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Co-Modality for Sydney's Ferries

By
Veronica Schulz[a], Michael Bell[b],
Shengda Zhu[c], Glenn Geers[d],
Jyotirmoyee Bhattacharjya [e]

[a,b,c,d,e] Institute of Transport and Logistics Studies (ITLS),
The University of Sydney, Australia

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ABSTRACT:

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KEY WORDS: ***co-modality, cargo hitching, crowdshipping, city logistics, ferries, public transport, sustainability***

AUTHORS: **Schulz, Bell, Zhu, Geers, Bhattacharjya**

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CONTACT:

INSTITUTE OF TRANSPORT AND LOGISTICS STUDIES (H04)

The Australian Key Centre in Transport and Logistics Management
The University of Sydney NSW 2006 Australia
Telephone: +612 9114 1813
E-mail: business.itlsinfo@sydney.edu.au
Internet: http://sydney.edu.au/business/itls

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Abstract

Logistics issues arising from the last mile delivery of goods in an urban environment are plentiful. Co-modality, whereby the movement of freight and passengers are integrated on the same public transport mode, can mitigate road congestion and promote sustainable transport. This working paper investigates the merits of using co-modality for the 'intermediate mile' with Sydney's ferries in Australia. A global review of field trials found that a high level of stakeholder interaction and a robust data management system are necessary to ensure the success of the endeavour. A review of the transit assignment literature led to the selection of the frequency-based transit assignment model to locate spare capacity in the ferry network before the pandemic. Additionally, there was an evaluation of every ferry station's suitability for handling cargo with proposals for storage areas within each ferry station. An assessment of a range of Unit Load Devices (ULDs) in which goods are carried led to the selection of the 'meter cube' container as the most viable for Sydney's ferries. Tracking and tracing requirements were reviewed. Four business models are developed for different delivery processes and types of cargo – pickup and delivery of full meter cube containers, parcels transported in meter cube containers, or perishable goods transported in refrigerated meter cube containers. The repositioning of empty meter cube containers is not considered in detail. Potential limitations, risks and next steps for the successful implementation of co-modality for Sydney's ferries are detailed.

1. Introduction

Supply chains that serve the needs of society are increasingly challenging to create and support. The global growth of e-commerce has increased the number and difficulties of consumer deliveries. The resulting urban traffic congestion presents challenges for the safe, reliable, and cost-effective movement of goods.

In Sydney, Transport for NSW (2018) has predicted that e-commerce sales will double every five years, increasing the volume of goods moved within and between Greater Sydney's three polycentric cities; the Eastern 'Harbour' City, the Central 'River' City, and the Western 'Parkland' City. Mobility issues, resultant to the evolution of the three cities, include increased road congestion, as private cars remain the preferred mode of transport (Transport for NSW, 2015). The limited road connections between the northern and southern sides of Sydney, divided by the harbour, exacerbates the issues. Current cross-harbour road connections include the Sydney Harbour Bridge, Sydney Harbour Tunnel, Gladesville Bridge, Iron Cove Bridge, Ryde Bridge, and Silverwater Bridge. Limited routing options and the tolls on some cross-harbour roads often leads to freight vehicles travelling further distances to reach their destinations. Cross-harbour freight movements by roadways can disrupt the aesthetic of the city landscape as many desire to reside along Sydney's harbour waterfront. The prevailing congestion and inefficient routing leads to increased emissions, including noise, carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter (PM).

Urban freight transport in Sydney is achieved largely by rail and road. Movement by rail is typically suitable for larger shipments over longer distances due to the economies of scale and lower emissions output per tonne-km. Transport via rail, however, is uncommon in Sydney for last mile delivery of consumer goods or for the purpose of wholesale or retail distribution within the urban area. Freight transported via road is performed by a wide array of vehicles; heavy trucks, light trucks, and vans. It is estimated that 21% of road congestion in Sydney is the result of freight vehicles (Transport for NSW 2015).

Greater Sydney's logistics challenges are exacerbated by passenger transport, whereby the preference of residents to travel by private cars has increased road congestion, traffic accidents and air pollution. Many European cities have witnessed similar problems. The potential for co-modality, where passenger and goods flows are combined on public transport networks, to alleviate these issues has been the subject of a number of field trials. Typically, in urban areas, co-modality is implemented on tram, bus or train networks. However, the NSW Government has five principle public transport modes; trains, buses, light rail, metro, and ferries. While Transport for NSW (TfNSW) oversees all of these networks, the operations, with the exception of the train network, have been tendered out to private transport operators. While most co-modal schemes utilise land transport, Sydney's expansive harbour would allow for ferries to be used co-modally. The ferry network has significant spare capacity on many routes much of the time, offering space that could be used for cargo. Shifting some cargo onto spare ferry capacity could alleviate some logistics challenges in Greater Sydney.

A gap exists in the literature regarding the merits of using ferry networks for co-modality in the 'intermediate' transport leg. This paper aims to contribute to the existing literature by studying the feasibility of using reserve ferry capacity to transport cargo, taking Sydney's ferries as a case study. A transit assignment model is used to highlight links in the ferry network with most spare capacity. Having established that the meter cube container is the most appropriate for use on ferries, this paper studies the business models for three pickup and delivery scenarios; full meter cube containers, parcels to be transported in meter cube containers, and refrigerated products to be carried in refrigerated meter cube containers. The business models consider stakeholder responsibility and the tracking and tracing of cargo.

2. Literature Review

2.1 Co-Modality

Co-modality represents the cohabitation of passengers and goods on public transport networks and is synonymous with the terms 'cargo hitching' and 'crowdshipping'. This literature review includes a bibliometric analysis using keywords to assist in demonstrating the evolution of co-modality as a theoretical concept towards practical applications. Moreover, the review of academic literature and field trials of co-modality illustrates key insights into the success of a project. There is a large literature on transit assignment. A brief review of transit assignment concepts leads to the selection of the classic frequency-bases assignment model of Spiess and Florian (1989) to identify links in the ferry network with highest reserve capacity on average.

2.1.1 Bibliometric Analysis
A bibliometric analysis was completed using the keywords 'co-modality', 'cargo hitching' and 'crowdshipping' using Scopus. This reveals that 'city logistics' has been the central context in the literature since 2012, as Figure 1 shows. Earlier research demonstrated the different theoretical frameworks for approaching co-modality; the terms 'optimisation', 'traffic management', 'transport policy', and 'information' were common (Figure 1).

The term 'case studies' began to be present in 2015, with detailed global co-modal schemes in numerous cities. This heralds a greater focus on the more practical side of 'co-modality'. In 2016, a greater emphasis on the passenger side of co-modality emerged as terms such as 'public transport', 'service' and 'passenger' appeared more frequently (Figure 1).

Additionally, as research into the topic expanded, a focus on the freight aspect of co-modality developed and terms such as 'urban freight transport', 'freight transport' and 'transport' became common in 2016 (Figure 1). A shift occurred in 2019 with additional attention given to co-modality's impact on the passenger experience and patronage. Furthermore, in 2020, the term 'cargo-hitching' became more widely used as an alternative to 'co-modality' (Figure 1).

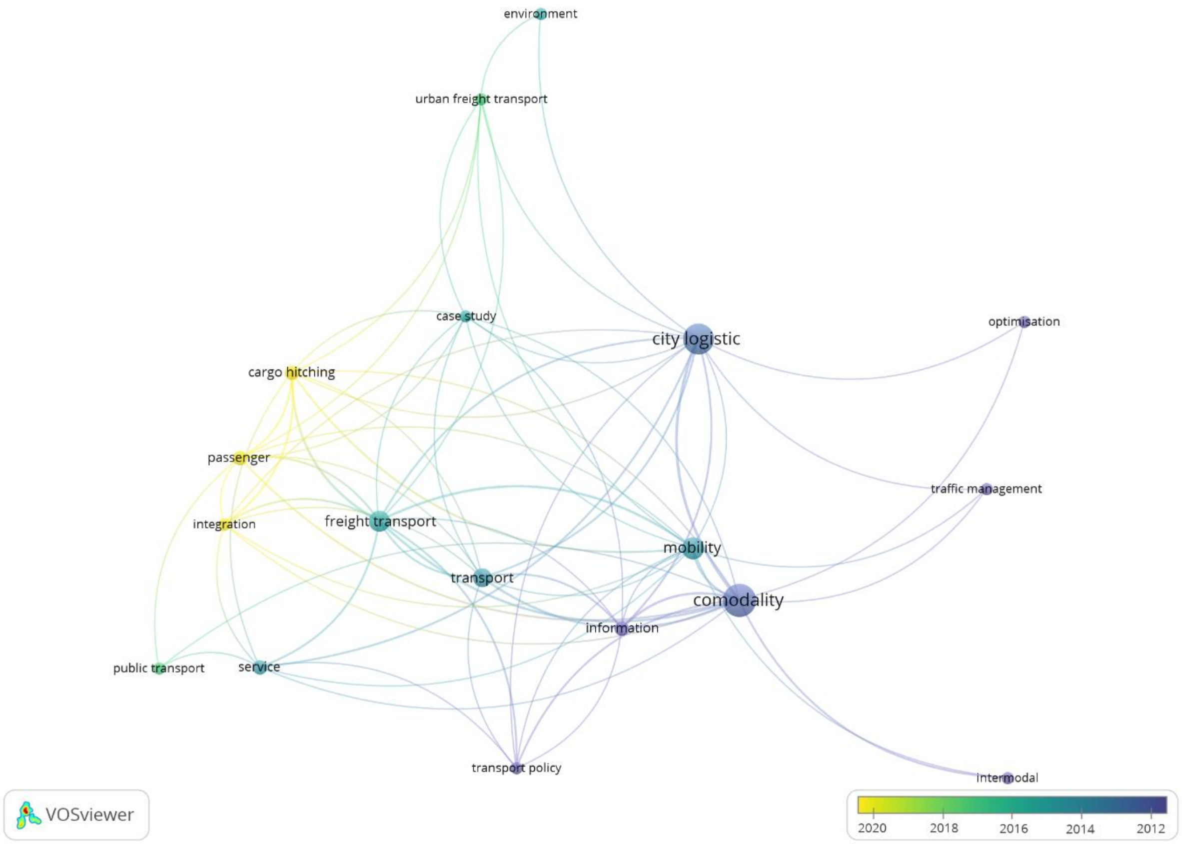

Figure 1 Bibliographic Analysis for 'Co-Modality'

2.1.2 Literature

Trentini & Mahléné (2010) originated the term co-modality to mean the synthesis of goods and passengers on urban public transport. In this sense, cargo can be carried on public transport modes like buses, subway systems, and light rail, as well as carsharing and bike sharing services, which are typically passenger only services.

Integration of people and goods on a single transport mode has the ability to reduce traffic congestion. Ghilas et al. (2013) noted that this is a frequent occurrence in long-haul transport, such as airplanes, to reduce the number of vehicles in use at any given time. However, this requires a management system capable of coordinating both passenger and freight flows as one system, ensuring adequate capacity for both. Arvidsson et al. (2016) postulate that increased use of information technology and infrastructure in the transport industry can increase the success of co-modality.

Arvidsson et al. (2016) stated that three key transport dimensions combine for a successful co-modal approach; space, vehicles, and time. Sharing road space between passenger and freight could alleviate road congestion. Additionally, using the same vehicles for both passenger and freight flows increases the utilisation of said vehicles. It is suggested that taxis and autonomous vehicles could potentially be suitable transport modes for both passengers and freight. In situations where freight and passenger flows cannot share the space and vehicle simultaneously, Arvidsson et al. (2016) suggested that they should be separated in time, whereby passenger services run during the day and freight is carried at night, for example.

Solving problems like high CO_2 emissions, transportation costs, noise and traffic congestion through co-modality is only a possibility with sufficient cooperation from stakeholders (Trentini & Mahléné 2010; Trentini et al. 2012; Arvidsson et al. 2016; Cochrane et al. 2017; Regue & Bristow 2013). Cochrane et al. (2017) argue that while these benefits exist, the biggest barriers to implementing co-modal solutions are political and organisational. A substantial shift from the current organisational approach to urban transportation is necessary. Van Duin et al. (2019) argued that for such an approach to function, integration between the institutional and business levels of both logistics companies and public transport companies is essential. Additionally, sufficient cooperation and support between all stakeholders, such as the public sector, private logistics companies and public transport operators, is necessary (Ghilas et al. 2013).

For long-term success, co-modality should be profitable for both the logistics operator and public transport operator (Cochrane et al. 2017). Alessandrini et al. (2012) stated that lower operating costs is the biggest incentive for logistics operators. For public transport operators, the advantage of implementing co-modality is the increased usage of public transport vehicles (Ghilas et al. 2013). However, Arvidsson & Browne (2013) suggest that conflicting stakeholder objectives can limit the success of co-modal projects. Moreover, the long-term viability of co-modality relies not only on profitability, but also on the social and environmental impacts on the city as well (Van Duin et al. 2019).

Major concerns regarding the impact on customer service levels exist. Savelsbergh & Van Woensel (2016) argue that the integration of passenger and freight flows on public transport should only occur if there are no negative consequences to passengers. Interference with passenger traffic has been the main barrier to the success of many co-modal trials implemented to date (Arvidsson and Browne 2013). Therefore, it is important to consider capacity constraints and determine the maximum amount of cargo that can be carried on public transport without impeding passenger satisfaction (Savelsbergh & Van Woensel 2016; Cochrane et al. 2017).

The commercial feasibility of co-modal projects relies on its seamless integration in supply chains. Giannopoulos (2008) emphasised the importance of robust cargo handling technology, such as equipment for cargo loading and unloading. The standardisation of the Unit Load Device (the container within which cargo is carried) is key to seamless connections between modes (Giannopoulos 2008).

