experienced on the airport line for Sydney Trains may be directly transferrable to the development of the co-modality concept.

A.2 HMW Question 2

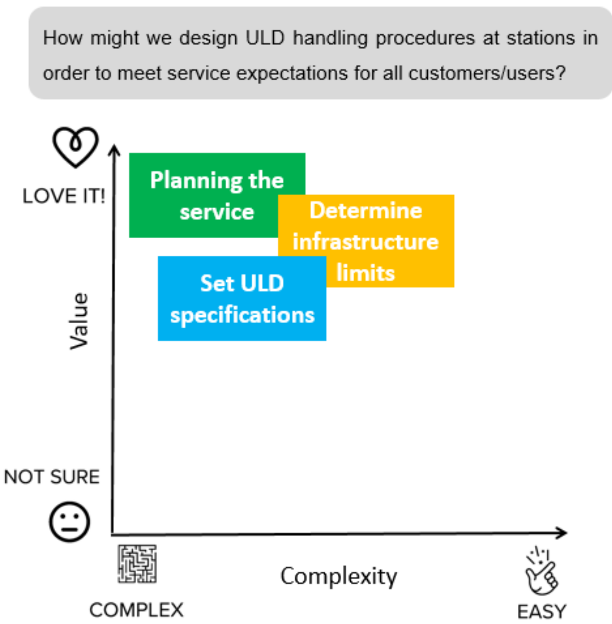

Figure 25 HMW question 2

The second HMW question (Figure 25) covering:

- Passengers – expect unencumbered movement, services not delayed by loading/unloading.
- Network operator – safe and efficient movement, reduce manual handling where possible (e.g., use lifts).
- Logistics operator – timetable integrity (dwell time) protected during loading/unloading, avoid peak passenger time, safe and secure movement within stations, safe stowage on the platform.

The key ideas include:

- **Planning the service** (value: very high | complexity: very high): A consistent theme from the workshop is that co-modality should not interfere with a passenger's journey, meaning passengers should board/disembark first, access lifts first and have an unimpeded journey. The idea is to set protocols in order to mitigate disruption to the service expectations of passengers and ensure an efficient co-modal journey for the freight. It was also discussed that all parties, including station staff and logistics operators, should be well informed of the co-modality operation by communication channels that share information on station changes, training, station navigation maps, etc.
  The value of planning is rated as very high. However, it was also rated as very difficult to implement, owing to the communication and reporting channels that would likely be required and potential inefficiencies to the cargo flow in order to maintain an unimpeded journey for passengers. It was also suggested that understanding the passenger storage capacity at different platforms and stations, pedestrian flow patterns on various platforms and stations and conducting trials of processes to load/unload ULDs is important prior to implementing the concept.
- **Determine infrastructure limits** (value: very high | complexity: moderate): Participants agree that the ULD must fit with the existing dimensional/spatial limits of public transport infrastructure. For example, the ULD would need to fit within the limits of lift doors as well as safely traverse ramps, gaps and steps between platform edges and train doors.
  The group valued determining the limits of infrastructure first and then having the ULD designed to fit within those limits. The complexity for doing this was rated as moderate, as it can be easily done, but requires an understanding of where the co-modal journey would occur. That is, an understanding of the station(s) and train sets on which the co-modal journey would occur is needed prior to measuring the limitations of those stations and train assets. For this to occur, there needs to be an operating model; for example, where is the logistics operator looking to operate to and from?
- **Set ULD specifications** (value: high | complexity: high): It is essential to set limits on weight and type of goods in the ULD, as well as the requirement to fit in lifts and pass over the train-platform step. However, the size of the ULD is partially contingent on the demand of the logistics operator. A larger ULD (e.g., roll cage), or several ULDs, require additional considerations of weight, the use of loading ramps at stations, multiple loads at the station, etc. which introduces further complexity to the implementation. By contrast, a satchel sized ULD that can be carried on and off a train with low implementation complexity and avoids issues relating to lifts, gaps between train and platform, and having a dedicated space on a carriage.
  Setting the ULD specifications is rated as high value, as it informs how the ULD would operate on the public transport network. The complexity was gauged as high, as the method to determine ULD size and weight is mainly contingent on the demand and business model of a logistics operator. For example, a point-to-point logistics operator may be able to carry a parcel in a satchel bag, whereas a logistics operator moving large numbers of CBD-bound parcels overnight may require a large roll cage type of ULD, which would operate differently on the public transport network than a satchel bag.

