Improving the connectivity of an urban transit ferry network through integrated regular-interval timetabling

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Abstract

This is a feasibility study to evaluate the application of integrated regular-interval timetable principles to an urban transit ferry system, in order to improve line connectivity and simplify operational management.

A new timetable was developed for Sydney Ferries with lines operating at fixed intervals and hubbing at the two central business district terminals, Circular Quay and Darling Harbour. Transfer waiting times of between 5 and 10 minutes were scheduled at both hubs. The study demonstrates there is potential to increase the number of origin-destination pairs with all day convenient services by 450 per cent. This was achieved with only a 12 per cent rise in revenue hours. Other benefits include safer operations due to the greater predictability of vessel movements, more efficient crew rostering, greater timetable legibility and better intermodal connections.

A reduction in net Government subsidies is also predicted as the increase in farebox revenue is expected to be greater than the growth in revenue hour payments. A further body of work is planned to model the impact of the new timetable on patronage and staff utilisation rates.

Critical to the success of the model is the need for detailed network planning to precede and lead infrastructure development. This reduces waste by prioritising infrastructure projects, including fleet replacement and wharf upgrades, to match network requirements. More efficient passenger exchange at terminals is also a priority to reduce variation in loading times caused by crowding.

1. Introduction

Sparing and Goverde (2013) observe that “public transport users prefer direct, short, high-frequency services in order to minimise travel time, waiting time and inconvenience.” But they also note it is “neither possible nor efficient” to achieve this for all origin-destination (OD) pairs. This is why the widely accepted model for well connected public transport networks is the high frequency grid (Dodson et al 2011, Mees 2010, Thompson 1977 and Nielsen et al 2005). It follows the principle that it is simpler and more efficient to connect large numbers of OD pairs by a pattern of horizontal and vertical lines which allow passengers to transfer where lines intersect. This creates Thompson’s “multi-destinational” network, in contrast with conventional radial patterns which direct commuters to and from the central business district.

The grid network works best at high frequencies, as transferring passengers do not experience long wait times, even if the connections are timed randomly. Barriers to transfers are further reduced if the fare structure does not impose an additional cost on the passenger for the inconvenience of transferring.

There are of course circumstances where demand levels do not justify high frequency services and/or a city’s topography is not conducive to a grid pattern. Mees (2010), Stone (2013) and Petersen (2014), among others have argued that the very successful integrated regular-interval timetabling (IRIT) used by the Swiss Federal Railways could be adopted as a model for effective public transport in regional and suburban areas where population density is not sufficient to justify high frequency services. IRIT based networks demonstrate that good connections can be achieved between lines, and with other modes, even with 30 or 60 minute headways (the time interval between services). They facilitate timed transfers at specified nodes to other lines or other modes, with only short waiting times and offer almost the same convenience as the high frequency grid.

Some ferry systems already operate regular-interval timetables, notably Brisbane Ferries and Swiss ferry services at Lake Thun and Lake Zurich. The Swiss ferries integrate well with the overall public transport network, but ferry to ferry connections are limited. Brisbane Ferries is notable for its high frequency, with 7.5 minute headways in the peaks and 15 minutes off peak, but is essentially a single line.

None of these networks have multiple opportunities for ferry to ferry connections. The purpose of this project was to examine the feasibility of applying IRIT to more complex urban transit ferry systems, using the Sydney Ferries network as a case study.

2. Application of IRIT to an urban transit ferry network

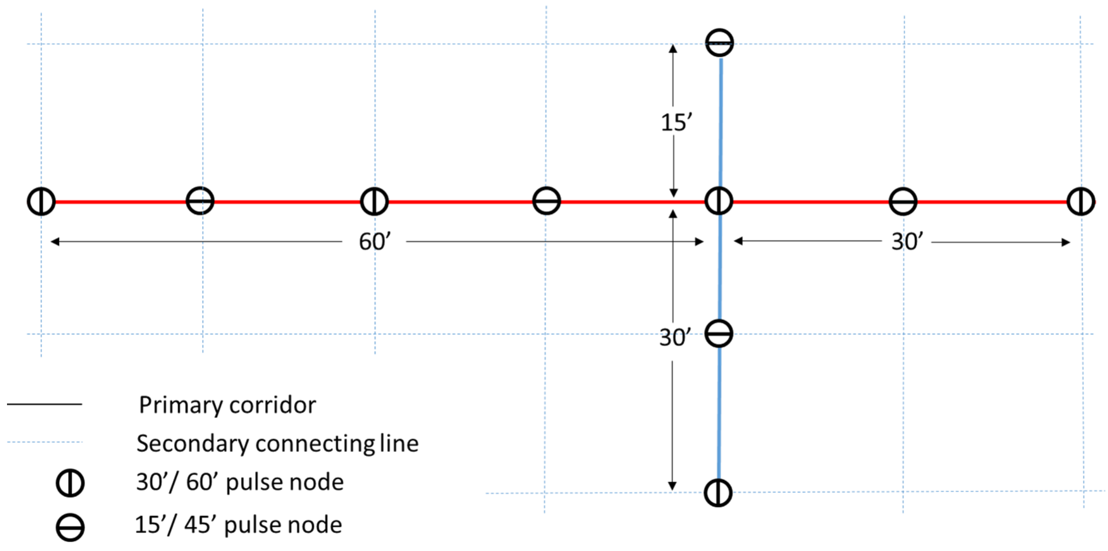
2.1 What is an integrated regular-interval timetable?