In addition to co-modality, the use of low emission vehicles, such as hybrid vehicles or electric vehicles, are suggested to further reduce emissions (Alessandrini et al. 2012; Arvidsson & Browne 2013;

Dampier & Marinov 2015; Trentini et al. 2012). Autonomous vehicles could be utilised as the technology matures and gains traction (Bruzzone et al. 2021). Lower impact delivery modes, such as bicycles or tricycles, are a potential option to reduce freight traffic at transit stops (Cochrane et al. 2017; Dampier & Marinov 2015; Trentini et al. 2012).

2.1.1 Global trials

Numerous field trials to explore the adoption of co-modality in an urban environment have taken place. CarGoTram was a co-modality project in Dresden, Germany, launched in November 2000 (Van Duin et al. 2019). Volkswagen (VW) and the public transport operator, Dresdener Verkehrsbetriebe (DVB), collaborated to allow dedicated cargo trams to supply the VW factory on one side of Dresden with car components from a logistics centre on the other side of Dresden (Regue & Bristow 2013). The trams utilised the same tramtracks as the passenger trams and were run on a timetable around passenger services (Arvidsson & Browne, 2013). Trams ran hourly on a 5km route; however, the frequency could be increased to every 40 minutes when required (Arvidsson & Browne 2013). Utilising trams in this way removed sixty truck trips from the public roads per day (Arvidsson & Browne 2013). CarGoTram was considered successful. However, in 2020, the project ceased due to a reduced demand for car parts at the assembly plant and the cost of rolling stock maintenance (Zhu et al. 2021).

The project CityCargo was launched as a pilot trial in 2007, in Amsterdam, Netherlands (Regue & Bristow 2013). Dedicated cargo trams and electric distribution vehicles transported cargo to businesses in the city centre from urban consolidation centres (Arvidsson & Browne 2013). Tram operator, GVB, and CityCargo worked in conjunction with each other to facilitate the operations (Arvidsson & Browne 2013). Two cargo services ran per day between 7am and 11pm (Van Duin et al. 2019). Utilising the co-modal approach as opposed to the traditional truck transport added an extra 15 minutes to the delivery schedule. Despite this, costs were reduced by 15%, 50% of commercial vehicles were removed from roads, and the trial was popular amongst smaller businesses such as restaurants (Arvidsson & Browne 2013). Irrespective of the benefits, the company failed to raise capital and declared bankruptcy in 2008 (Regue & Bristow 2013).

The GüterBim project in Vienna was a co-modal trial organised by the Austria Ministry for Transport and Innovations, Vienna Transport Authority and Vienna light rail operator, Wiener Lokalbahnen (Regue & Bristow 2013). It launched in August 2004 and utilised the existing rail network to run a cargo tram (Arvidsson & Browne 2013). The approach was oriented mainly towards hospitals, retail stores and waste disposal (Arvidsson & Browne 2013). GüterBim ceased operating in 2007 due to the financial and political implications when none of the stakeholders were willing to invest in a long-term commitment (Regue & Bristow 2013).

2.1.2 Modelling approaches

The tactical planning aspect and modelling approach for co-modality must account for both the flow of passengers and the flow of goods. Trentini et al. (2012) proposed a two-tiered system where goods are first consolidated into containers at urban consolidation centres. From there, they are transported by public bus services to designated stops. Finally, ‘city freighters’ (electric cargo bikes) will be responsible for the ‘last mile’ delivery. The model operates under the constraint that the flow of goods should not impede passenger flow and that containers must be picked up when the bus arrives (they cannot be ‘rolled’). The city freighters must return to the same bus stop and the return of empty containers to the urban consolidation centres is not considered. The model is formulated as a vehicle routing problem and solved by an Adaptive Large Neighbourhood Search (ALNS) heuristic.

Ghilas et al. (2013) formulates a pickup and delivery problem with fixed schedule lines which is solved by mixed-integer programming. On the pickup side, vehicles travel from the depot to a pickup location and drop the parcels at a station before returning to the original depot. On the delivery side, vehicles travel from the depot to the station and drop the parcels off at the destinations before returning to the original depot. Linking pickup and delivery, the parcel travels along a public transport route, which is operating under a fixed schedule. The objective function of the model minimises total operating costs, which includes the operating costs of pickup and delivery, and the cost to transport by public transport. The model suggests that this approach can reduce operating costs, CO_2 emissions and alleviate congestion. However, this approach is limited by failing to consider how customer service levels may be impacted.

Li et al. (2014) proposed an approach where passengers and goods cohabit taxis as opposed to public transport. Li et al. (2014) formulated a Freight Insertion Problem (FIP) model based on the share-a-ride problem (SARP). In this instance, passenger demand is first satisfied with parcel demand inserted afterwards into pre-defined routes. The model is solved using mixed-integer linear programming, optimising a profit function. Building on this, Ronald et al. (2016) formulated a SARP and a FIP mixed-integer programming model using on-demand transport and found that high levels of customer satisfaction can still be achieved even when carrying goods and passengers simultaneously.

2.2 Transit Assignment Model

Transit assignment models aim to estimate line loadings between origins and destinations in public transport networks. Early attempts at transit assignment models, like Dial (1967) and le Clercq (1972), assumed that travellers would simply travel along the shortest origin-destination (OD) path. These models favour direct paths, irrespective of total travel time. They are limited by the assumption of a fixed waiting and in-vehicle time. In practice, issues around common lines are prevalent. The common line problem arises when transit lines share stops, increasing the complexity of the choice problem. Sometimes a longer route might be preferable if its bus arrives first and the bus for the shorter route is not expected for a while. Chriqui & Robillard (1975) proposed a heuristic method to obtain a solution, whereby a line is only 'attractive' when a traveller's expected travel time is reduced by its inclusion in the choice set. In so doing, Chriqui & Robillard (1975) assume that buses arrive at the stop randomly with line-specific frequencies and that each passenger boards the first bus that arrives at their stop on an attractive line.

Spiess & Florian (1989) in their seminal paper showed that the Chriqui & Robillard (1975) heuristic, referred to as a 'strategy', is the solution to a linear programming problem and moreover that the linear programming problem can be solved by a modified form of Dijkstra's algorithm run from the destination to all possible origins. Nguyen & Pallottino (1988) introduced the concept of the 'hyperpath' to represent all potentially optimal paths between an origin and a destination, which is the set of paths resulting from the Chriqui & Robillard (1975) heuristic. By extension, every hyperpath consists only of hyperpaths, in the same way as every optimal path consists only of optimal subpaths (Wu et al. 1994: Cominetti & Correa 2001; Kurauchi et al. 2003; Cepeda et al. 2006). Bell et al. (2015) reformulated the transit assignment model proposed by Spiess & Florian (1989) in matrix notation, and in so doing, presents a solution that can easily be implemented in scripting languages that process matrices.

Many studies have considered the effects of congestion on a traveller's route choice, achieving varying levels of accuracy and realism. In some cases, the congestion impact is considered by a calculation of in-vehicle time, done through using a discomfort cost if passengers are on high-volume services (Spiess & Florian 1989; Nguyen & Pallottino 1988). While the model formulated by Nguyen & Pallottino (1988) is limited by the presumption that waiting time at transit stops is not affected by congestion, the solution suggested by de Cea & Fernández (1993) minimises total travel time that includes both the in-vehicle time and waiting time. Further, this study accounted for vehicle capacity constraints and assumed that, as passenger flows increase, the travel time will increase. In this sense, the waiting time is increased by travellers queuing to board services. Moreover, the assumption that increased congestion may lead to passengers seeking out alternative routes is considered, with the number of alternative routes increasing as congestion increases.

Wu et al. (1994) further considered the effects of congestion stipulated by de Cea & Fernández (1993), calculating the in-vehicle transit time and waiting time as flow dependent, leading to a congested transit assignment approach. As transit stops become more congested, the waiting time and time to board the service increases. Wu et al. (1994) is limited by the assumption that a traveller will board the first service to arrive at their transit stop, irrespective of in-vehicle crowding. Capacity constraints can increase congestion at stops. Cepeda et al. (2006) produced a heuristic solution using the MSA (method of successive averages) algorithm to ensure that passenger flows are feasible with respect to line capacity, and in cases where the network is too congested, reveal instances where supplementary capacity is necessary. Cepeda et al. (2006) assumed that line frequencies are related to passenger flows.

Acknowledging the limitations of assuming that travellers will board the first service that arrives irrespective of in-vehicle crowding, Kurauchi et al. (2003) introduced the idea of failure to board. Kurauchi et al. (2003) suggested that travellers may choose not to board overcrowded services, leading to a non-zero fail-to-board probability. This can result in a greater spread of passenger flow. Gentile et al. (2005) posited the importance of online information provided at stops as a determinator of a traveller's failure to board. Greater certainty on arrival times could lead to some travellers not boarding the first attractive service to arrive. Schmöcker et al. (2008) suggested that a traveller who fails to board the initial route may change their route choice if, after a certain time, there is too much congestion.

Schmöcker et al. (2011) extended the work done by Schmöcker et al. (2008) and introduced 'fail to sit' probabilities. A common passenger behaviour on public transit networks is their preference to sit, rather than stand. Schmöcker et al. (2011) suggested that seat capacity should be constrained alongside vehicle capacity in an equilibrium model. They also assumed that travellers waiting to board services each have the same probability of boarding and therefore they are competing for a seat. Additionally, it was suggested that travellers who are standing on the vehicle could upgrade to a seat at each stop as those previously seated passengers alight. It was suggested that travellers may 'fail to board' their intended route when there are no seats. To determine the shortest hyperpath that accounts for 'fail to sit' probabilities, Schmöcker et al. (2011) introduced a discomfort cost for standing.

Table 1 summarises the literature on frequency-based transit assignment models.

Table 1 Transit Assignment Model Literature Classification

Paper	Strategy	Hyperpath	Congestion at stops	Vehicle capacity	Failure to Board	Failure to Sit	Online Information	Matrix Algebra	Co-modality
Nguyen & Pallottino 1988	✓	✓	✓						
Spiess & Florian 1989	✓		✓						
de Cea & Fernández 1993	✓		✓	✓					
Wu et al. 1994	✓	✓	✓						
Lam et al. 1999	✓		✓	✓					
Cominetti & Correa 2001	✓	✓	✓	✓					
Lam et al. 2002	✓		✓	✓					
Kurauchi et al. 2003	✓	✓	✓		✓				
Gentile et al. 2005	✓	✓					✓		
Cepeda et al. 2006	✓	✓	✓	✓					
Schmöcker et al. 2008	✓	✓	✓		✓				
Schmöcker et al. 2011	✓	✓	✓			✓	✓		
Bell et al. 2015	✓	✓						✓	
This Paper	✓	✓						✓	✓

3. Methodology

3.1 Data collection

The data utilised to determine vacant capacity on the ferry network was derived from secondary data sources. TfNSW is the government agency responsible for managing the majority of public transport services in New South Wales, including the Sydney Ferries network. TfNSW provides open access to their data. Due to the reduced patronage as a result of COVID-19, historical data was sourced for this research.

The data necessary to formulate a transit assignment model includes passenger flows by origin and destination, the ferry timetable, and the ferry station locations. The OD data was derived for a 60 day period between February and March 2016. The timetable used is from September 2016. There are two reasons for utilising data from this period. Firstly, there was no historical timetable data available during February or March 2016. Secondly, there were no timetable changes to the ferry services between February and September 2016. At the time, the Sydney Ferries network consisted of 7 ferry lines: F1 Manly, F2 Taronga Zoo, F3 Parramatta River, F4 Darling Harbour, F5 Neutral Bay, F6 Mosman Bay, and F7 Eastern Suburbs. Service frequency during the off-peak time period was utilised. Furthermore, ferry lines F3 and F7 occasionally consisted of express services. Express services were disregarded, and an average frequency was used. The ferry station location data required is in longitude and latitude coordinates from 2016. Since then, new ferry stations have been introduced (e.g., Barangaroo Wharf) and some ferry stations have been unoccupied (e.g., Darling Harbour Wharf). The ferry stations utilised were in operation between February and September 2016.

To calculate the reserve capacity for each travel link, it is necessary to know the maximum passenger capacity for each line. This necessitated secondary data regarding vessel fleet capacity. Data on the individual ferry vessels in rotation and the subsequent ferry line that the vessel operates on was collected via TfNSW's open data access.

Determining suitable ferry stations capable of handling cargo required the use of both secondary and primary data. To consider suitable road access to a ferry station, secondary data was sourced from Google Maps. A field analysis at certain ferry stations was completed to determine if suitable loading zones exist at ferry stations or could be implemented. Due to the COVID-19 lockdown in Greater Sydney, only five ferry stations were viewed: Balmain, Birchgrove, Circular Quay, Cremorne Point, and Manly. To supplement the remaining ferry stations, secondary data from Google Maps Street View was obtained. Similarly, this was the case for determining storage space within a ferry station and illustrating where a dedicated storage area could be placed. Inclusion of suitable ramps at ferry stations was inferred from secondary data. TfNSW's 'planning' feature was used, which detailed which ferry stations are wheelchair accessible, to determine if ramp access was adequate. Data on the size of the gangways that are used on the ferry network was sourced from TfNSW.

3.2 Transit assignment

Error! Reference source not found. provides an illustration of network coding used in this paper. A ferry station consists of a collection of nodes, one for each line and direction, one for boarding and one for alighting. Links connect nodes. For one line operating in both directions there are four travel links. There is one link for boarding each line and direction and one link for alighting each line and direction. Links are also included for transferring between each line and direction. Hence for a ferry station serving one line in both directions there are four nodes, four travel links, two boarding links, two alighting links and two transfer links. For a ferry station serving two lines in both directions there will be two more nodes, four more travel links, two more boarding links, two more alighting links, and ten more transfer links for possible transfers between lines and within the new line. In the model, waiting time is taken into account for boarding and transferring. Waiting time en route to a specific destination is set equal to the inverse of departure frequency of all attractive lines, on the assumption that both passengers and buses arrive randomly.