A.3 HMW Question 3

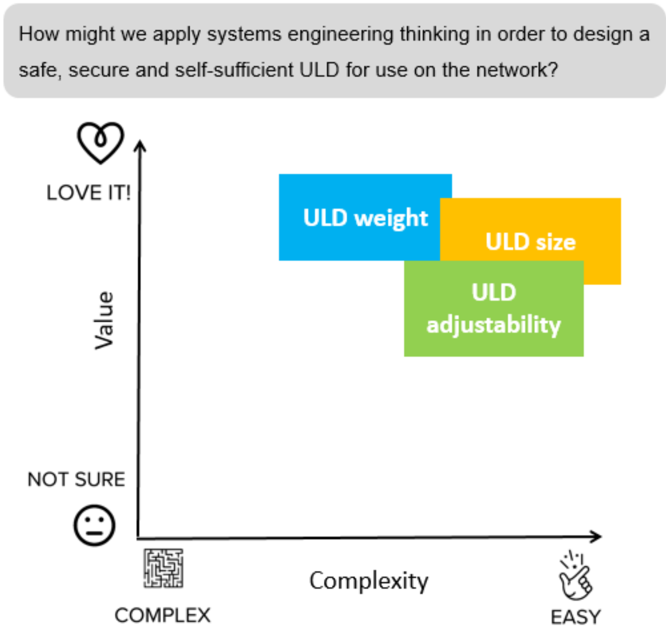

Figure 26 HMW question 3

The third question (Figure 26) covering:

- Passengers – expect unencumbered movement, services not delayed by loading/unloading.
- Network operator – safe and efficient movement, reduce manual handling where possible (e.g., use lifts).
- Logistics operator – timetable integrity (dwell time) protected during loading/unloading, avoid peak passenger time, safe and secure movement within stations, safe stowage on the platform.

The key ideas include:

- **ULD size** (value: high | complexity: very low): This group echoed the thoughts of the other group focused on HMW 1, where the concept should start small by first considering a satchel size or large suitcase sized ULD. A small ULD that can exist on the network right now does not require significant systems engineering thinking, hence a scoring of very low complexity and high value toward advancing the concept.
  In the mid to long term, ULDs with a larger size or even a dedicated carriage was thought to be more compatible with the logistics operators' desire to achieve economies of scale. The greater the size and handling requirement of the ULD, the more complex it is to implement on the existing public transport network, and therefore, the greater systems engineering thinking required.
- **ULD adjustability** (value: high | complexity: moderate to easy): The group discussed the value of having the ULD be adjustable so that it can be expanded and compressed in line with the nature of the journey or parcel demand. The group rated the complexity to design and operate an adjustable ULD as moderate, and the value as high, as it could improve the flexibility of handling by the courier and mitigate unnecessary interaction with other commuters.
- **ULD weight** (value: very high | complexity: moderate): The group discussed the need for setting weight limits on ULDs, in order to ensure safe handling and less risk to the general public. The group thought the weight limit should be guided by safe work requirements and ergonomic practices in line with the size of the ULD. For example,

20-30 kg weight limit for a suitcase sized ULD or 12 kg for a mail backpack (satchel) sized ULD.