The characteristics of an integrated regular-interval timetable have been well documented (eg Johnson et al 2006, Maxwell 1999, Tzieropolous 2010). From the passenger perspective, the timetable has two important features:

- consistent, clock face scheduling. Extra services can be scheduled in the peaks, but the underlying off peak structure is maintained all day.
- services "pulse" at network nodes. If services operate at a 30 minute interval, for example, vehicles arrive at hubs a few minutes **before** the hour and half hour and departures are scheduled a few minutes **after** the hour and half hour. This allows passengers to transfer between lines with a short, convenient waiting time. Pulsing can also occur at intermediate stops on a line where inbound and outbound vehicles pass. At these stops, it is possible to make transfers to other modes for passengers travelling in both the inbound and outbound directions.

From a planning perspective, IRIT networks must observe some "rules" to create convenient connections. The first rule is that the stopping patterns are symmetrical in both directions. This ensures the outbound and inbound runs take the same time. The second is that the time required by a vehicle (or vessel) to complete its round trip, including layovers at either end, must be a whole integer multiple of the headway.

Figure 1: Simple 30' Interval Public Transport Network with Connecting Nodes



The simplified example in Figure 1 demonstrates what such a network might look like. It is a 30' interval network with two primary lines intersecting at a hub. The round trips are 3 hours for the red line and 1.5 hours for the blue line. Inbound and outbound vehicles cross at intermediate nodes, creating opportunities for convenient connections with secondary lines.

The main benefit of a network designed this way is that, in theory, every OD pair in the network can be connected by a journey with no more than one transfer. And all the transfers occur at nodes with short waiting times, so the inconvenience of transferring is minimised. This level of connectivity between OD pairs is many times greater than networks without timed transfers, or which are not high frequency grids.

IRIT networks also have disadvantages, which have been noted by Luthi (2009) and Maxwell (1999):

- It may not be possible for all lines in a network to abide by the "whole integer multiple" rule, without inefficient long layovers on at least some lines.
- There can be infrastructure cost implications for hub terminals. Hubs must have capacity to accommodate vehicles/ vessels from all lines, as arrivals and departures occur at about the same time. Also, capacity is underutilised outside pulse times.
- A high level of punctuality is required to avoid passenger dissatisfaction at missing connections. If required punctuality standards are not met, customers will be less inclined to take advantage of promised timed transfers and potential patronage gains will not be fulfilled.

Any plan to implement an IRIT network for ferries would need to address these risks.

2.2 Methodology

In order to test the practical application of IRIT to a complex urban transit ferry system, a series of timetables were developed for the Sydney Ferry network following IRIT principles. Vessel blocks were also prepared (schedule of travel of each vessel by day), revenue hours calculated and a count made of OD pairs where the timetable facilitated convenient journeys all day, seven days a week. A reticular diagram, based on the techniques used by Swiss public transport planners (SMA, 2014) was also created for the final preferred timetable to ensure no berthing conflicts were scheduled. The process of building the reticular diagram led to iterative changes to the preferred timetable. Some modifications were made to the traditional Swiss reticular diagram format to better suit ferry operations, especially by including wharf faces in the diagram where more than one vessel was required to berth at a single terminal at the same time.

As a means of evaluating the preferred timetable, revenue hours and convenient journeys all day between OD pairs were also calculated in the current Sydney Ferry timetable.

Operating costs for the current Sydney Ferry system were sourced from publicly available audit reports (New South Wales Auditor-General (2014)).

In building the timetable, an assumption was made that existing vessel operating speeds will continue and current speed restrictions in Sydney Harbour and the Parramatta River are unchanged.