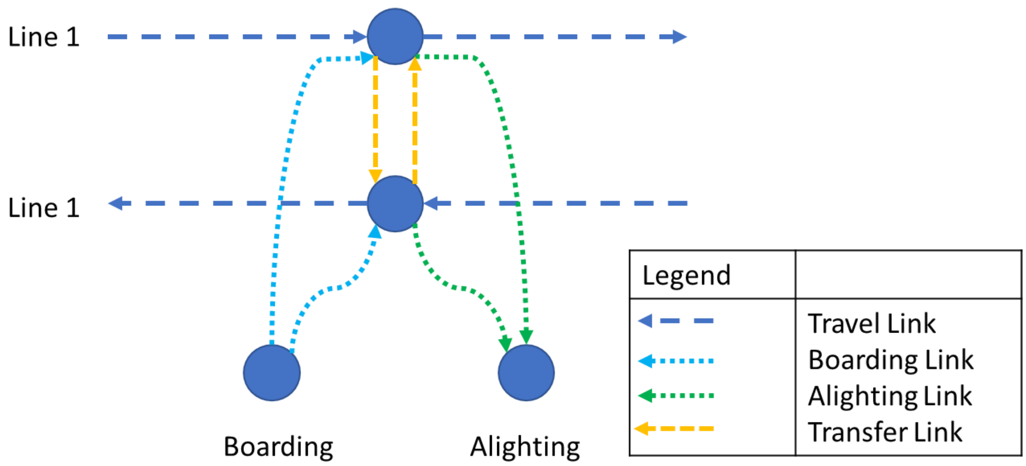

Figure 2 A ferry station serving one line in both directions

The Sydney Ferries network as modelled consists of 7 ferry lines and 36 ferry stations (Figure 3).

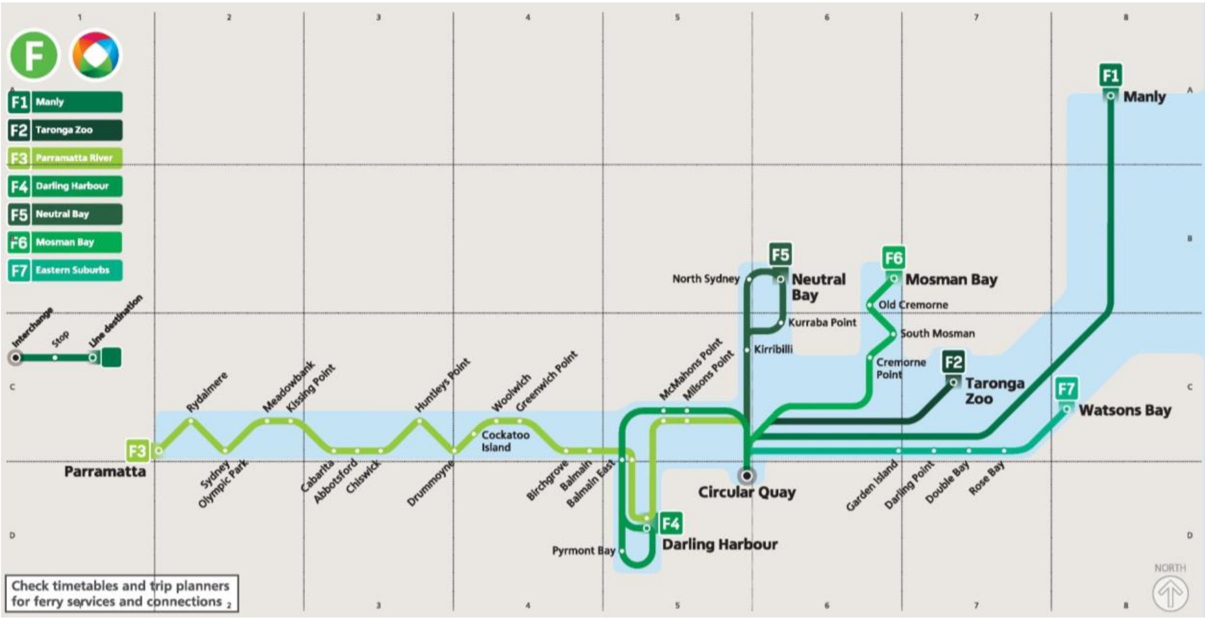

Figure 3 Sydney Ferries network (source: https://transitmap.net/sydney-ferries-2015/)

The first step of building the model required numbering each node. Then, node-to-node links were numbered, including travel links, boarding links, alighting links and transfer links. In total, there are 337 links on Sydney's ferry network. Travel links are all instances of travel between two adjacent ferry stations. For Sydney's ferry network, there were 75 travel links, 150 boarding and alighting links, and 228 transfer links.

Consistency checks were completed to validate the network. To ensure that the ferry network was connected, it was checked that every stop could be reached from every other stop. Moreover, it was ensured that each link had an entrance node and an exit node.

Elements of a transit trip, without the waiting time element, are denoted by a constant nonnegative time (or cost). Links are denoted by $a \in A$, nodes by $i \in I$ and the network by $G = (I, A)$. The destination node is denoted by r and the demand between node i to r is represented by g_i, $i \in I - \{r\}$. Every link is assigned a frequency $f_a, a \in A$. Boarding and transfer links are assigned the frequency of the line being boarded while the frequency of every other link is set equal to a very large value ($f_a \leftarrow \infty$). The assignment problem is solved by the following two-stage algorithm (taken from Spiess and Florian, 1989):

Spiess and Florian frequency-based transit assignment algorithm

For all $r \in I$

Stage 1: Find the hyperpaths:

$u_i \leftarrow: \infty, i \in I - \{r\};\ u_r := 0;\quad f_i \leftarrow 0, i \in I;\quad S \leftarrow A;\ \bar{A} \leftarrow \emptyset$

Repeat while $S \neq \emptyset$

Find $a = (i, j) \in S$ that satisfies $u_i + c_a \leq u_{i'} + c_a\ \forall\ a' = (i', j') \in S$

$S \leftarrow S - \{a\}$

If $u_i > u_j + c_a$ then $u_i \leftarrow \frac{f_i u_i + f_a(u_j + c_a)}{f_i + f_a}$, $f_i \leftarrow f_i + f_a$, $\bar{A} \leftarrow \bar{A} + \{a\}$

Stage 2: Assign demand to the hyperpaths:

$V_i \leftarrow g_i, i \in I$

For each $a = (i, j) \in A$ in decreasing order of $(u_j + c_a)$

If $a \in \bar{A}$ then $v_a \leftarrow \frac{f_a}{f_i} V_i,\ \ V_j \leftarrow V_j + v_a$ otherwise for $v_a \leftarrow 0$.

The output of this algorithm are the anticipated link loadings $v_a, a \in A$, and the expected hyperpath costs $u_i, i \in I - \{r\}$, for each destination $r \in I$.

3.3 Unit Load Device Choice

The most suitable Unit Load Device (ULD), the term used to refer to the container in which cargo is carried, was decided by considering the attributes of four different ULDs. The ULDs considered are metre cube containers, roll cages, hand trolleys and luggage suitcases. The choice of which ULD to use is impacted by several factors. Firstly, a ULD that can be used along multiple points in the supply chain has the ability to facilitate a seamless integration of co-modality. A ULD that has enough capacity to carry the cargo is necessary. Also, it is important to consider the size of the ULD that is most appropriate for storage in ferry stations and onboard the ferries to avoid degrading the passenger experience and deterring travellers from using the ferry network. Moreover, a suitable ULD would be able to be loaded onto ferry vessels with ease and stability to mitigate accidents and reduce delays. The ULD used must be secure to reduce theft and not be susceptible to water and weather damage. Moreover, considering how the repositioning of empty ULDs will occur is necessary. Lastly, to support a seamless connection between the ferry transport leg and the transport legs to and from the ferry station, it is necessary to consider a ULD suitable for use in conjunction with different vehicle types. The type of vehicle used is considered primarily by its suitability in an urban context, such as size and emissions.

Overall, ULDs are evaluated using a High-Medium-Low suitability scale for eight criteria:

- Capacity for cargo
- Size dimensions for storage on vessels and stations
- Loading and unloading process
- Theft mitigation
- Water and weather protection
- Stacking of empty containers
- Repositioning of empty containers
- Integration with other transport modes

3.4 Ferry Station Suitability

To ascertain the suitability of a ferry station facilitating co-modality, the Level of Service (LoS) was used on certain characteristics. The rating system consisted of 6 levels, A through F (Planning Tank 2020). These have been interpreted to describe co-modal operational conditions:

- A: Best
- B: Good
- C: Workable but not good
- D: Sometimes unworkable
- E: Often unworkable

- F: Completely unworkable

Every ferry station was evaluated based on 4 criteria; road access, loading zones, storage space, and ramps. Transporting cargo to a ferry station requires road access. Road access was assessed based on a combination of factors; the road options leading towards the ferry station, the road width, and the traffic conditions. Loading zones are necessary to unload and load cargo. This was evaluated on the availability of loading zones; if no loading zones were present, the potential for a loading zone was assessed. Storage space within the ferry station is necessary to store cargo in between ferry services. This was assessed by the available space within a prospective ferry station. Lastly, ramps are necessary to transport cargo from the loading zone to the ferry station, and they must be an adequate size to handle both cargo flows and passenger flows. Any ferry station with wheelchair access achieved a rating of D or higher, and ferry stations with no wheelchair access achieved an F. To differentiate between the ferry stations with wheelchair access, the width and smoothness of ramp surface was considered. The gangways used by Sydney Ferries are standardised to be a minimum of 2.4 metres wide, measuring 1.2 metres wide for each direction, and thus, assessing the ease of loading cargo from a ferry station onto the vessel is not necessary. Typically, LoS C and D are appropriate for planning purposes. Subsequently, ferry stations had to achieve a D LoS or higher in every category to be deemed suitable.

3.5 Ferry Station Storage

Determining where the storage area will be placed in each ferry station is necessary. However, ferry station designs in the Sydney Ferries network differ from each other. While some of the smaller ferry stations have similar layouts, larger ferry stations like Circular Quay differ more drastically. Five ferry stations of differing size and layout were used to design possible storage spaces. These ferry stations are Balmain, Birchgrove, Circular Quay, Cremorne Point and Manly. Preference for the storage area location is in close proximity to wall edges and the station guard area, and further away from passenger waiting areas.

4 Results/Analysis

4.1 Capacity on board

The transit assignment model allocated passenger flows to ferry links for a 60-day period. In most cases, station-to-station links are serviced by only one ferry line. Thus, all passengers travelling between those two stations have only one option for travel. However, ferry lines F3 and F4 overlap significantly, leading to the sharing of traffic between these lines. Link utilisation and load is shown in Table 2, sorted by link utilisation. On average and for the period studied, the ferry system clearly had significant spare capacity on board so the prospect of allocating some space to cargo would seem to be possible across the network as a whole. However, there are peaks in ferry traffic, so during these times there may be little or no spare capacity. There may therefore need to be restrictions on the use of certain links at certain times for carrying cargo.

Table 2 Link utilisation and load, sorted by link load

Line	Station-to-Station	Link utilisation	Link load
F4	Darling Harbour - Pyrmont Bay	0.193652002	185751
F4	McMahons Point - Balmain East	0.181749896	174335
F4	Circular Quay - Milsons Point	0.168640534	161760
F4	Pyrmont Bay - Balmain East	0.161215596	154638
F1	Circular Quay - Manly	0.157672348	416255
F1	Manly - Circular Quay	0.156612121	413456
F4	Balmain East - Darling Harbour	0.153868588	147591

F4	Milsons Point - McMahons Point	0.14640638	140433
F7	Garden Island - Darling Point	0.118818807	113971
F7	Double Bay - Rose Bay	0.11778774	112982
F7	Circular Quay - Garden Island	0.116333403	111587
F7	Darling Point - Double Bay	0.115406589	110698
F7	Watsons Bay - Rose Bay	0.114942661	110253
F7	Rose Bay - Watsons Bay	0.113842786	109198
F7	Rose Bay - Double Bay	0.103896997	99658
F7	Double Bay - Darling Point	0.103145329	98937
F3	Cockatoo Island - Drummoyne	0.084033316	197243
F3	Woolwich - Cockatoo Island	0.076494121	179547
F3	Huntleys Point - Chiswick	0.072690014	170618
F3	Abbotsford - Cabarita	0.07209228	169215
F3	Kissing Point - Meadowbank	0.070532123	165553
F3	Drummoyne - Huntleys Point	0.068645194	161124
F3	Chiswick - Abbotsford	0.068156101	159976
F3	Cabarita - Kissing Point	0.066896728	157020
F3	Sydney Olympic Park - Rydalmere	0.065923228	154735
F3	Meadowbank - Sydney Olympic Park	0.062474438	146640
F7	Darling Point - Garden Island	0.060503545	58035
F3	Parramatta - Rydalmere	0.054386929	127657
F7	Garden Island - Circular Quay	0.050787114	48715
F3	Rydalmere - Parramatta	0.049521558	116237
F3	Sydney Olympic Park - Meadowbank	0.048444956	113710
F5	Kirribilli - North Sydney	0.048049645	46070
F3	Circular Quay - Milsons Point	0.046509032	109166
F2	Circular Quay - Taronga Zoo	0.045460382	74355
F3	Rydalmere - Sydney Olympic Park	0.044602079	104690
F3	Kissing Point - Cabarita	0.044560327	104592
F2	Taronga Zoo - Circular Quay	0.041894718	68523
F3	Meadowbank - Kissing Point	0.041133691	96549
F3	Abbotsford - Chiswick	0.040855913	95897
F6	Cremorne Point - South Mosman	0.040550868	66325
F3	McMahons Point - Darling Harbour	0.04027405	94531
F5	Circular Quay - Kirribilli	0.038873592	37272
F6	Circular Quay - Cremorne Point	0.038462949	62910
F3	Milsons Point - McMahons Point	0.038239605	89756
F3	Cabarita - Abbotsford	0.038144172	89532