A.4 HMW Question 4

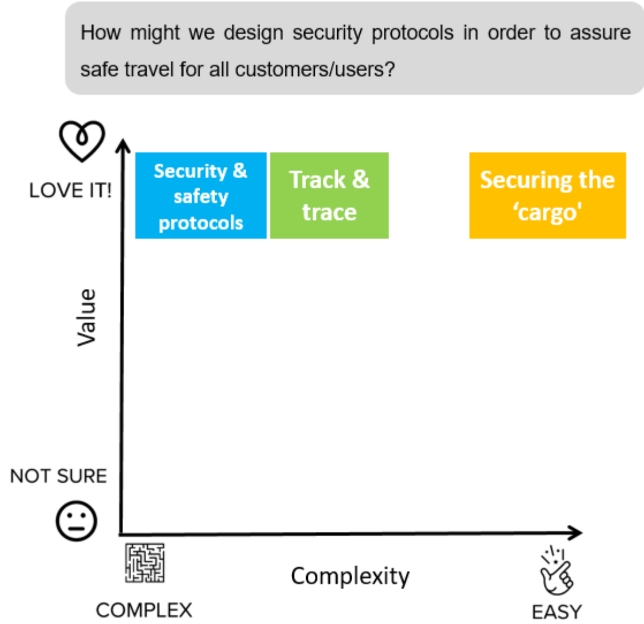

Figure 27 HMW question 4

The fourth HMW question (Figure 27) covering:

- Passengers – safe journey, no hazardous/dangerous substances, ULD accompanied and purpose self-explanatory.
- Network operator – no carriage of dangerous goods, real-time information, CCTV coverage.
- Logistics operator – no unacceptable safety risk, ULD secured/locked, track and trace functionality.

The key ideas include:

- **Security and safety protocols** (value: very high | complexity: very high): Following existing industry standards such as ISO27001 and ISO9001, as well as CCTV monitoring and dangerous good classification. Devise security protocol for 'guardian' status – with security status depending on cargo value.
  Security and safety protocols would be of high value. As the unaccompanied option is preferred by the logistics provided, the complexity is also rated as high.
- **Track and trace** (value: very high | complexity: very high): The group thought that the ULD should be trackable on the public transport network, with a scannable label linking to the carriage number, security chip/seal, RFID or Bluetooth enabled. A 'trusted trader' scheme was also discussed, whereby trustworthy logistics operators could access the train timetabling system to update their consignment status and share more detailed information of their co-modal cargoes with logistics operators and/or shippers.
  Track and trace are rated very high value. Participants from the public transport sector flagged the need to ensure the authenticity of parcels within the ULDs being sent on the network alongside passengers. In contrast, the logistics operator needs to locate their consignments and update their delivery status. It is rated as very complex because both stakeholders would have high requirements, and it is complex to integrate the different data streams/feeds.

- **Securing the cargo** (value: high | complexity: low): The group discussed the need to ensure the cargo/ULD was secure, particularly when operating on a moving public transport vehicle. The means to secure a ULD vary, depending on the size of ULD in operation. A simple bicycle lock to secure satchel sized ULDs onboard trains and in stations using existing posts or railings. Whereas on the other side of the spectrum, a roll cage sized ULD would need lashing and/or braking methods on a carriage. Securing the cargo in the carriages is rated low complexity, with discussion centring on the ease of locking and monitoring a satchel sized ULD. However, the group noted that when dealing with different cargo sizes, the complexity may escalate. Its value is rated as high because it is needed to ensure the co-modal journey does not present additional risk to the operation of the network or passengers.

A.5 HMW Question 5

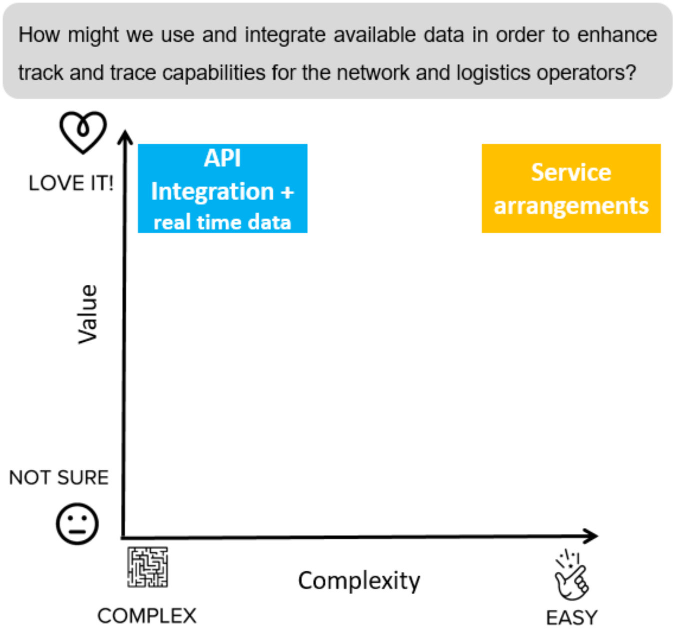

Figure 28 HMW question 5

The fifth HMW question (Figure 28) covering:

- Network operator – real-time location of ULD(s), contents, courier's contact details.
- Logistics operator – real-time train/network operation, station accessibility (lift), the synergy between Opal card and internal systems.