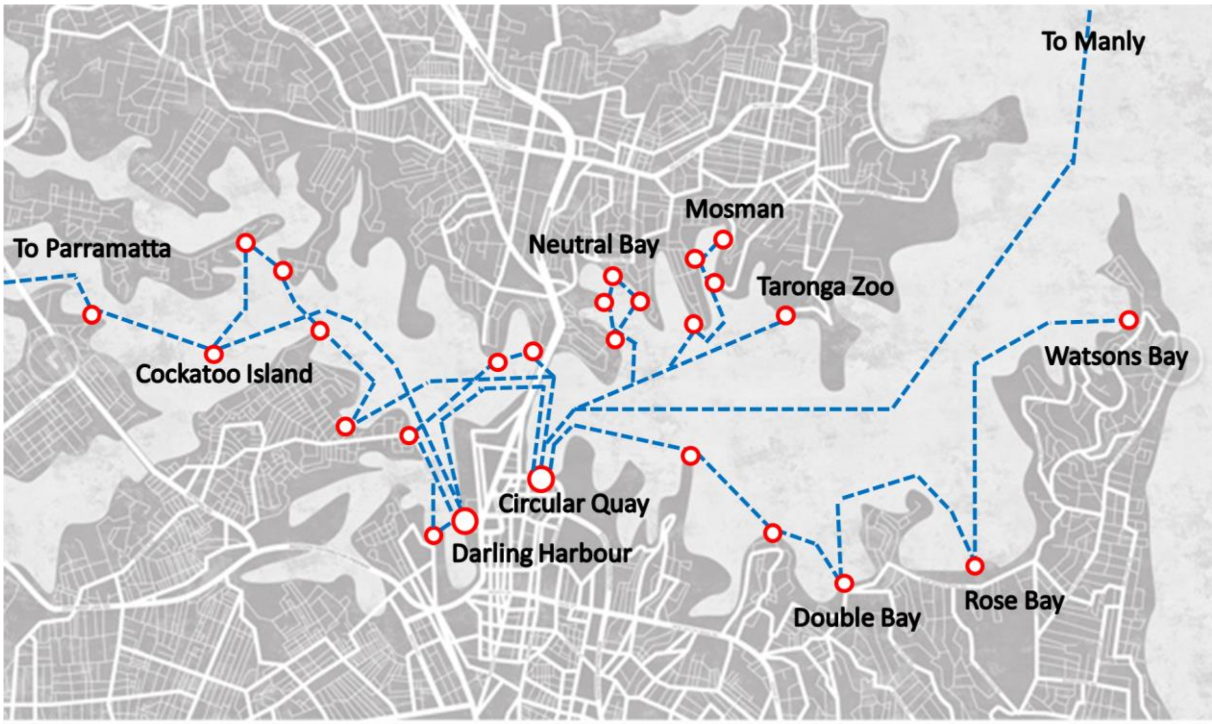
The implications for operational management, operating costs, infrastructure and safety were also evaluated.

2.3 About Sydney Ferries

Sydney Ferries is a passenger only ferry system with a network of 8 routes and 36 terminals. A private company, Harbour City Ferries, operates the services under contract to Transport for NSW (TfNSW). TfNSW is responsible for timetabling, setting fares and owns the vessels and other major assets, which are leased to the operator.

The network is arranged in a conventional radial pattern with routes hubbing at Circular Quay (Figure 2). Some Parramatta River services terminate at Darling Harbour on the western edge of Sydney's CBD. All routes operate at 30 minute intervals between the peaks, except the Cockatoo Island line (60 minute intervals off peak). Peak frequencies across all lines are 30 minutes or less.

Figure 2: Map of Current Sydney Ferries Network



In some important respects, the network does not comply with IRIT principles:

- clock face headways are not maintained all day
- stopping patterns on the same route can vary and are not always symmetrical in both the inbound and outbound direction
- line connections are not co-ordinated at the Circular Quay hub and ferry to ferry transfers usually require passengers to wait for between 10 and 30 minutes.

The outcome for customers is that there is only a limited range of OD pairs which they can travel between with ease all day. Although there are 36 terminals, only 96 OD pairs have convenient all day connections in both directions. Convenient all day connections are defined as journeys which meet three criteria:

- services operate at a minimum headway of 60 minutes between 7 am and 10 pm
- no more than one transfer is required for any journey
- transfer wait times are between 4 and 10 minutes. A wait of less than 49 minutes does not provide enough buffer in case of a delay and a wait in excess of ten minutes is inconvenient for the passenger.

Consider the example of a person who needs to travel from the tourist precinct of Darling Harbour to the popular beach destination of Manly. The ferry from Darling Harbour in the off peak arrives at Circular Quay 3 minutes after the Manly Ferry has departed, creating a 27 minute wait before the next sailing.

The lack of convenient ferry to ferry connections means that, on the whole, Sydney Ferries only offers journeys between OD pairs on the same line. The network mainly moves passengers to and from the central business district. This is not consistent with actual travel requirements as reported through the Household Travel Survey (Bureau of Transport Statistics NSW, 2014). Across all modes, travel to and from work comprises 15% of all travel in the Greater Sydney Metropolitan area. The Sydney Local Government Area is the destination of just 10% of all journeys, for any purpose.

As no two periods in a day are exactly alike, the timetable is *aperiodic*. The lack of a repeating pattern not only makes the timetable less legible for customers, but it also makes operational and safety management more difficult. When stopping patterns change over the course of a day, or are not symmetrical in the inbound and outbound directions, it is more difficult to control the systemic causes of delay, such as berthing conflicts at intermediate stops. Ferry masters are less able to anticipate the movements of other ferries, as do non ferry vessels in Sydney Harbour, such as cruise ships.

There is also an infrastructure cost implication in aperiodic timetables. Ferry terminals at intermediate stops are normally designed to berth one vessel at a time. If the point on a route where the outbound and inbound vessels cross is a single berth ferry terminal, then a conflict occurs which can delay one of the vessels by 2 or 3 minutes. It is difficult to avoid such conflicts in an aperiodic timetable because the cross overs will happen at different places over the course of a day. The costly solution to this would be to make all terminals dual berthing.