F3	Balmain East - Balmain	0.037662747	88402
F5	Kirribilli - Circular Quay	0.034873801	33437
F3	Huntleys Point - Drummoyne	0.034280845	80464
F4	Balmain East - McMahons Point	0.032197665	30884
F3	Chiswick - Huntleys Point	0.032063736	75260
F4	Milsons Point - Circular Quay	0.031996455	30691
F5	Kurraba Point - Kirribilli	0.031478932	30182
F5	Neutral Bay - Kurraba Point	0.029715269	28491
F5	North Sydney - Neutral Bay	0.02929078	28084
F3	Greenwich Point - Woolwich	0.02725343	63969
F3	Darling Harbour - Balmain East	0.026984279	63338
F6	Old Cremorne - Mosman Bay	0.026891661	43984
F3	Cockatoo Island - Woolwich	0.024851738	58332
F6	South Mosman - Old Cremorne	0.02426877	39694
F3	Drummoyne - Cockatoo Island	0.023408316	54944
F3	Greenwich Point - Birchgrove	0.022661469	53191
F3	Birchgrove - Greenwich Point	0.021728442	51001
F3	Woolwich - Greenwich Point	0.021371421	50163
F3	Balmain - Birchgrove	0.020813736	48854
F6	Old Cremorne - South Mosman	0.020301418	33205
F6	Mosman Bay - Old Cremorne	0.018184764	29743
F6	Cremorne Point - Circular Quay	0.017572145	28741
F3	Balmain - Balmain East	0.016915474	39704
F6	South Mosman - Cremorne Point	0.016574957	27110
F3	Birchgrove - Balmain	0.016307515	38277
F3	Darling Harbour - McMahons Point	0.010161469	23851
F3	Balmain East - Darling Harbour	0.009387781	22035
F3	Milsons Point - Circular Quay	0.00706544	16584
F3	McMahons Point - Milsons Point	0.00644044	15117
F4	McMahons Point - Milsons Point	0.004473259	4291

Loading and unloading are likely to present a challenge as cargo will have to share the gangways with passengers. This may also lead to restrictions when and where cargo is carried.

4.2 Ferry station suitability

Ferry stations were rated on four criteria to determine their suitability in handling cargo. Ferry stations with a Level of Service (LoS) of D or higher on every criterion are deemed suitable. Based on this, twenty-four out of the thirty-six ferry stations are appropriate for facilitating co-modality. The remaining 12 ferry stations are unsuitable in at least one other criteria (Table 3). Six ferry stations were lacking suitable road access. As this is immensely difficult to remedy without major infrastructural changes and investment, it is unlikely that these ferry stations could be used in the near future. However, ferry stations that fail on the other three criteria (loading zones, storage space and ramps) have the potential to be used with more modest infrastructural upgrades.

Table 3 Ferry Station Rating using Level of Service (LoS)

Ferry Station	Road Access	Loading Zones	Storage Space	Ramps
Circular Quay	C	C	D	A
Balmain	C	C	C	A
Balmain East	C	C	C	A
Birchgrove	C	D	C	F
Cabarita	C	C	C	A
Chiswick	D	D	C	A
Abbotsford	C	C	C	A
Cockatoo Island	F	D	C	A
Cremorne Point	D	C	C	A
Darling Harbour	E	E	C	A
Darling Point	F	F	C	C
Double Bay	C	D	D	C
Drummoyne	D	E	D	A
Garden Island	E	E	E	C
Greenwich Point	C	C	D	F
Huntleys Point	C	C	D	C
Kirribilli	E	E	E	C
Kissing Point	C	C	C	C
Kurraba Point	E	E	C	F
Manly	C	C	D	A
McMahons Point	C	C	C	C
Meadowbank	A	A	C	A
Milsons Point	D	D	C	C
Mosman Bay	D	A	C	C
Neutral Bay	C	D	C	C
North Sydney	D	C	E	F
Old Cremorne	E	E	E	F
Parramatta	C	C	D	A
Pyrmont Bay	D	D	D	C
Rose Bay	C	C	C	A
Rydalmere	C	C	D	C
South Mosman	D	D	D	F
Sydney Olympic Park	B	A	D	C
Taronga Zoo	C	D	D	C
Watsons Bay	D	C	C	F
Woolwich	C	A	D	C

4.3 Ferry station storage

Birchgrove Wharf is one of the smaller ferry stations on the F3 Parramatta Line. The ramp to enter and exit Birchgrove station is on the top right-hand side, and the entrance and exit for the ferry vessel is at the bottom (Figure 4). The proposed storage area within this ferry station is in the top left corner (Figure

4). This area was chosen due to the distance away from the open water and the presence of glass walls. It was also chosen because it is further away from passenger waiting areas. Lastly, this spot was chosen because the cargo, as it is loaded onto the ferry station from the ramp, passes the station guard area, ensuring they are alerted to its delivery.

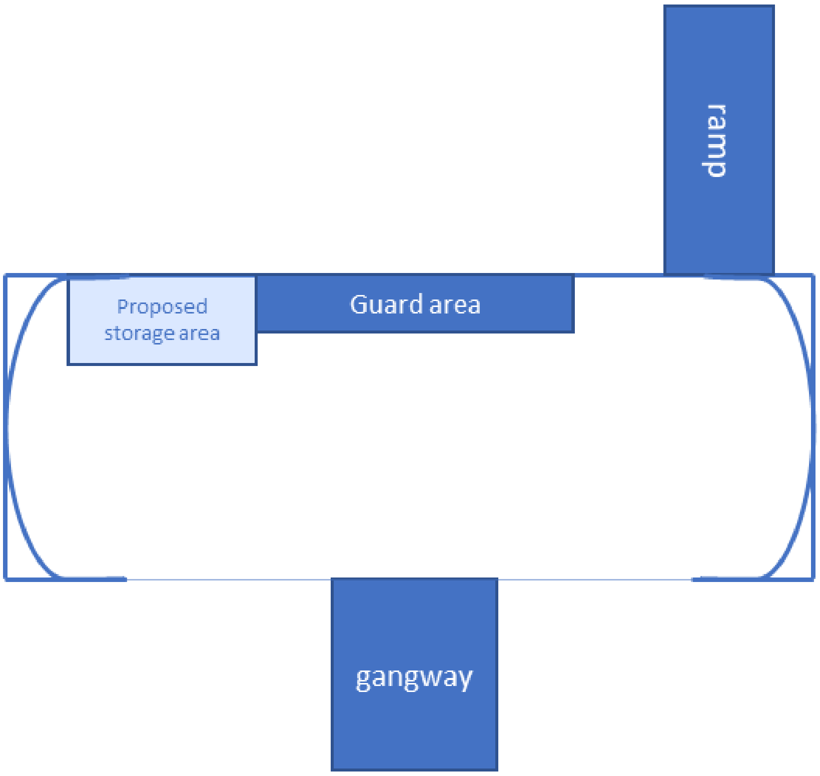

Figure 4 Birchgrove Wharf Storage Area

Balmain Wharf is also one of the smaller ferry stations on the Sydney Ferries network, residing on the F3 Parramatta Line (Figure 5).

Figure 5 Balmain Wharf

Balmain Wharf is of a similar size to Birchgrove Wharf, and yet differs in design. The ramp to enter and exit the ferry station is on the left side, and there is a railing that goes along the whole left-hand side of the station (Figure 6). In this case, the proposed storage area is in the top left corner next to the railing. This was chosen as it is further away from the passenger waiting areas and in close proximity to the station guard area.

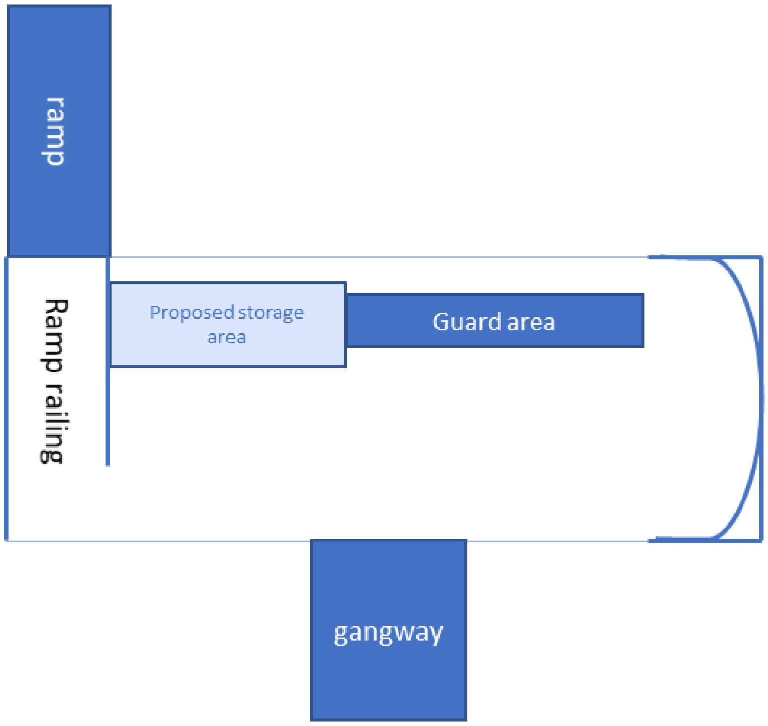

Figure 6 Balmain Wharf Storage Area

Cremorne Point Wharf is a medium sized wharf on the F6 Mosman Bay line. The layout is the left-right reflection of the Birchgrove Wharf. The ramp to enter and exit the station is on the top left corner and is opposite the ferry vessel entrance and exit (Figure 7). The proposed storage area for Cremorne Point Wharf is in the top right corner and was chosen due to the distance away from the passenger waiting areas and close proximity to the station guard area.

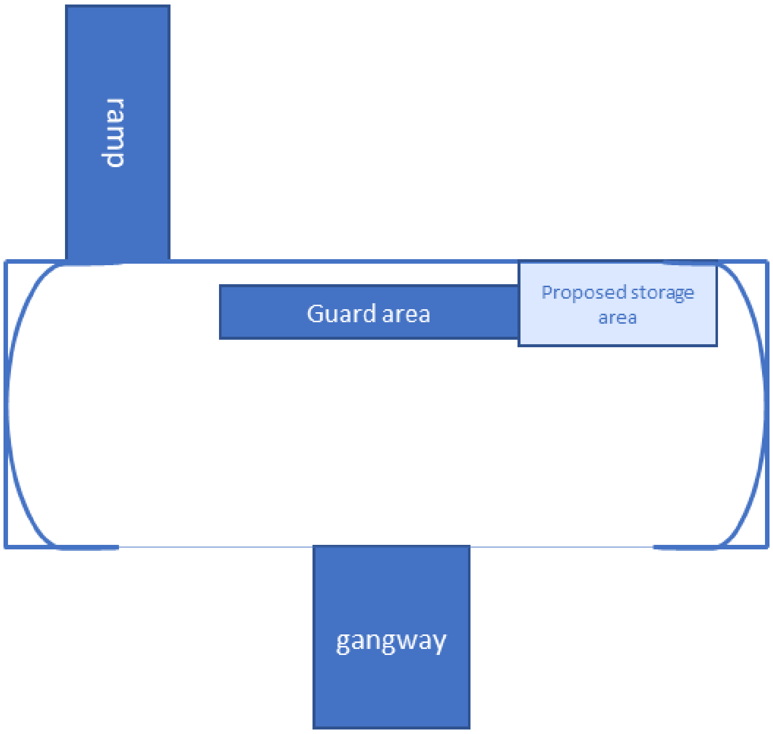

Figure 7 Cremorne Point Wharf Storage Area

Manly Wharf is on the F1 Manly line and differs substantially to the previous ferry station examples. Manly Wharf has two levels and includes a large ramp that goes to the upper level (Figure 8).

Figure 8 Manly Wharf Ramp

The traveller path at ground level, from the gates to the gangway, is complicated. Travellers must enter the gates on the left side and walk straight, up, and then down to enter the ferry vessel. Consequently, the proposed storage area is on the ground level away from passenger waiting areas and in front of the station guard area (Figure 9). While this positioning leads to a longer loading and unloading process, it would be feasible as travellers are restricted from boarding the vessel two minutes before the departure time. In this two minute period, ULDs can be loaded onto the vessel.