The key ideas including:

- **Application programming interface (API) integration + real-time data** (value: very high | complexity: high): Data from network and logistics operators could be integrated with the API whereas the logistics operators can access to real-time data and updated ETA via the API. There could be some potential opportunities to use existing apps such as NextThere.
  API Integration and real-time data are of high value. The complexity is rated as high because it needs cooperation between different sectors. However, it needs professional comments from the IT sector and depends on the available devices and technologies for further evaluation.

- **Service arrangements** (value: very high | complexity: moderate): Service arrangement could be contract specific to decide the exact service level agreements (SLA), definitions for checkpoints and KPIs.

Service arrangements between stakeholders are rated as very high value. The process to make agreements would not be easy as it needs several rounds of negotiations. Therefore, its complexity is rated as moderate.

Appendix B Model parameters (sensitivity tests)

Table 4 Parameters for sensitivity tests

Name	Value
Delivery parameters	
Distance to CBD (km)	35.00
Consignment weight (kg)	5.00
Consignments for delivery	10.00
Co-modal delivery	
ULD capacity(kg)	50.00
ULD handling time (hr, to/from truck)	0.10
ULD handling cost ($, to/from truck)	2.00
ULD handling time (hr, in station)	0.10
ULD handling cost ($, in station)	2.00
Truck ULD capacity (ULDs)	6.00
Train capacity (ULDs)	6.00
ULDs for delivery	1.00
Hourly rate ($/courier)	30.00
Truck delivery	
Truck speed (km/h)	50.00
Truck Time to/from CBD (hr)	0.70
Truck load (kg)	350.00
Deliveries/stop	1.00
Number of stops	10.00
Probability of congestion	50%
Congestion time between stops (hr)	0.25
Driving time between stops (hr)	0.10
Delivery time/parcel (hr)	0.14
Couriers/truck	1.00
Hourly rate ($/truck)	8.00
Hourly rate ($/courier)	30.00