There are other operational costs related to aperiodic timetables. If vessels arrive at (or depart from) a hub at irregular times, crew rostering inefficiencies are unavoidable due to a lack of modularity. This adds to labour costs, the main cost item for most ferry operators. An aperiodic timetable can also be difficult to change without disturbances to the existing network. Even scheduling extra services for special events can prove almost impossible without creating new berthing conflicts.

2.4 Application of IRIT to Sydney Ferries

Some features of the Sydney Ferry network make it amenable to the IRIT model. Most lines already operate at 30 minute intervals between the peaks and, with minor changes to stopping patterns, it is possible to make round trips on all lines to be a whole integer multiple of 30 minutes.

The proposed reconfigured network, including specification of frequencies, vessel requirements, line connections and revenue hours, is summarised in Table 1. A network map is provided in Figure 3.

The main issue that needed to be addressed was berthing congestion at the network hub at Circular Quay. There are currently 9 lines terminating at Circular Quay, but only 7 wharf faces are available in the peaks[1]. This means not all lines can pulse at Circular Quay due to berthing conflicts. In view of this, the two lines running west of the Harbour Bridge (Parramatta River and Cockatoo Island) are proposed to terminate at the Barangaroo hub, a new terminal under construction which is due to replace the current King Street Darling Harbour terminal in 2016. Barangaroo and Circular Quay are connected by the Darling Harbour line.

[1] The count of lines terminating at Circular Quay includes Double Bay services, which operate separately from the Rose Bay line during the AM and PM peaks.

Table 1: Overview of line configuration in IRIT based Sydney Ferry network

Line Cluster	Cycle Time	Peak Interval	Week-day Off Peak Interval	Maximum Operating Speed	Peak vessel requirement	Convenient connecting lines(1)	Hub	Annual Revenue Hours
Baseline:								
Manly	1:30	0:30	0:30	14 knots	3	Darling Harbour; Double Bay; Taronga Zoo; Neutral Bay; White Bay	Circular Quay	12020
White Bay/ Darling Harbour/ Taronga Zoo (2)	2:00	0:30	0:30	20 knots	4	River, Watsons Bay; Double Bay; Mosman; Neutral Bay; Manly; Cockatoo Is	Circular Quay or Barangaroo	18956
Neutral Bay/ Double Bay (3)	1:30	0:30	0:30	14 knots	3	Darling Harbour; Watsons Bay; Taronga Zoo; Mosman; Manly; White Bay	Circular Quay	9200
Watsons Bay	1:00	0:30	0:30	25 knots	2	Darling Harbour; Neutral Bay; Double Bay; Taronga Zoo; White Bay	Circular Quay	8746
Mosman	1:00	0:30	0:30	14 knots	2	Darling Harbour; Neutral Bay; Double Bay; Taronga Zoo; Watsons Bay; Manly; White Bay	Circular Quay	6481
River/ Parramatta	3:00	1:00	1:00	20 knots	3	White Bay; Darling Harbour; Cockatoo Is; Taronga Zoo	Barangaroo	
River/ Sydney Olympic Park (4)	2:00	1:00	1:00	20 knots	2	White Bay; Darling Harbour; Cockatoo Is; Taronga Zoo	Barangaroo	24004
Cockatoo Island	1:00	0:30	1:00	20 knots	2	Darling Harbour; Taronga Zoo	Barangaroo	6243
Extra Departures in the peaks								
Rose Bay	0:30	0:30		25 knots	1		Circular Quay	602
SOP/Circular Quay	1:30	0:30		20 knots	3		Circular Quay	2242
SOP/Barangaroo	1:30	0:30		20 knots	3		Barangaroo	819
				Manly boats	3		Total Rev. Hours	89318
				IH slow boats	7		Current hours:	80000
				IH fast boats	7		% incr on current:	12%
				River boats	10			
				Total	**27**			

(1) No more than one transfer and passengers have 4-10 minute wait at interchange. Applies all day, seven days a week.
(2) Zoo combined with Mosman in AM and PM peak as occurs currently; 0:15 interval for Zoo and Darling Harbour on week-ends.
(3) Double Bay operates at 1:00 interval in off peak.
(4) Hours include River trips to Parramatta and extra Sunday trips

Completion of the new Wynyard Walk project will make Barangaroo a more attractive entry point to the city from locations west of the CBD. It will provide an unimpeded 6 minute walk from the Barangaroo terminal to Wynyard Station and George Street in the heart of the city.

The existing network is also expanded by extending the Darling Harbour line to the White Bay Power Station, in anticipation of the Bays Precinct redevelopment.