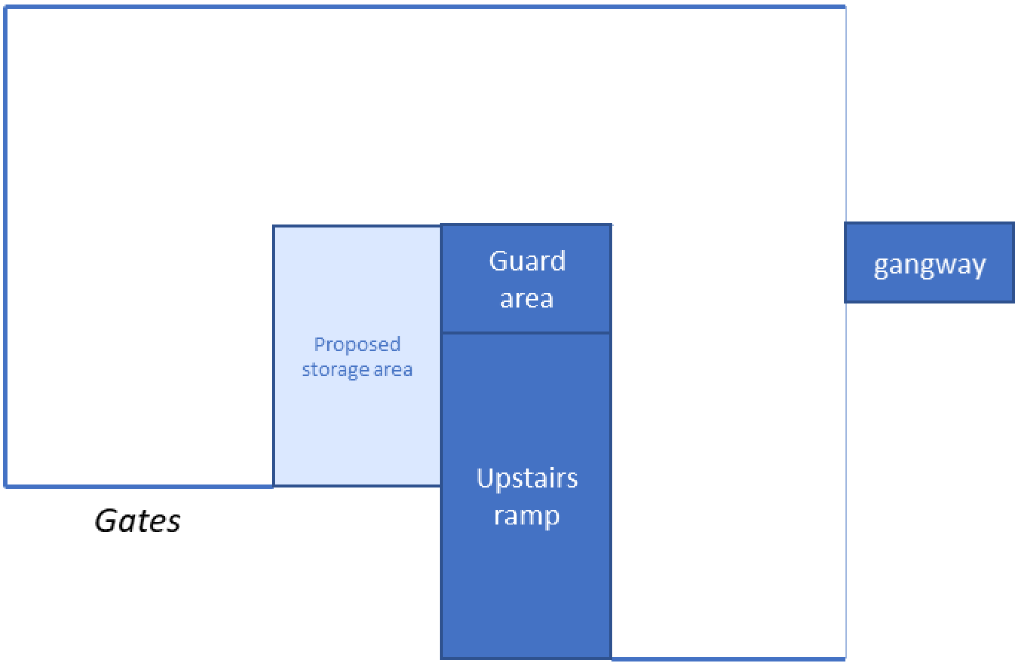

Figure 9 Manly Wharf Storage Area

Numerous wharves are used by Sydney Ferries at Circular Quay; Wharf 3, Wharf 4, Wharf 5, and Wharf 6[1]. This is because Circular Quay is used for all seven ferry lines. Accordingly, it is not only necessary to have a dedicated storage area for each individual wharf, but a central drop-off/pick-up storage space

[1] Wharf 1 and Wharf 2 are reserved for tourist and other special services.

that services the entirety of Circular Quay. In this manner, cargo is dropped off at the central area in Circular Quay. Shortly prior to the ferry service arrival, cargo is taken from the central area to the corresponding wharf. It sits in the dedicated wharf storage area briefly before being loaded onto a vessel. Conversely, for cargo that is leaving Circular Quay on a different transport mode, cargo is taken from the wharf to the central area. From there, other vehicles pick up the cargo to take it to its final destination. Cargo can also be transferred between different lines. As opposed to moving cargo between wharves, cargo will be transferred to the central area before being taken to its next wharf shortly before the service arrives. This reduces disruption along Circular Quay, thus ensuring greater civilian safety along the pier.

The wharves at Circular Quay all differ in layout. Wharf 3 is sectioned into two parts to facilitate travellers entering and exiting simultaneously. Travellers exiting move through the left side and travellers entering move through the right side (Figure 0). Travellers enter through the gates and walk straight, go under the upstairs ramp to the gangway. The proposed storage area is on the right hand side, next to the guard area and far away from the passenger waiting areas.

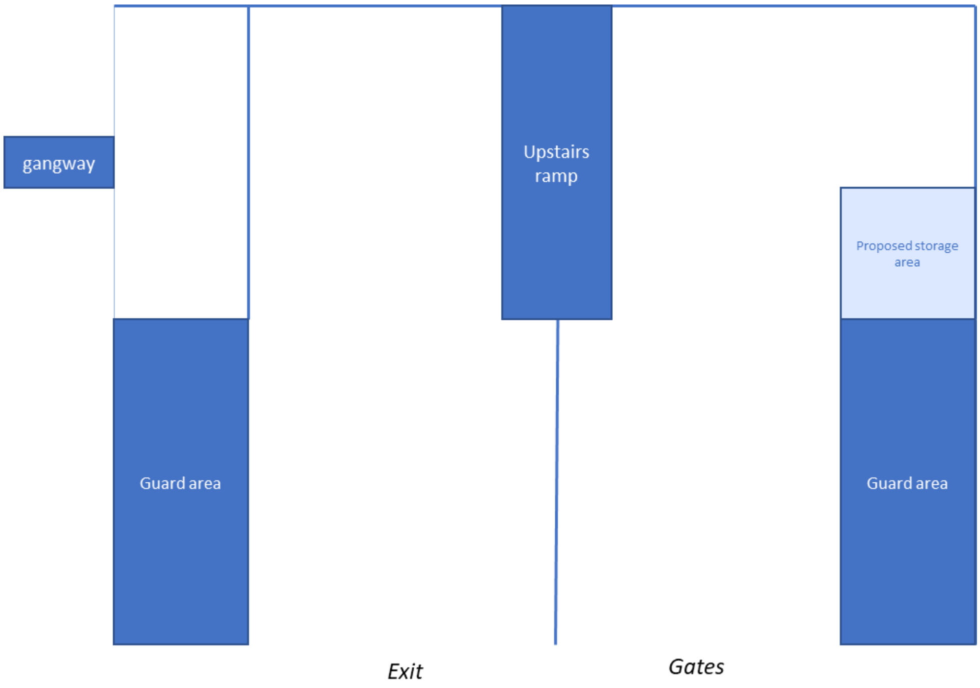

Figure 10 Circular Quay Wharf 3 Storage Area

Wharf 4 at Circular Quay has two sections, Side A and Side B, which can facilitate two ferry vessels. The proposed storage area can be used for both sides. In this case, it is on the left side, next to the station guard area and enclosed by barriers (Figure 1). This area is typically sectioned off from passengers.

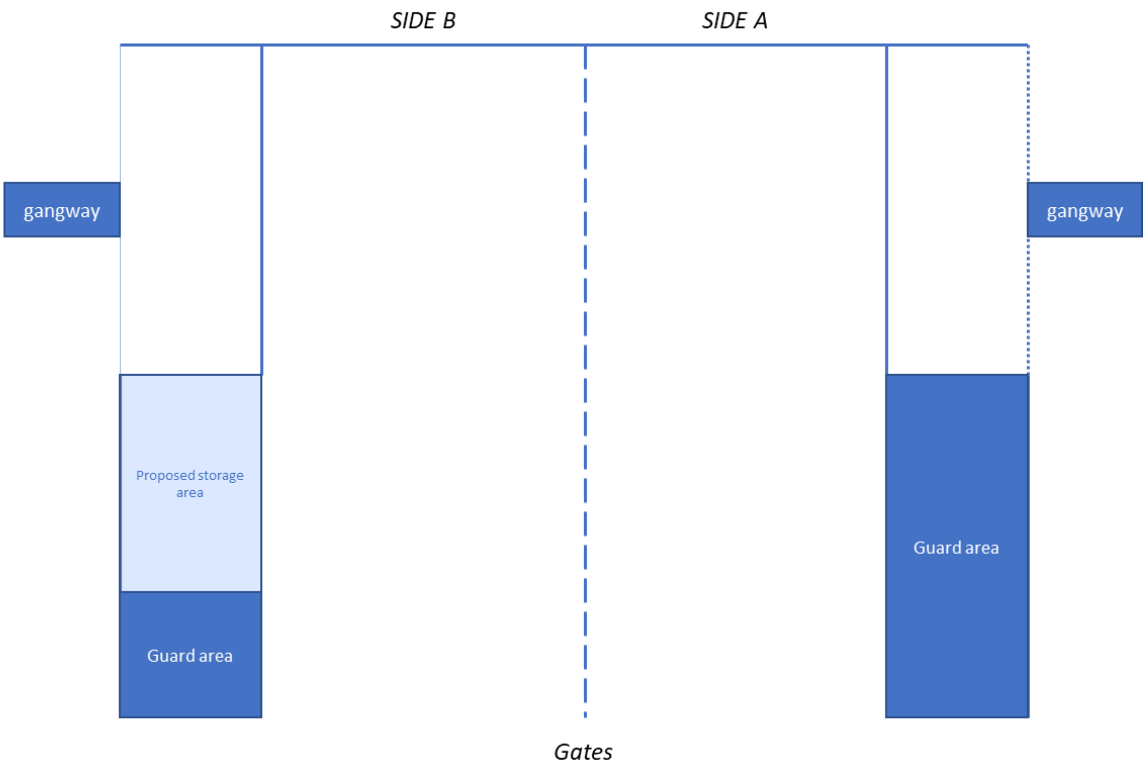

Figure 11 Circular Quay Wharf 4 Storage Area

Wharf 5 at Circular Quay is similar in layout to Wharf 4. In this case, there is room on both sides for the storage area. Therefore, there is one storage area for Side A on the right side, next to the guard area, and another storage area for Side B on the left side, next to the guard area (Figure 2). Similar to Wharf 5, these zones are enclosed by barriers and are typically sectioned off from passengers.

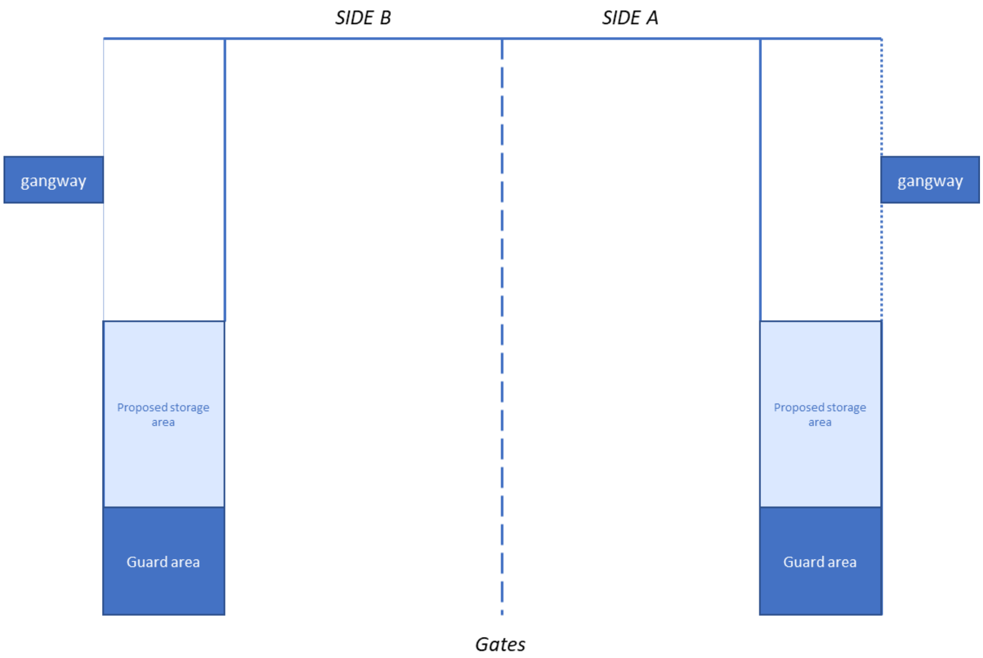

Figure 12 Circular Quay Wharf 5 Storage Area

Wharf 6 at Circular Quay is one of the smaller wharves at Circular Quay. This wharf also has two sides: Side A and Side B. In this case, as the wharf is smaller, there is only one proposed storage area. It is on the right side, next to the station guard area (Figure 3). It was chosen over the empty space on the bottom right side, due to its proximity to the station guard area. The proposed storage area is further away from passenger waiting area and will service both sides of the Wharf.

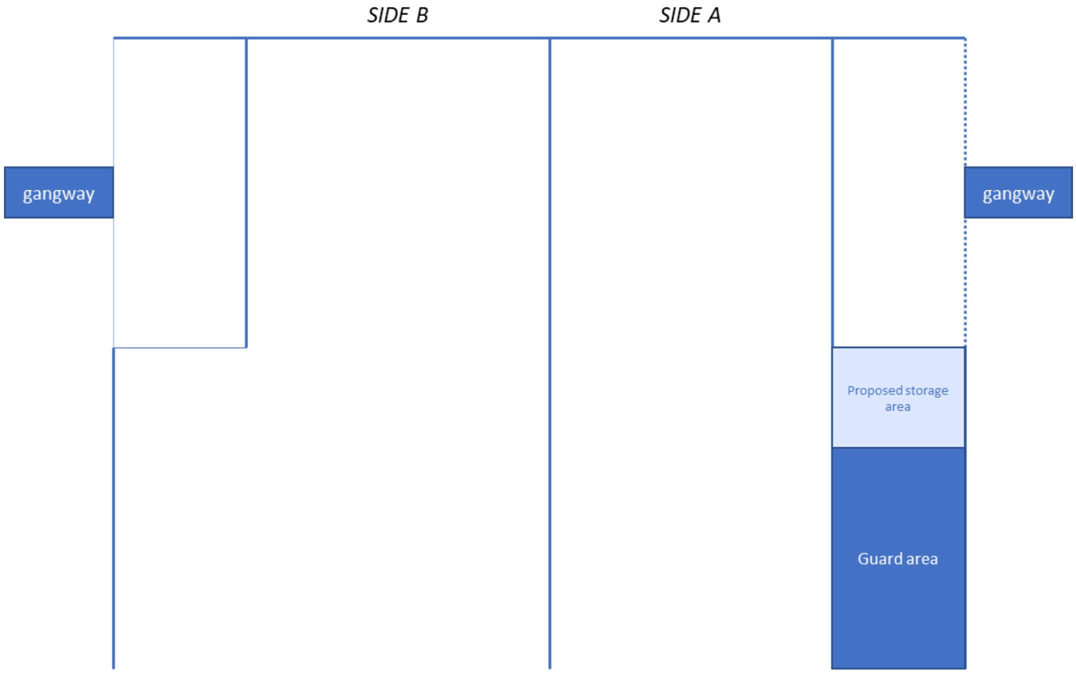

Figure 13 Circular Quay Wharf 6 Storage Area

4.4 Unit Load Device Choice

Four ULDs (metre cube containers, roll cages, hand trolleys and luggage suitcases) were compared to determine the most appropriate ULD for use on the ferry network.