Appendix C Capacity analysis—two more examples

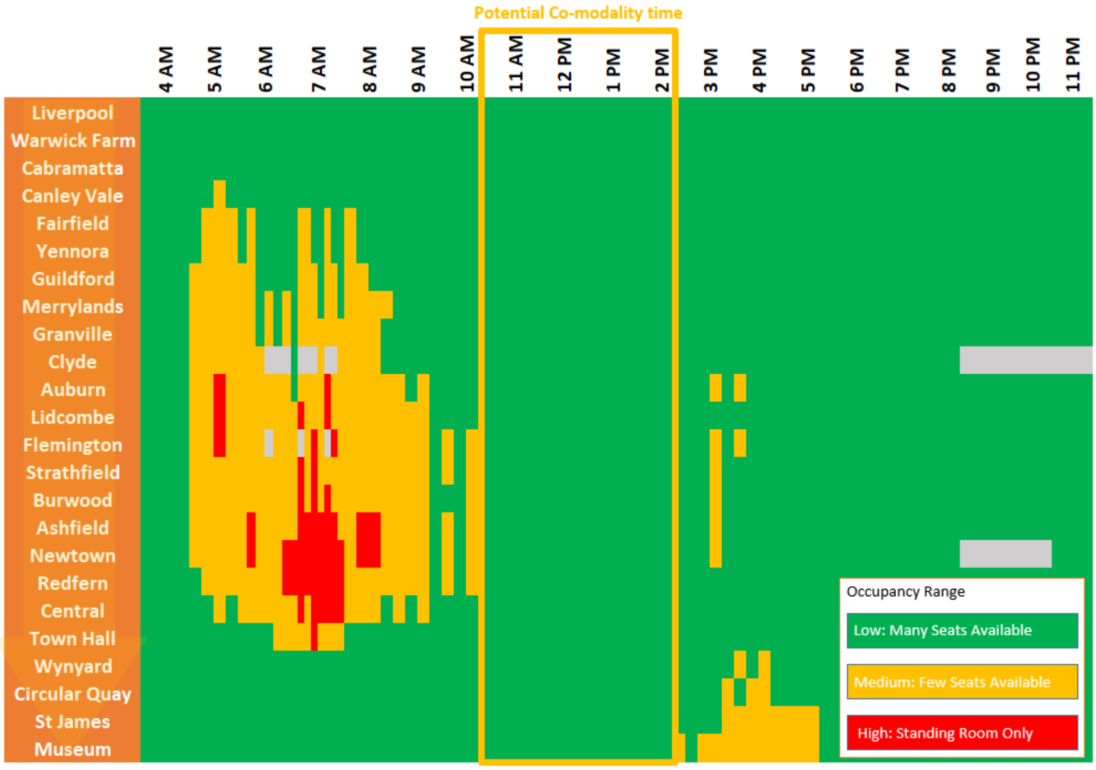

Figure 29 Capacity analysis—Liverpool

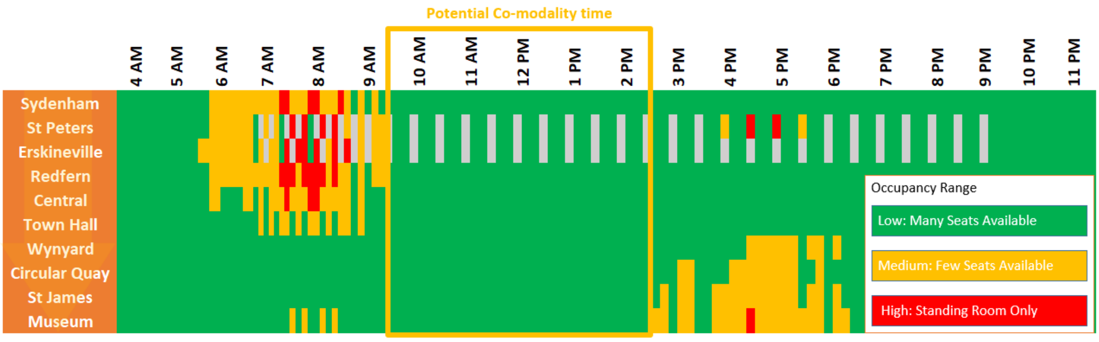

Figure 30 Capacity analysis—Sydenham

Appendix D Data from the logistics operator

D.1 Data cleaning process

The original dataset from the logistics operator contains 1564 data entries. After assigning minimum consignment volume and calibrating deliveries' deadweight and volume, there are 1561 entries in the cleaned dataset (Figure 31).

Data cleaning
Min volume 0.001
Consignment to pure number
Delete Items>1 but only single entry (2019: 251, 502, 964)
DeadWeight = DeadWeight/Items; Volume = Volume/Items

Figure 31 Data cleaning process

D.2 Parameter calibration

D.2.1 Data filtering process

Method	Data entries
Cleaned dataset	1561
Of which, destination is Sydney CBD	1554
Of which, occurs on 3-6 Sep + 9 Sep (weekdays)	1481
Of which, the delivery occurs same day	411
Of which, both the pick-up/delivery occurs during the daytime (5am to 7pm)	388
Of which, the deadweight is less than 5kg	300
Of which, more than one day with at least 2 parcels	227
Of which, the pick-up is relatively close to a rail line	196
Of which, co-modal has more than 15 mins potential saving	94

Figure 32 Data filtering process

Deadweight less than 5 kg (300/388): the parcels deadweight is filtered as less than 5 kg mainly for the sake of their handiness when shuffling at heavy rail stations and the manoeuvrability of ULDs. The weight distribution of the parcels is presented in Figure 33, and 77% of the parcels are kept.