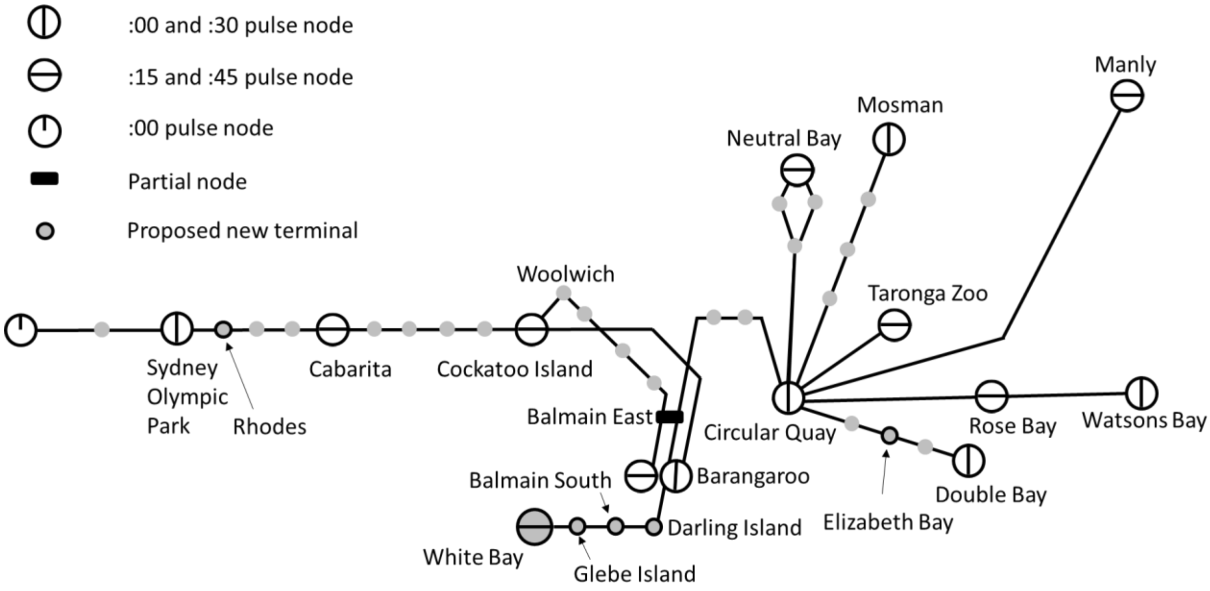
This design means the Darling Harbour, Parramatta River and White Bay lines pulse on the hour and half hour at Barangaroo. All lines east of the Harbour Bridge (and the Darling Harbour line) pulse at Circular Quay on the hour and half hour.

Balmain East is a partial node. Passengers from the Cockatoo Island line can transfer at Balmain East to the Darling Harbour line to reach Circular Quay. Wait time in the inbound and outbound directions is 5 minutes. There is also a 15'/45' pulse at Cockatoo Island to enable passengers from Balmain East, Balmain, Birchgrove, Greenwich or Woolwich to transfer at the Island for Parramatta River destinations.

To the east of the Harbour Bridge, there is little change to the current network, except Rose Bay and Watsons Bay form a separate line from Double Bay. This makes both lines 60 minute return trips with symmetrical stopping patterns inbound and outbound. An extra stop is added to the Double Bay line at Elizabeth Bay. The stopping pattern for the Watsons Bay line is consistent all day, with an intermediate stop at Rose Bay only. This extends Watsons Bay services to include commuter peak journeys.

The new network retains a radial pattern, which seems unavoidable in the Sydney harbour/ riverine environment. One problem with radial networks is that a hub transfer can create an unacceptably indirect journey. For example a passenger on the Double Bay line may be able to transfer to the Watsons Bay line with a short wait at Circular Quay, but this is unlikely to be their preferred option as it would be a very indirect route.

Figure 3: Network map of proposed IRIT plan for Sydney Ferries



Consideration was given to adding a ring line to connect Rose Bay with Taronga Zoo, Cremorne Point, Milsons Point, McMahons Point, Balmain East and Barangaroo. The advantage of this initiative is that passengers travelling from east of Sydney Cove could access Barangaroo, traverse the harbour between the north and the south or transfer to the Parramatta River line, without diverting into Circular Quay.

The ring line option was discarded, however, on the basis of the significant additional revenue hour costs. It also meant that if connections on ring line nodes were to be convenient, then the Parramatta River and Watsons Bay lines would pulse at 15’ and 45’ at Circular Quay, resulting in a loss of connectivity with other lines at Circular Quay.

For the majority of journeys, however, routing through the hubs at Circular Quay and Barangaroo does not create a major diversion. To lessen any inconvenience, lines are through-routed where possible. For example the Taronga Zoo, Darling Harbour and White Bay lines are actually a single line, so passengers do not have to transfer from their vessel if their origin and destination are located on one of these three sub-lines.

3. Findings

3.1 Connectivity

To test the impact of the new timetable on connectivity, a comparison was made between the existing timetable and the proposed IRIT timetable in relation to ferry only journeys between OD pairs. An OD pair connection was deemed convenient if a journey could be made in both directions and met all of the following criteria:

- the journey can be made at any time between 7 am and 8 pm week-days and 8 am and 8 pm week-ends with a service frequency of at least 60 minutes
- no more than one transfer is required and
- waiting time for all transfers is between 4 and 10 minutes. The minimum waiting time for transfers at Circular Quay was set at 5 minutes in view of the potential for longer walking distances between connecting ferries.

Based on these criteria, the number of convenient OD pair connections increased from 96 in the current timetable to 526 in the proposed IRIT network, an improvement of 450%.