Metre cube containers are becoming popular for last mile delivery in many cities worldwide. The dimensions of metre cube containers are 80cm (width), 120cm (length), 100cm (height), measuring one cubic metre in volume. Overall, they can carry up to 125kg of cargo. Their rectangular shape allows them to be compactly stored adjacent to each other at ferry stations and onboard ferry vessels. Metre cube containers have four wheels to push the containers, assisting in the loading and unloading process. As gangways are 1.2m wide, metre cube containers are suitable to load and unload off ferries. The wheels have an auto-lock function, allowing them to be secured onboard the vessel. The metre cube containers are fully enclosed, thus protecting the cargo from theft. As the containers are weather protected, there is a reduced risk of weather damage and water damage from the harbour. The design of the containers renders them incapable of folding up when empty, increasing the difficulty to stack and reposition empty containers. However, when used in conjunction with microhubs, there is the potential for empty containers to be reused soon after the delivery round is finished, without the need to bring the container back to a distribution centre to be reloaded with cargo. Metre cube containers are typically used in conjunction with e-cargo bikes (Figure 4). Rather than unloading and loading cargo onto different transport modes for each leg, the whole container can be secured onto the bike, increasing time efficiency. Despite this, e-cargo bikes can only carry a single metre cube container at any given time. The number of e-cargo bikes and delivery riders must increase as a result, as does the time to load metre cube containers onto numerous different e-cargo bikes. Regardless, e-cargo bikes are a low-impact transport mode; use of these bikes to transport the metre cube containers to and from the ferry stations is energy efficient and can alleviate traffic congestion and noise pollution.

Figure 14 Metre Cube Container loaded onto an E-Cargo Bike (DHL 2019)

Roll cages are popular within many supermarket and retail supply chains. The dimensions of a single roll cage are 80cm (width), 76cm (length), 177cm (height) and it can carry up to 500kg. Similar to metre cube containers, the rectangular shape of roll cages makes it easy to store them next to each other, both onboard the ferry and at the stations. Roll cages can easily be pushed due to the four wheels on the bottom, which can be manually locked. Further, the dimensions of the roll cages are a suitable size for the gangways. Despite this, the height of roll cages can decrease stability when being loaded on the gangway. Roll cages are metal cages that can be folded down (Figure 5); this allows for increased efficiency when stacking empty roll cages. While a cover can be placed on top to provide greater security for the cargo, the metal roll cage and the cargo inside are susceptible to weather and water damage due to inevitable corrosion. Use of a roll cage would require either a large truck to transport the roll cage to and from the ferry station, or it would require the loading and unloading of cargo at the ferry station. While electric or hybrid trucks can be used to reduce emissions and alleviate noise pollution, their large size renders them unsuitable for urban environments. Further, loading and unloading cargo at ferry stations is a tedious and complicated process and increases the possibility of theft.

Figure 15 Roll Cage (Rollstore n.d.)

Hand trolleys can come in many different sizes and therefore can hold differing volumes of cargo (Figure 6). Different sized hand trolleys can be utilised to match the amount of cargo transported. Consequently, storing cargo on hands trolleys on the station and vessel can be difficult. Further, securing the cargo onto the hand trolley is necessary to load and unload cargo from ferry vessels. Despite this, the wheels on the hand carts simplify the process. The particular hand trolleys used must be a width suitable for the 1.2m gangway. The drawback of using a hand trolley is that its cargo is left uncovered, posing a potential security risk. As hand trolleys are typically constructed from metal, they are susceptible to corrosion in a marine environment. Moreover, as hand trolleys are not enclosed, the cargo could be damaged by the weather. Many hand trolleys are foldable and easily stackable when empty. The hand trolley and the cargo cannot be loaded together in one unit when transferring from different transport legs. The use of hand trolleys requires decoupling the hand trolley and the cargo, thus each cargo item must be loaded and unloaded onto other transport modes individually. This means that the empty containers would not need to be repositioned, and space would be required for storing empty containers within the ferry station. However, the irregular shape of hand trolleys may limit the space efficiency. The individual cargo items can be loaded onto many low-impact vehicles, such as e-cargo bikes, electric vans, or hybrid vans.

Figure 16 Potential Hand Trolleys (Walmart n.d.)

Luggage suitcases are a potential solution when only small amounts of cargo are being transported. Their small size and rectangular shape make storing the ULD in the ferry station and onboard the vessel simple. Loading and unloading luggage suitcases is simplified by the wheels typically on suitcases. However, it is necessary to utilise high quality suitcases to reduce the possibility of broken wheels. Luggage suitcases are typically smaller than the 1.2m gangway; however, the small size of luggage suitcases means that if large amounts of cargo are transported, many suitcases will be needed. As one person can realistically load or unload an average of two luggage suitcases, many trips are necessary, increasing the station dwell time. This could reduce passenger satisfaction. Luggage suitcases are fully enclosed and, depending on the style, are weather and waterproof, reducing security risks and damage. As luggage suitcases cannot be folded, ample space is required to store the empty suitcase. This could cause additional difficulties when repositioning empty containers. However, utilising microhubs, similar to the case for metre cube containers, could allow for better utilisation of containers and uncomplicate the repositioning of empty containers. Luggage suitcases can be transported by electric or hybrid vans to and from the ferry station.

Table 4 summarises the characteristics of each ULD. By accounting for these criteria, the ULD most suitable to carry cargo on the ferry network is the metre cube container. The main reasons for choosing the metre cube container are their substantial cargo capacity, their dimensions and auto-lock wheels; which are advantageous for storage on ferry stations and vessels. The wheels and low height allow for a smooth and safe loading and unloading process. Metre cube containers are the most suitable for reducing the potential for theft and ensuring protection from ocean water and weather damage. While metre cube containers cannot be stacked efficiently when empty, they can easily be repositioned through the use of microhubs. Further, using the containers in conjunction with e-cargo bikes for the final last mile delivery has a low impact on the urban environment and has the benefit of reducing emissions.

Table 4 Summary of ULD Performance Comparison

	Metre cube containers	**Roll cages**	**Hand trolleys**	**Luggage suitcases**
Capacity for cargo	High	High	Medium	Low
Size dimensions for storage on vessels and stations	Medium	Medium	Medium	High
Loading and unloading process	High	Low	Medium	Medium

Theft mitigation	High	Medium	Low	High
Water and weather protection	High	Low	Low	High
Stacking of empty containers	Low	High	High	Low
Repositioning of empty containers	Medium	Low	Low	Low
Integration with other transport modes	High	Low	Medium	Medium

4.5 Tracking and Tracing

The level of tracking and tracing necessary is dependent on numerous factors along the supply chain. Firstly, understanding the degree of tracking and tracing that stakeholders, such as logistics operators, public transport operators and customers, desire is crucial. Some stakeholders may be satisfied with their parcels tracked and traced at certain checkpoints. Alternatively, stakeholders may be interested in real-time access to their parcel’s location. Likewise, tracking and traceability at the individual packaging level may be favoured or stakeholders could be content with it at the ULD level. This is crucial to allow stakeholders to share freight and cargo information with their own stakeholders. It can also improve safety and security when moving cargo alongside passengers.

The choice between personnel supervising or accompanying cargo on the ferry vessel or leaving it unaccompanied influences the scale of tracking and tracing expected by stakeholders. When cargo is accompanied onboard the ferry vessels, a lesser degree of tracking and tracing is required due to the guarantee of protected cargo. In the case of unaccompanied cargo, however, the amount of tracking and tracing must be heightened for greater security and coordination between security checkpoints. The decision on whether to accompany cargo on the ferry vessel or allow it to be unaccompanied alters the placement of cargo when onboard the ferry vessel. If unaccompanied cargo is permitted, a dedicated storage area onboard the vessel is necessary. This would have to be secured from passengers. It is also integral to decide the main stakeholder responsible for supervising the cargo

A robust tracking and tracing system would require cooperation and information sharing between the different stakeholders. The management system must integrate data from TfNSW, the logistics operator, the cargo owner and other relevant parties. Leveraging API (application programming interfaces) capability to apply transparency and enable real-time tracking of the ULD and its consignment is fundamental and can be achieved by using the Open Data access supplied by TfNSW for the Sydney Ferries network. A data stream of parcel information sourced from the logistics operator must be used. Lastly, corresponding service information, such as the specific ULD used and the OD for the trip. ULD’s should be assigned a unique code that can be identified through use of barcodes, QR codes or RFID. Further, use of smart ULDs could heighten the level of traceability and visibility through the supply chain.

5 Business Models

Co-modal transport in Sydney, as opposed to cargo delivery by truck, promises lower operating costs, alleviates emissions, and can increase time efficiency. Despite this, there is no one way to structure the business model. Important decisions, such as the type of cargo transported, ownership of infrastructure, the delivery process, stakeholder involvement, level of cargo supervision, the data management system and the cost structure are dependent on many factors. Nevertheless, co-modality remains a viable option to serve the ‘mile before last’ delivery, in conjunction with conventional delivery options.

In the four proposed business models, some things remain constant. Firstly, the logistics operator is responsible for purchasing the ULDs and is liable for its maintenance. In this manner, the logistics operator must have oversight of every ULD. Secondly, the process of loading and unloading ULDs from ferry vessels is the responsibility of the ferry operator. The ferry operator, under their contract with TfNSW, has accountability for the conditions of the ferry stations, ferry vessels and equipment, such as gangways. Hence, the ferry operator is responsible for any issues that may threaten the status of their service. As ULDs must be loaded onto the vessels that are managed by the ferry operator by a gangway managed by the ferry operator, it is clear that the ferry operator should have control over this portion of the process. In this manner, should issues arise with the condition of the infrastructure and equipment, resultant to the loading and unloading of ULDs, the relationship between the ferry operator and the logistics operator will not be jeopardised. A dedicated storage area onboard ferries should be allocated to store ULDs. The storage space onboard ferries is dependent on the size of the vessel, the overall estimated cargo size transported accounting for passenger movement. Furthermore, in all business models, when the ULD is deposited at the ferry station to be transported via ferry, the ferry operator becomes responsible for the contents of the ULD. As the logistics operator has ownership of the ULDs, it is necessary that TfNSW overseas the approach and facilitates the relationship between both stakeholders to ensure both parties are cooperating and coordinating effectively.

Additionally, the cost structure for each individual business model remains the same. It is comprised of the upfront investment, ongoing costs, and potential revenue. The logistics operator must invest in a sufficient number of ULDs and e-cargo bikes. Sydney Ferries must invest in retrofitting storage areas into ferry stations. Lastly, the logistics operator, Sydney Ferries operator and TfNSW, must jointly invest in a robust data management system. The complexity of the data management system increases the costs involved. The logistics operator has ongoing costs for delivery riders, and ULD and e-cargo bike maintenance. Sydney Ferries must pay ongoing costs for ULD handling on ferry stations and vessels. Conjointly, the three parties must also pay ongoing costs for the maintenance and upgrade of the data management system. As co-modal transport can reduce transport costs, profit generated by the logistics operator will increase. Sydney Ferries can achieve an additional revenue stream by engaging in co-modal transport. While the foundation of the cost structure is constant for each business model, the cost of individual aspects in the business models could differ.

5.1 Business Model 1

This business model is built on the same foundation as a standard container shipping business model. For this model, full container loads of non-perishable goods are transported for same-day delivery. In this manner, a single ULD contains a consignment for a single customer. The ULD utilised is a metre cube container.

5.1.1 Delivery Process

Using co-modality to transport consignments increases the number of transport legs required to ship a single ULD. There are four main legs in the process (Figure 7). The process begins when the seller packs the ULD provided by a logistics operator. The ULD is then transported to the logistics operator’s warehouse. The ULD is then delivered to a corresponding ferry station using an e-cargo bike, which can, at any one time, transport a single metre cube container. From here, the ULD is loaded onto the ferry vessel. At the other end, the ULD is unloaded off the ferry vessel and re-loaded onto another e-cargo bike. Lastly, the full ULD is delivered to the consignee. In this model, the ULD must be returned to the logistics operator by the consignee, which can be achieved by feeding the empty ULD back through the ferry network.

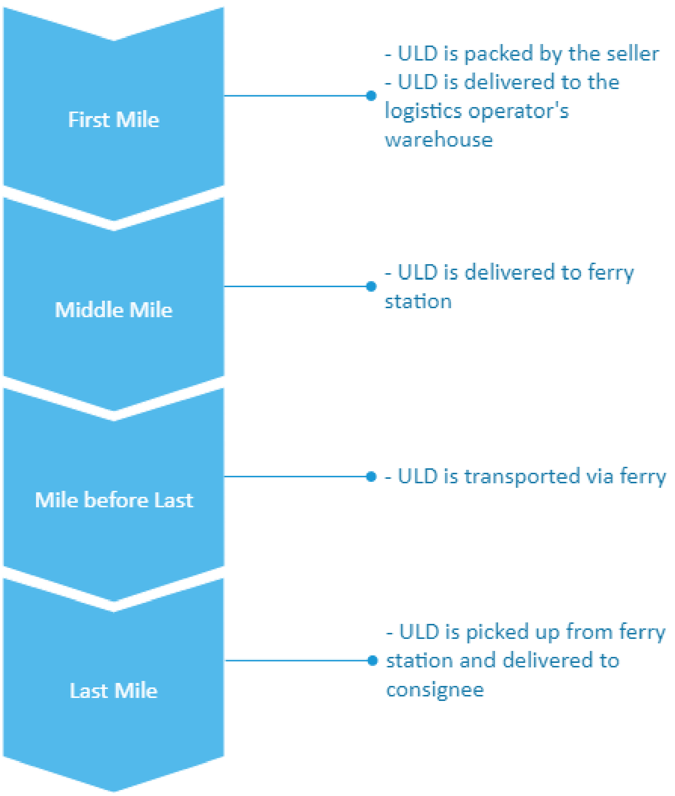

Figure 17 Business Model 1 and 2 Delivery Process

5.1.2 Stakeholder Involvement

The viability of co-modal transport arises from the success in stakeholder interactions. In this process, numerous stakeholders are involved (Figure 18), necessitating the outline of different stakeholder responsibilities and interactions.