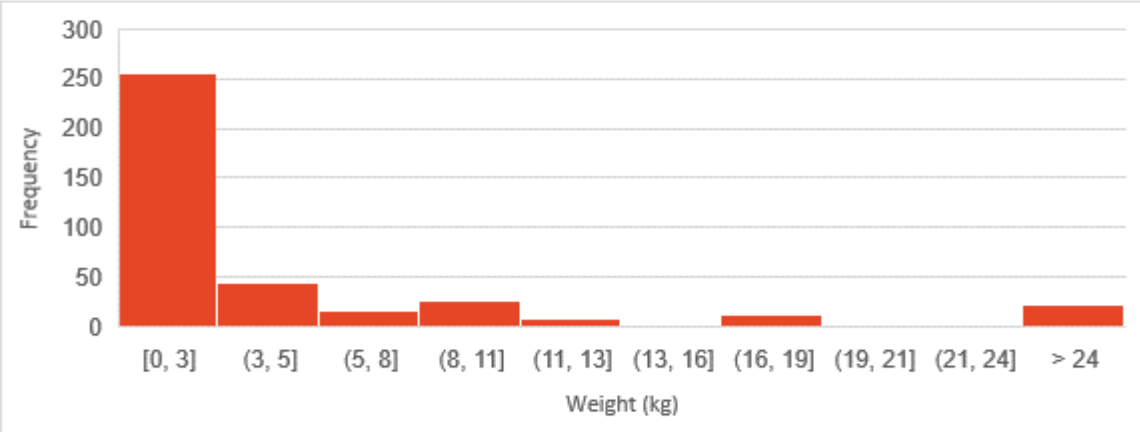

Figure 33 Same day parcels deadweight

Close to a heavy rail line (196/227): pick-up suburbs with nearby heavy rail stations and with relatively long distance to Sydney CBD are considered viable to co-modality. Suburbs such as Warriewood (no nearby station) and Redfern (too close to CBD) are deemed as not suitable for co-modality.

Co-modality's potential time saving (94/196): if the co-modal option took no longer than 15 minutes longer than the truck option, the parcel was deemed a possible candidate for the middle mile journey to be conducted by co-modality. Take Alexandria as an example (Table 5), as co-modality's delivery time is the same as truck delivery, it is treated as viable for co-modality.

Table 5 An example of the co-modal potential saved time

	Google Maps and Sydney Trains journey planner calculations									
Origin suburb	Line	Nearest station	Origin to station (mins)	Shuffle time from van to station (mins)	Travel time from station to Central (mins)	Total delivery time for co-modal (mins)	Truck delivery time from origin to Central (mins)	Saved logistics operating time (min)	Co-modal potential (min)
Alexandria	T3	St Peters	2	5	7	14	14	**7**	**0**

D.2.2 Inputs for market size for same day deliveries in Sydney CBD (Section 5.3.1)

Annual total deliveries

1 billion annual parcel deliveries, adjusted from 934 million in 2019[4] with an 8% YOY adjustment.

Population, Sydney CBD

376, 000 is based on the employment projections in Sydney CBD. [5]

Population, Australia

Simplified as 25 million. [6]

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[4] https://www.pitneybowes.com/us/shipping-index.html#

[5] https://opendata.transport.nsw.gov.au/dataset/employment-projections

[6] https://www.abs.gov.au/ausstats/abs%40.nsf/94713ad445ff1425ca25682000192af2/1647509ef7e25faaca2568a900154b63?OpenDocument

% of same day, low

A low bound assumption of the proportion of same day deliveries amongst total deliveries is set at 5%. This conservative value was determined given the varying global estimations of the same day market and the growing nature of this delivery segment.

% of same day, high

The logistics operator data had an average of 28% (411/1481) of deliveries constituting the same day. The data were treated in the method outlined in Figure 32.

This percentage is suggested to be high and reflects the market focus of this operator. From discussions with other logistics operators, it is understood that others do not have such a focus on the same day (more towards overnight deliveries that can be consolidated), suggesting that the application of this upper bound in understanding the same day parcel market for the entire Sydney CBD will produce an excessive, and unrealistic, value.

% of same day, med

Given the upper and lower bounds, a middle ground was determined at 15%. This value is assumed to be a better representation of the same day market for Sydney CBD and is taken forward in the calculations.

D.2.3 Inputs for market size for co-modality deliveries in Sydney CBD (Section 5.3.2)

% of co-modal, low

A low bound assumption of the proportion of same day deliveries amongst total deliveries is set at 10%. This conservative value was determined considering a small start or slower uptake from the industry.