A small part of the improvement was due to an increase in the number of terminals, up from 36 to 40, but overwhelmingly it is due to the symmetry of stopping patterns and the establishment of timed transfers at hubs. For example, there are currently only four terminals with convenient all day connections to King Street Darling Harbour (soon to be Barangaroo) terminal, out of a possible total of 35. This increases to 39 out of 39 in the IRIT timetable.

A quantitative assessment was not made of changes to bus connections, although improvements can be anticipated here also. There are at least 14 pulse nodes in the proposed network where a bus service can conveniently connect with both the inbound or outbound ferry at either 00'/30' or 15'/45'. As the timetable is periodic, these connections operate all day. Even where stops are not strictly pulse nodes, such as Cremorne Point, bus connections still work, but with a longer layover for the bus in the same way that occurs now.

Improvement in bus connections would depend on these bus networks also adopting IRIT principles.

3.2 Costs

Under the contract with Transport for NSW, most funding for the operation of Sydney Ferries is based on revenue hours. Monthly payments to the operator are offset by farebox revenue collected directly by Harbour City Ferries. As ferry travel in Sydney is covered by Transport for NSW's smartcard ticketing system, the Opal Card, operator collected fares are now much reduced as most passengers purchase their travel through the Opal Card.

Under the current Sydney Ferries timetable, around 80,000 revenue hours are contracted. In 2013-14 this was as at a cost of $A136 million, less $43.16 million recovered in fares (NSW Auditor General 2014). This leaves a net annual Government subsidy for operating costs of $83 million.

The IRIT network proposed in this paper increases revenue hours to 89,300 per annum or 12% more than the current network.

For the net government subsidy to be reduced, patronage (and farebox revenue) would need to rise by more than 35 per cent, a reasonable expectation in view of the 450 per cent increase in convenient OD pair connections. A further stage of work is required to forecast changes in demand flowing from the improvement in connections.

The cost to government of ferry operations also reflects the price of revenue hour payments, which are determined by competitive tender at 7 year intervals. The structure of the timetable impacts on operator costs, especially in crewing and peak vessel capacity requirements. If vessels return to a hub at irregular times, rostering is less efficient with high ratios between shift time and in-vessel time. This ratio can be reduced in an IRIT network because vessels return to the hub at about the same time and depart at about the same time.

The Swiss experience (Tzieropolous 2010) demonstrated improved efficiency in IRIT networks through higher vehicle utilisation rates. This study of Sydney Ferries showed a similar outcome. Despite a 12 per cent increase in revenue hours, the requirement for 27 operating vessels in peak periods are unchanged from current levels.

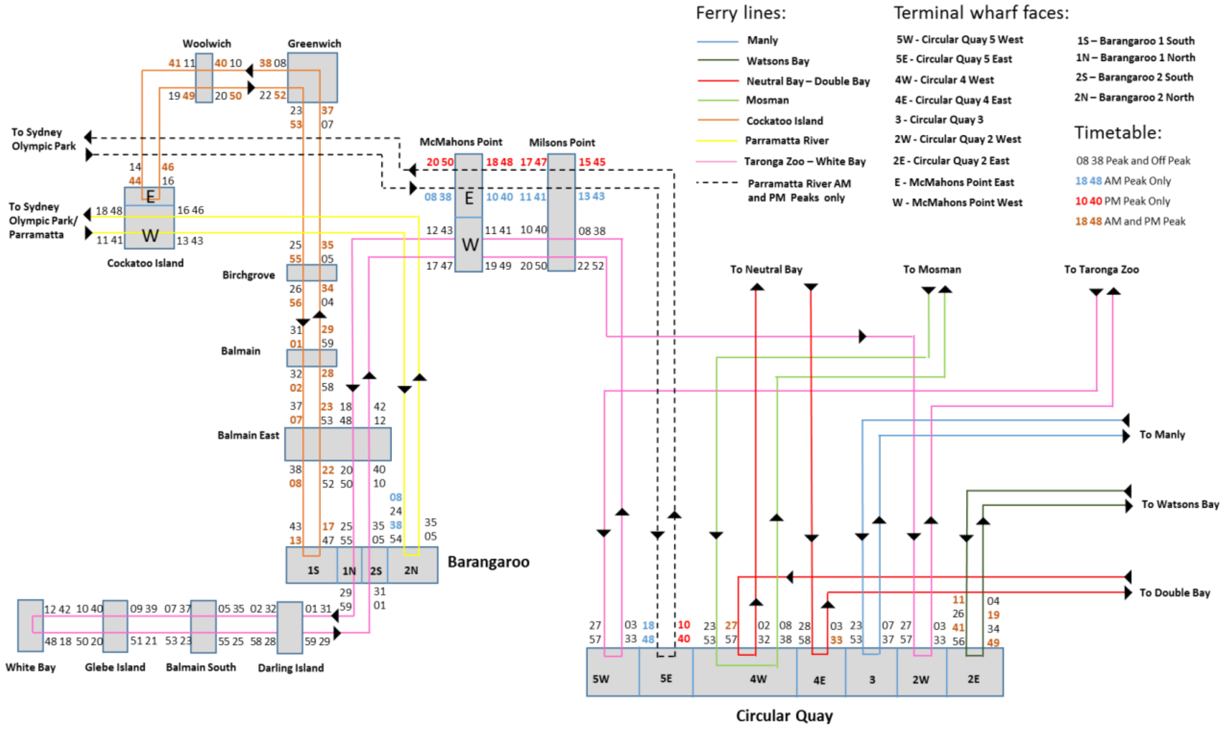
3.3 Berthing Congestion

A common criticism of IRIT networks is the potential impact on terminal infrastructure. If vehicles converge on hubs at the same time, the terminals must have the capacity to accommodate them all.