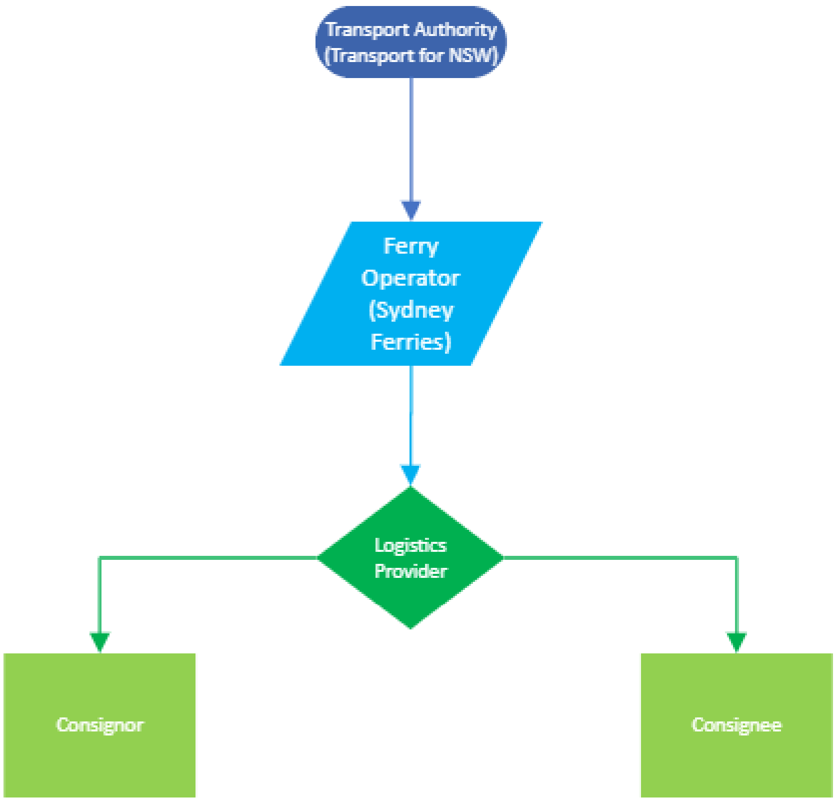

Figure 18 Business Model 1 and 2 Stakeholders

The seller and buyer first interact and designate the consignor, the party responsible for the cargo shipment. The consignor must contact the logistics provider to organise the shipping and ULD. However, as ferry operations occur on a much smaller scale than international shipping, only one logistics operator will be granted the right to the operations and must supply the ULDs. Subsequently, the seller packs the consignment into a ULD provided by the logistics operator. On the opposite side, when the ULD is delivered to the consignee, they become responsible for returning the ULD to the logistics operator. To ensure the business model is attractive to the consignee, the consignee is required to simply contact the logistics operator when they are ready to return the ULD. From there, the logistics provider will organise the transport of the ULD back to their warehouse. Due to the use of co-modality, the logistics provider remains in contact with Sydney Ferries, for use of their ferry services. Sydney Ferries is responsible for facilitating the shipping leg on the ferries and as such, has accountability for the cargo when it is in their hands. Sydney Ferries is responsible for the loading and unloading of ULDs, and security and safety of cargo at the station and on the vessel. This allows Sydney Ferries to have visibility on what happens on their vessels and supports greater job creation. The logistics operator and Sydney Ferries must agree on the charge cost to transport a single ULD on a ferry service, balancing cost savings for the logistics provider and revenue generation for Sydney Ferries. As Sydney Ferries is holistically controlled by the Transport Authority, TfNSW, cooperation between both parties must ensue. Overall, TfNSW remains the body that overseas and approves the entire co-modality scheme. Sharing of data between stakeholders in necessary to facilitate the tracking and tracing.

5.1.3 Level of Cargo Supervision

For the ‘mile before last’ leg, Sydney Ferries takes responsibility of the consignment. While waiting for the ferry service, the ULD is stored in the storage areas and remains supervised by station guards. ULDs are loaded onto and unloaded off ferry vessels by Sydney Ferries personnel. Onboard the vessel, ULDs are left unsupervised. In this respect, ULDs must be placed in a safe and secure area to ensure passenger safety is not compromised and to mitigate theft risks. Determining a suitable area onboard vessels in the responsibility of Sydney Ferries personnel. While the ULDs are technically unsupervised, ferry personnel onboard the vessel should be capable of mitigating any issues that may arise. A robust tracking and tracing system will assist in ensuring safe passage of ULDs when unsupervised.

5.1.4 Data Management System

The data management system requires data sharing between three main parties: TfNSW, Sydney Ferries, and the logistics operator. The system requires master data for certain elements to function. Firstly, the logistics operator must assign each ULD and e-cargo bike with IDs. As cargo is shipped by the ULD, cargo is tracked and traced at the container level. An ID must also be assigned to delivery riders. Sydney Ferries must generate IDs for the individual vessels, ferry stations, and storage locations.

To begin the process, the logistics operator will generate a manifest with a tracking number detailing the ULD ID, service to use and the ferry stations, produced through a tactical optimisation planning model. Once the ULD has been delivered to the logistics operator’s warehouse, it will go through a security checkpoint. The logistics operator will then notify Sydney Ferries that a ULD will be delivered to the respective stations at a given time. When the ULD is delivered to the first ferry station, it will need to go through a security checkpoint, located in the storage area. This scan will be uploaded into the data management system to update the ULD status and location for the benefit of the stakeholders. Once the ULD has been loaded onto a vessel, the onboard storage location must be inputted into the data management system. This allows for Sydney Ferries personnel on the destination ferry station to know where to pick up the ULD and for TfNSW and Sydney Ferries to oversee capacity levels on ferry services. At the destination ferry station, Sydney Ferries personnel must scan the ULD to acknowledge it has been delivered. The storage location at the ferry station must be inputted for the benefit of the logistics operator delivery rider, who collects the ULD. The logistics operator will then receive a notice that the ULD is ready to be picked up. The delivery rider will scan the ID to acknowledge that the consignment is now in their hands. Additionally, proof of delivery should be confirmed by the consignee’s signature or photographic evidence. Once the delivery has been made, the delivery rider must update the delivery status as complete. In this manner, ULDs can be tracked at every intersection where the consignment changes hand.

5.2 Business Model 2

Stakeholders may request for a higher level of tracking and tracing due to the safety concerns of leaving cargo unsupervised onboard ferry vessels. In this manner, it may be necessary to implement real-time tracking. Using the full container load method to transport non-perishable goods from business model 1 as a basis, this business model investigates the accessibility of real-time tracking for co-modality.

5.2.1 Stakeholder Involvement

Different stakeholders must collaborate and cooperate to ensure the success of the business model. In a similar vein to Business Model 1, the main stakeholders include TfNSW, Sydney Ferries operator, logistics operator, and the consignee and consignor (Figure). The stakeholders collaborate in constant to Business Model 1. However, due to the real-time tracking and tracing requirement, extra care must be considered. Real-time tracking and tracing require additional data streams, increasing the complexity of incorporating data from the stakeholders.

5.2.2 Level of Cargo Supervision

Consistent with Business Model 1, the only instance where cargo is unsupervised during the transport is onboard the ferry vessel. Again, it is required that ULDs are placed in a safe and secure location. However, the use of real-time data tracking increases the visibility of the ULD while it remains unsupervised, further mitigating theft risks and increasing passenger safety.

5.2.3 Data Management System

The proposed data management system supports real-time data access to consignments to allow stakeholders, including TfNSW, Sydney Ferries, and the logistics operator and their customers, to locate the ULD at any given time. The data management system has been first introduced by Zhu et al. (2021) for the purpose of co-modality on a train network.

Three data streams must be combined: TfNSW ferry information, ULD data from the logistics operator, and co-modality relevant information such as service information and storage locations (Figure 19). Ferry information is accessed through TfNSW’s open data portal, using their Application Programming Interfaces (API). The logistics operator will supply ULD data including its tracking number. Additionally, a unique ID will be generated to each ULD in use. Co-modality related information can be obtained through TfNSW’s General Transit Feed (GTFS) for specific scheduled ferry service information. In this manner, the trip ID, timetable, and specific wharf can be retrieved. As ferry services commence, vehicle IDs, real-time location, departure and arrival times, and delay data is updated with real-time GTFS (GTFS-R).

For each ULD in use, the scheduled ferry service information must be given. Further, the ULD storage location in the station and onboard the vessel must be recorded into the system to alert personnel at the destination station of the location, to ease the unloading process. This would also contribute to a more accurate indication of capacity.

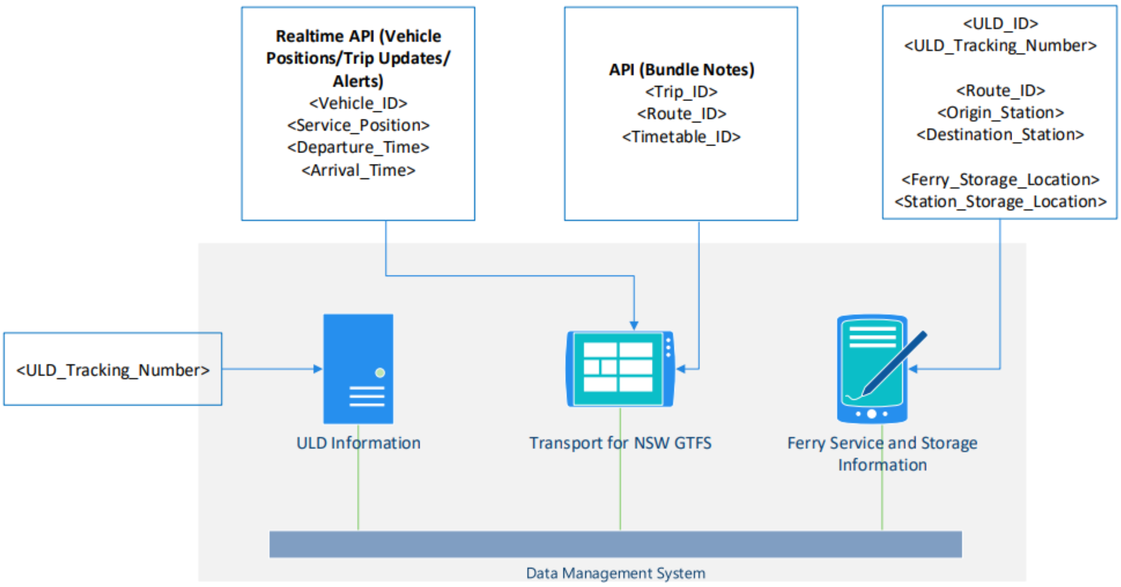

Figure 19 Business Model 2 Data Management System

In this data management system, the ULDs are not tracked in real-time. It is, however, assumed that if a ULD has been accurately scanned onto the vessel, it can be tracked by tracking where the vessel travels. Despite this, full visibility of the ULD cannot occur if ULDs are not scanned correctly or if issues, such as theft, occurs onboard the vessel.

5.3 Business Model 3

This business model utilises similar aspects to the previous business models but deviates in the type of cargo transported. As opposed to transporting full container loads, a ULD is made up of numerous smaller parcels of non-perishable goods that require same-day delivery.

5.3.1 Delivery Process

Transporting smaller parcels as opposed to full container loads increases the complexity of the delivery process (Figure 0). In this business model, the logistics operator is now obligated to accumulate the individual parcels and must pack the ULD with the allocated parcels at their warehouse. From this point, delivery riders transport ULDs to their designated ferry stations. ULDs are loaded onto their respective ferry vessels and transported to their destination station. Once at their destination, delivery riders pick up their allotted ULD and begin the final mile delivery route. As many parcels are within one ULD, the delivery rider is required to make many stops and should acquire proof of delivery in the form of a signature or photo for every parcel delivered. Once the delivery rider has completed their route, they must transport the empty ULD to either a microhub to be repacked or, if at the end of the day, back to the warehouse. Instead of delivery riders transporting an empty ULD all the way back to the warehouse, vans will transport parcels to microhubs by which delivery riders will visit instead to refill their ULDs.