% of co-modal, high

The upper bound was gathered from the logistics operator data. As previously mentioned, this operator is considered to do an above-average proportion of same day deliveries, meaning statistically their data would reflect a greater potential proportion of parcels that would suit co-modality. By refining the number of same day deliveries conducted within the weeks worth of data provided, applying a range of assumptions as to how the operation would be conducted, the average number of same day parcels that would suit co-modality worked out to be roughly half (196/411, 48%). It is suggested this is an optimistically high value and assumes that all parcels able to be sent in by train for the middle mile would do so, irrespective of how long the middle mile took by rail versus by road. In reality, this would likely not occur.

% of co-modal, med

The middle ground was determined as 23% (94/411) by using the logistics operator data and applying assumptions to the choice that the operator may make. It looked at the number of co-modal parcels and applied an assumption that co-modal middle mile journeys that took no longer than 15 minutes more to be conducted as compared with the truck/van delivery method were contestible.

D.2.4 Inputs for potential benefits calculation (Section 5.4)

Distance/trip, km

taking Alexandria as an example (Table 6), the travel distance to St Peters is 1 km and to CBD is 4.6 km, a 3.6 km saved truck distance is recorded for one co-modality trip. Among all the potential trips, the saved distance is averaged at 24.2 km/trip.

Table 6 An example of the co-modal saved distance

Origin suburb	Line	Nearest station	(Co-modal) To station (km)	(Truck) To CBD (km)	distance (km)
Alexandria	T3	St Peters	1	4.6	3.6

Saved operating cost

According of Table 5, the total saved logistics operating time for a co-modality trip from Alexandria is 7 minutes, which is the difference between truck delivery time to CBD and co-modality's travel time to St Peters station and the corresponding shuffle time. For all the potential co-modality trips, the average logistics operating time saved is 29.67 minutes, or 0.49 hour.

The parameters to calculate potential environmental externality (Table 7) and congestion reduction (Table 8) benefits are derived from *Transport for NSW Economic Parameter Values*.

Table 7 Environmental externality costs parameters (Source: TfNSW, 2020)

Table 39 Externality unit costs for freight vehicles (cents per kilometre travelled) – urban

Externality type	Light commercial vehicles	Rigid trucks	Articulated trucks
Air pollution	7.56 (5.60 to 12.44)	16.50 (8.00 to 20.19)	65.82 (31.93 to 80.54)
GHG emissions	2.35 (2.19 to 2.47)	3.67 (1.84 to 6.42)	14.64 (7.34 to 25.62)
Noise	1.29 (0.90 to 1.79)	2.75 (1.83 to 3.67)	10.97 (7.31 to 14.64)
Water pollution	1.13 (0.84 to 1.86)	2.47 (0.83 to 3.03)	9.87 (3.30 to 12.08)
Nature and landscape	0.84 (0.84 to 1.63)	0.27 (0.27 to 0.56)	1.08 (1.08 to 2.22)
Urban separation	1.23 (0.73 to 1.74)	1.84 (0.92 to 2.76)	27.34 (3.67 to 11.00)
Upstream and downstream costs	7.85 (5.60 to 10.09)	14.69 (12.85 to 16.52)	N/A

Source: Light and heavy vehicles from Guide to Project Evaluation, Part 4, Project Evaluation Data, Austroads, 2008. Rail from NGTSM, Part 3, Appraisal of initiatives, Australian Transport Council 2006 Values indexed to June 2019 prices (ABS Series ID A2325806K).
Notes: Average load per vehicle is assumed based on ABS 2018 Survey of Motor Vehicle Use.

Table 8 Congestion reduction cost parameter (Source: TfNSW, 2020)

Table 20 Marginal road congestion cost in Sydney

Vehicle type	PCE factors	Marginal congestion cost in Sydney (cents/vkt)
Passenger vehicles & LCVs	1.00	44.88
Rigid trucks	3.00	134.64
Trailers	6.00	269.28
Articulated trucks	5.00	224.40
B doubles	8.00	359.04
Double road train	8.00	359.04
Triple road train	10.00	448.80
2 axle buses	2.00	89.76
3 axle buses	3.00	134.64

Source: BITRE (2016) Estimating urban traffic and congestion cost trends in Australian cities. Working paper 74, Bureau of Infrastructure, Transport and Regional Economics Values indexed from June 2010 prices to June 2019 prices (ABS Series ID A2325846C).