The issue is pertinent to Sydney Ferries, which has long endured severe congestion at Circular Quay. Vessels held off Circular Quay while waiting for a berth to become available can delay following services. Owing to space limitations, adding wharf faces is not a viable solution at this location.

Terminating Cockatoo Island and Parramatta River lines at Barangaroo minimises the risk of congestion at Circular Quay. This is demonstrated in the reticular diagram at Figure 4, which shows the time of arrival and departure of ferries at terminals in the section of the network between Circular Quay and Cockatoo Island.

Figure 4: Reticular diagram for part of proposed IRIT based Sydney Ferry network



By using the new Barangaroo terminal as a hub for the Cockatoo Island and Parramatta River lines, all lines terminating at Circular Quay have their own wharf faces, avoiding conflicts when vessels pulse on the hour and half hour. One exception to this is Wharf 4 west, which is shared by departures for the Neutral Bay and Mosman lines. This is workable because Mosman has a longer layover at Circular Quay (14 minutes), so vessels operating Mosman services are able to unload passengers at 4 west and move “into the corner” before the arrival and departure of the Neutral Bay ferry.

On the Parramatta River, additional services are operated in the AM and PM peaks, which terminate at Circular Quay and include stops at McMahons Point and Milsons Point. At these times only, there is a potential conflict with the Darling Harbour line at McMahons Point, but the new wharf planned by Roads and Maritime Services at McMahons Point will allow two vessels to berth, thus removing this risk.

Berthing conflicts at intermediate wharves are minimised as the timetable builds a buffer of at least 2 minutes between the scheduled departure of one vessel and the arrival of the next. This means inbound and outbound vessels cross in open water, unless they are scheduled to arrive together at a terminal which provides for double berthing. This is easier to achieve in a periodic timetable as what happens in one period is repeated throughout the day, seven days a week.

Apart from McMahons Point and Cockatoo Island, none of the intermediate terminals in this part of the network need double berthing. In each case, the arrival time of a vessel is two minutes or more after the previous vessel is scheduled to depart. For example, the outbound Darling Harbour ferry crosses over with the inbound vessel mid-way between Balmain East and McMahons Point avoiding a conflict at either wharf.

4. Discussion

4.1 Connection reliability

An IRIT network is only as good as the reliability of its connections. Passengers like short wait times at connecting nodes, but customer confidence in making journeys with transfers can evaporate if a connection is missed.

Eliminating terminal conflicts from the timetable, as outlined in section 3.4, is part of the solution. The other task is to reduce variation in passenger loading time. It takes approximately 60 seconds for 50 passengers to board or disembark a Sydney Ferry via a single gangway at Inner Harbour terminals. If 100 disembark and 100 board at the same terminal, via a single gangway, then the dwell is 4 minutes, leaving aside time to tie and untie lines. During major events particularly, these delays are multiplied at subsequent stops.

Measures are available to speed up passenger exchange. They include the deployment of two gangways, using wider double gangways, ensuring terminal design supports efficient ingress and egress from the pontoon to the landside and designing vessels so passengers can move freely through the ferry following embarkation. These need to be adopted in conjunction with each other so that dwells are kept to a maximum of 2 minutes.

This is not to say all causes of delay can be eliminated. Temporary wash restrictions, recreational vessel activity and a multitude of other minor incidents are unavoidable, but a two minute buffer in the timetable can keep the impact of these to a minimum.

Given the importance of connectivity in an IRIT network, it would be desirable to undertake further work to model the impact of disturbances on network performance.

4.2 Network modularity

The repeating pattern of an IRIT network gives it a modular quality. It is not difficult to expand the network, or increase frequencies, without disturbing other elements. As an example, the extension of the Darling Harbour line to White Bay could be effected without any change to the timetable for other existing lines. Instead of terminating at Barangaroo with a 10 minute layover, the round trip time was extended by 30 minutes to include White Bay. With 30 minute intervals, one additional vessel was required.

Increasing frequencies in the peak period in an IRIT network will not normally create congestion at the hubs if the stopping pattern (and therefore journey time) is unchanged, as each line has an individual wharf face allocated to it at the hub. But berthing conflicts can arise between inbound and outbound vessels at intermediate stops. On a 30 minute journey with 30 minute headways, there is one cross over (at the 15 minute point). This increases to three cross overs if there are 15 minute headways, adding to the probability of a berthing conflict. The risk of conflict can be reduced if the additional services run dead in the contra peak direction and berthing priority is given to vessels travelling in the peak direction.