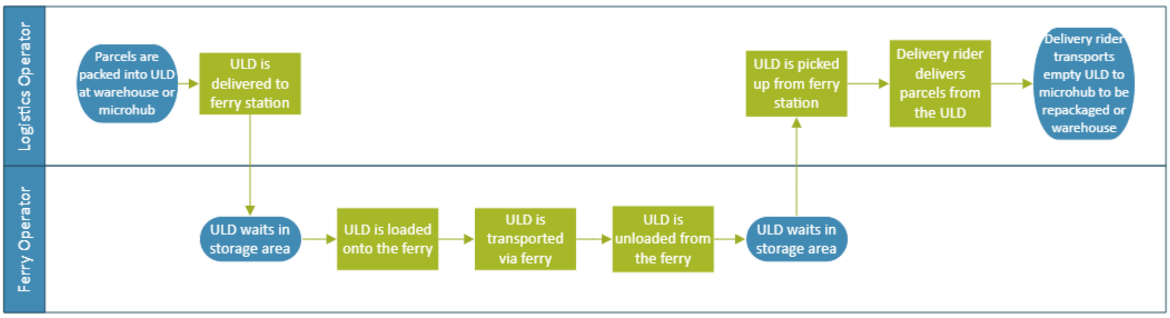

Figure 20 Business Model 3 Delivery Process

5.3.2 Stakeholder Involvement

Facilitating seamless movement of goods and passengers together requires relationships between stakeholders. The NSW state transport authority, TfNSW, is required to facilitate the initial interaction and ongoing relationship of parties. Overall, TfNSW is the body that must approve of the method and the charging cost to transport a ULD on the network. TfNSW contracts out the ferry network to Sydney Ferries. Sydney Ferries, alongside the logistics operator, ultimately share the majority of responsibility for operating the co-modal network. Firstly, the logistics operator must interact with their customers and ensure that their customer satisfaction levels do not diminish in this procedure. Congruent to Business Model 1, only one logistics operator will initially be granted the rights to operate. The logistics operator and Sydney Ferries operator must interact in numerous occasions when the ULD passes through an interchange (Figure 0). Both parties are required to pass the ULD through a security checkpoint. The initial security checkpoint occurs when at the warehouse, with a second checkpoint at the ferry stations. This ensures the safety and security of passengers and cargo. Once delivery riders from the logistics operators have delivered the ULD to the origin ferry station, Sydney Ferries personnel must pass the ULD through their security checkpoint and store the ULD in the storage area while waiting for their service departure. At this point, Sydney Ferries holds accountability for the protection of the cargo. Further, Sydney Ferries personnel are responsible for loading and unloading the ULD from the vessels, due to their authority over the ferry vessels, stations, gangways and ultimately, all the contents onboard the ferry. Relinquishing control of this process could have negative effects on the relationship between the logistics operator and Sydney Ferries, should ferry infrastructure and equipment be damaged. The use of microhubs warrants the involvement of some Local Government Areas (LGA) in Sydney. Cooperation from LGAs must occur to agree on which parking areas to operate the microhubs from.

5.3.3 Level of Cargo Supervision

Cargo is supervised by personnel at all points, excluding the ferry leg. The party responsible for supervising the cargo alters at different points in the process (Figure 0). In the instance where cargo is transported on the ferry, it remains unsupervised. Sydney Ferries are responsible for any issues, such as theft, that may arise, during this leg. Consequentially, it is necessary to secure the ULD in a suitable location that deters threats to ensure the safety of the cargo. Additionally, it must be placed in a secure location to protect passengers. The data management system should be robust enough to provide transparency of cargo while unsupervised.

5.3.4 Data Management System

The data management system required for this business model requires more complexity as the number of consignments increases. Data sharing still must occur between the three primary stakeholders: TfNSW, Sydney Ferries, and the chosen logistics operator. The customer preference of tracking a parcel whilst in transit affects the level of tracking and tracing necessary in the system.

Master data must be defined. The logistics operator will generate IDs for every ULD and e-cargo bike used. The ID will be placed on an easily detectable space on the ULD. Additionally, an ID for each delivery driver must be created. It is required that Sydney Ferries generate IDs for their vessels, ferry stations and storage area used in the approach.

Shipping of smaller parcels co-modally necessitates the tracking and tracing function at a parcel level. The logistics operator begins the process by generating tracking numbers for each parcel. Thereafter, a manifest will be produced detailing the parcels included in each ULD. Information detailed in the manifest includes the ULD ID, ferry service, origin-destination ferry stations. Once packed with the required parcels, the ULD will pass through a security checkpoint that will notify both the logistics operator that it is ready to proceed to the next step, and Sydney Ferries that a ULD is in transit to the origin ferry station at an approximate time. At the next interchange at the origin ferry station, Sydney Ferries personnel will check the ULD through their own security checkpoint to update the delivery status of the ULD. Subsequently, once the ULD has been loaded onto the ferry vessel, the status must be updated again to reflect the ULD’s storage location. This will alert the destination ferry station where the ULD is onboard the ferry to expedite the unloading process. At the destination station, Sydney Ferries personnel will unload the ULD, place in the storage area and proceed to scan the ULD’s ID, updating the location and notifying the logistics operator that the ULD is ready for pick up. When the delivery rider arrives, they must scan the ULD again, to show that the ULD is out for final delivery. The delivery rider will proceed on their delivery route, making numerous deliveries. After each parcel is delivered, the delivery rider must scan the parcel's tracking number, showing that the parcel has been delivered. At every interchange, it is necessary to update the status of each individual parcel for the customer.

5.4 Business Model 4

This business model investigates the viability of delivering perishable goods, such as groceries. The temperature sensitive nature of these goods poses a dilemma. The metre cube containers should be smart and must be retrofitted to be refrigerated, in order to keep perishable goods from spoiling. However, the numerous instances during transportation where the ULD exchanges hands complicates the use of refrigerated containers that need to be plugged in. ULDs must be insulated and have cold compacts. While the ULD is waiting in the storage area on the wharf and while it is onboard the vessel, it must have access to a power source. The cold compacts in the ULDs must be cooled prior to the delivery to ensure the cold temperature lasts for the entire delivery, especially when the ULD cannot be plugged in to a power source. The sensors in a smart ULD can send information regarding temperature fluctuations, shock detections, its geolocation, and any other unusual activity. In this business model, cargo can either be delivered to individual customers or restaurants.

5.4.1 Delivery Process

The delivery process requires coordination from three stakeholders: the food wholesaler, the logistics operator, and Sydney Ferries (Figure 1). Firstly, the food wholesaler must package all their orders. Then, the logistics operator will organise orders to be collected from the wholesaler's warehouse. These orders will be packaged into the corresponding ULD and transported to the ferry station by the logistics provider. At this interchange, the ULDs responsibility will change hands to Sydney Ferries, who will transport the ULD into the storage area, while it waits for its ferry service to arrive. Sydney Ferries will load the ULD onto the ferry at the origin station and unload at the destination station. The logistics operator will then pick up the ULD at the destination station and the delivery rider will deliver parcels to the wholesaler's customers, obtaining proof of delivery for each parcel. At the end of the route, the delivery rider will either transport the empty ULD back to the wholesaler's warehouse, if there are more deliveries to be made, or deliver the empty ULD back to the logistics operator's warehouse.

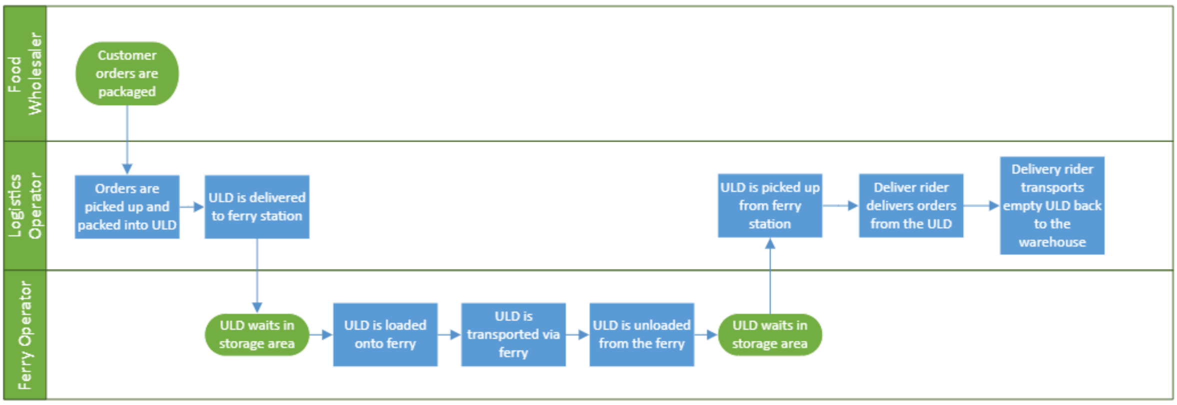

Figure 21 Business Model 4 Delivery Process

5.4.2 Stakeholder Involvement

It is necessary for stakeholders to collaborate to ensure the success of the approach. The food wholesaler, who remains a customer of the logistics operator, must remain in contact with their own customers to satisfy their order requirements. This ensures that customer satisfaction for their goods remains high. Further, the contact between the food wholesaler and logistics operator must continue to transpire to ensure deliveries are occurring at the standard of the food wholesaler's requirements. The logistics operator and Sydney Ferries must coordinate the points where the ULDs change hands. Overall, TfNSW must facilitate the entire process, easing stakeholder interactions and, thus, ensuring its success.

5.4.3 Level of Cargo Supervision

In line with the previous business models, cargo is supervised for most of the process, except for when the ULD is onboard a ferry vessel. However, the use of a smart ULD, that has 24/7 visibility, providing real-time tracking and tracing, ensures its safety when unsupervised.

5.4.4 Data Management System

The use of a smart ULD allows for real-time tracking and tracing of the consignment at any time. In this manner, the logistics operator has access to the ULDs location and status. The logistics operator must provide the food wholesaler and Sydney Ferries with access to this information. Further, the food wholesaler, if they wish, can provide this level of tracking to their individual customers.

Using this system still necessitates ferry service information to be shared by TfNSW between stakeholders, for the logistics operator to determine the optimum ferry service for a specific ULD delivery. In this manner, it can be utilised in conjunction with the data management system from Business Model 2 (Figure). In this case, the ULD information will encompass the real-time data from the smart container.

6 Discussion

6.1 Limitations

The methodology used to calculate vacant capacity on the ferry network consisted of the transit assignment model combined with a capacity calculation. The transit assignment model used was that proposed by Spiess & Florian (1989), operating under the assumption that congestion has negligible effect on a passenger route choice. However, more recent transit assignment models have more realistically demonstrated the effects of congestion on a passenger's route choice and are more accurate in their results. Despite this, the Sydney Ferries network lacks the complexity of the typical transit networks, such as bus networks, that transit assignment models are typically used for. Moreover, the Sydney Ferries network is heavily underutilised. Therefore, the usage of this transit assignment model is presumed satisfactory here.

The COVID-19 lockdown restricted the number of ferry stations that could be viewed first-hand. Moreover, the accuracy of the design of a ferry station's storage space is skewed as it was completed by estimating the wharf size. More accurate storage spaces should be designed for each ferry station.

6.2 Opportunities

Numerous opportunities exist for co-modal cargo transport. Co-modality can serve the 'mile before last' to diminish heavy truck usage in Sydney. Combining co-modality with e-cargo bikes and electric vans can alleviate congestion and reduce emissions. The four proposed business models allow for various types of cargo to be transported: full container loads, smaller parcels, or perishable goods. For the case of Greater Sydney, a trial whereby full container loads, as per Business Model 1, is recommended. The last mile pickup and delivery is simpler and the data management system in Business Model 1 is less complex and requires less investment than the real-time tracking system proposed in Business Model 2. The repositioning of empty meter cube containers by ferry presents further cost saving opportunities and additional revenue for Sydney Ferries.

6.3 Risks

Numerous co-modality schemes have failed due to the lack of public cooperation and funds. The success of the proposed co-modal approach could be threatened if the regulatory transport authority fails to oversee the scheme holistically and stakeholders fail to cooperate with each other. Developing these relationships early and the development of appropriate regulation is a priority.

Failing to consider passenger satisfaction could diminish patronage on the ferries, so the form of co-modality must take into account the needs of both cargo and passenger movement. Passenger satisfaction must be measured and any reduction in patronage should be investigated.

A major risk in transporting cargo via the ferry is the ferry station dwell time. Prompt loading and unloading of the ULDs is necessary to maintain schedule integrity. However, performing this task too quickly risks cargo damage and staff safety. These two risks can be balanced through staff training.

As ULDs are susceptible to schedule and dispatch errors, instances may occur when the ULD misses its stop or is carried on the wrong service. It is necessary to implement a process to correct and minimise these issues.

6.4 Benefits

Provided carrying cargo does not interfere with passenger flows or disrupt ferry schedules, the marginal cost to Sydney Ferries is low, enabling the ferry operator to undercut other modes of freight transport. Sydney Ferries can benefit from this endeavour as ferry utilisation is increased and cargo transport could offer an extra revenue stream. Adopting a co-modal scheme benefits TfNSW by removing vehicles from roads and improving environmental benefits by alleviating congestion and emissions. Moreover, this logistics solution could further support NSW's plan for net zero emissions by 2050. Co-modality could increase the liveability of Greater Sydney.

6.5 Future steps

Having identified Business Model 1 as the most promising, initially at least, the costs and benefits need to be studied in greater detail than has been possible here. This would require the involvement of potential stakeholders. Finally, a field trial should be conducted to explore the practicality of the concept and Business Model 1.

7 Conclusion

Increased road congestion, traffic accidents and air pollution are challenging problems for city logistics. Co-modality, whereby freight and passenger flows are integrated, has been investigated in numerous contexts worldwide. This working paper explores how Sydney's ferry network can be utilised to transport 'mile before last' cargo.

A review of previous field trials, and their lack of sustainable success, has highlighted the need for a robust business model. A transit assignment model applied to Sydney Ferries' 2016 network and origin-destination passenger flows revealed significant spare capacity on board which could be used to transport cargo. A study of potential Unit Load Devices (ULDs) led to the selection of meter cube containers. The suitability of ferry stations to handle these ULDs in addition to passengers showed promise in most cases. Based on this, the following four Business Models were investigated:

1. The pickup and delivery of full meter cube containers.
2. The same as 1 but with real-time tracking and tracing.
3. The pickup and delivery of parcels to be consolidated into meter cube containers for transport by ferry.
4. The pickup and delivery of perishable items to be consolidated into refrigerated meter cube containers for transport by ferries

Overall, the most suitable business model appears to be Business Model 1. In this case, full container loads are transported by the ferry network. For this to occur successfully, strong stakeholder cooperation is necessary. As a future endeavour, combining aspects of Business Models 3-4, real-time tracking and tracing, and different cargo types, should be investigated. The next step to actualise this concept is approaching and collaborating with relevant stakeholders and modelling the cost structure and benefits.

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