4.3 Predictability of vessel movements

As the same vessel movements are repeated every 30 or 60 minutes all day in an IRIT network, it becomes much easier for crews to anticipate safety risks. Other vessels operating around them, including cruise ships, can also learn the regular pattern of ferry movements. If a systemic risk is identified, fixing it in one period can eliminate it from all periods.

A particular benefit for Sydney Ferries of IRIT is the likelihood of safer vessel movements in Sydney Cove. As all arrivals at Circular Quay are scheduled between 7 and 2 minutes *before* the hour and half hour, and all departures are between 2 and 7 minutes *after* the hour and half hour, there is no point in time when a vessel reversing from the Quay will cross the path of an arriving vessel.

The greater legibility of an IRIT network makes it easier for crew to meet other operational goals. The repeating and memorable pattern of the timetable helps ferry masters to develop a regular tempo or cadence, which help to ensure berthing conflicts are avoided and all connections are met.

5. Conclusion

This study suggests the adoption of integrated regular-interval timetable principles in an urban transit ferry system offers potential for substantial improvements in network connectivity and reductions in government subsidies. The IRIT network developed for Sydney Ferries created a 450 per cent increase in OD pairs with convenient ferry connecting journeys all day. This was achieved with a 12 per cent increase in revenue hours and no change in peak vessel requirements. Net subsidies would reduce if patronage increased by more than 35 per cent, or less if expected operational efficiencies, including higher staff utilisation rates, were realised.

There is also scope to improve intermodal connections, safety and reliability because of the periodic structure of the timetable which creates a more predictable pattern in vessel movements.

A further program of work is required to forecast the growth in demand generated by the increase in OD pair connections. Work also needs to be undertaken to determine whether the modular design of the IRIT will achieve expected labour efficiencies, as experienced in some European countries.

The need to address systemic causes of delays is critical to the success of IRIT in an urban transit ferry network. This is partly achieved by eliminating scheduled berthing conflicts, but principally by improving passenger exchange processes at terminals. This reduces the variation in loading times, which can be substantial with Sydney Ferries' current gangway, vessel and terminal designs.

As highlighted by Stone (2013), the Swiss experience demonstrates why long term network planning should precede infrastructure development. Swiss timetables are planned in microscopic detail 20 years in advance of implementation, enabling infrastructure plans to be prioritised to optimise the performance of changed timetables.

The benefit of this approach is also made clear by this study of the Sydney Ferry network. A well designed ferry network can save money by highlighting exactly where terminal upgrades should occur and how they are designed; the operating speed, seat capacity and gangway arrangements of new vessels; and the locations of interchanges to allow passengers to transfer between ferries and other modes of public transport.

While outside the scope of this study, the potential benefits of IRIT identified for ferries in this study suggest an evaluation of its application to other public transport modes in Sydney may also be worthwhile.

References

Bureau of Transport Statistics, Transport for NSW (2014) *Household Travel Survey Report: Sydney 2012/13*

Dodson, J Mees, P Stone, J and Burke, M (2011) *The Principles of Public Transport Network Planning: A review of the emerging literature with select examples*. Griffith University Urban Research Program Issues Paper 15.

Johnson, A Shires, J Nash, C and Tyler, J (2006) Forecasting and appraising the impact of a regular interval timetable *Transport Policy* 13, 349-366

Luthi, M (2009) *Improving the Efficiency of Heavily Used Railway Networks through Integrated Real-Time Rescheduling*. PhD dissertation submitted to ETH Zurich.

Maxwell, R (1999) Intercity rail fixed-interval, timed-transfer, multihub system: applicability of the “Integraler Taktfahrplan” strategy to North America Transportation Research Board Vol. 1691, 1-11

Mees, P (2010) *Transport for Suburbia: Beyond the Automobile Age* London Earthscan

New South Wales Auditor-General (2014) *Financial Audit Volume Seven: Focusing on Transport*

Nielsen, G Nelson, J Mulley, C Tegner, G Lind, G Lange, T (2005) *Public Transport – Planning the Networks* HiTrans Best Practice Guide 2: Interreg IIIB European Union. Stavanger

Petersen, T (2014) Public transport beyond the fringe pp 149-165 of Gleeson, B and Beza, B (ed) *The Public City: Essays in Honour of Paul Mees* Carlton: Melbourne University Publishing

SMA (2014) www.fahrplanfelder.ch/fileadmin/fap_pdf//Netzgrafik/Netzgrafik2014.pdf

Sparing, D and Goverde, R (2013) Identifying effective guaranteed connections in a multimodal public transport network *Public Transport* 5 (1/2) 79-94

Stone, J (2013) Planning for affordable transit infrastructure and service expansion: two European case studies *Australasian Transport Research Forum 2013 Proceedings* Brisbane

Thompson, G (1977) Planning considerations for alternative transit route structures *Journal of American Institute of Planners* 43(2) 158-168

Tzieropoulos, P Emery, D and Buri, J-D (2010) Regular-interval timetables: theoretical foundations and policy implications *12th World Conference on Transportation Research* Lisbon