INTEGRATION OF THE NWRL WITH THE EXISTING SYDNEY TRAINS NETWORK

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1.0 ABSTRACT

The existing train corridor between Chatswood and the CBD is ill-suited to the projected increase in patronage due to the NWRL opening in 2019. In this portfolio, the existing Sydney Trains infrastructure along with the increase in patronage will be analysed from a systems engineering perspective and a solution involving the lengthening of trainsets to 16 cars will be proposed. Extensive background information is presented, then design requirements and various concepts are presented. These concepts are then mapped against design requirements, with in depth functional analysis and subsystem identification used. As the design grows in maturity, detailed subsystem analysis takes place, along with a detailed outline of construction steps and operational details. Throughout the paper it is demonstrated that the proposed solution meets the design requirements in a superior fashion. The paper concludes outlining steps taken to communicate the proposed changes with the general public in innovative manners.

Keywords: System Engineering, Sydney Trains, Chatswood, NWRL, System Design Process.

2.0 SYDNEY'S TRANSPORT CRISIS

2.1 UNPRECEDENTED GROWTH IN THE NORTH WEST

Sydney is amidst a population growth boom. According to the Australian Bureau of Statistics, Sydney's net growth population is the highest in the country at 103,000 people in the period of June 2012 to June 2013 (Australian Bureau of Statistics, 2014). However, this growth is not evenly distributed across the city. The locale of Kellyville in the North-West growth corridor saw the largest single population increase in the country, adding over 13000 residents in the financial year of 2012-2013 (Australian Bureau of Statistics, 2014). This rapid growth has presented a number of problems for the state of NSW, most importantly that of infrastructure. The North-West corridor is situated some 36km North-West of the Sydney CBD, with the only form of feasible transport to the CBD being provided by private motor vehicle. During the peak times, commuting times are regularly 1.5 hours. The NSW government has accepted that this is not appropriate, and has begun to build what they hope will solve the transport crisis: the North-West Rail Link.

2.2 THE NORTH-WEST RAIL LINK

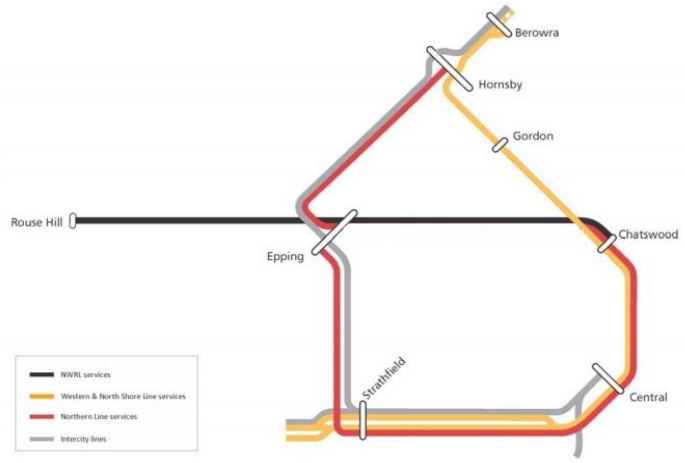

FIGURE 1: TRACK LAYOUT AT THE COMPLETION OF THE NWRL IN 2019. BLACK – NWRL, YELLOW – NORTH SHORE LINE, RED – WESTERN LINE, GREY – INTERCITY SERVICES.

The NSW State Government is currently in the construction phase of the $8.3 Billion North-West Rail Link (NWRL) that is slated for opening in the first half of 2019 (Transport For NSW, 2015). The mostly underground rail line will connect the north western suburbs of Rouse Hill, Norwest, Bella Vista, Castle Hill and Cherrybrook to Chatswood via the existing Epping to Chatswood rail link (Figure 1). The new line will terminate at Chatswood. However, unlike the existing Sydney Trains network, the NWRL will be privatised and will use single deck metro style trains instead of the existing double deck suburban style rail carriages currently on the Sydney Trains network. The existing tracks in the Epping to Chatswood rail link will be removed and re-laid with new track, with all points of physical track interface with the existing Sydney Trains network being removed (Figure 1). This will result in the NWRL being operated as a completely independent network, with only two points of passenger interface with the existing Sydney Trains network at Epping and Chatswood. Patronage projections are in the vicinity of 27 million per year for the entire NWRL system (Transport for NSW, 2011).

2.3 OVERCROWDING OF CHATSWOOD INTERCHANGE

Particular concern is raised with the interchange at Chatswood. Government reports indicate that ⅔ of passengers who alight the NWRL at Chatswood will continue their journey south into the CBD via the existing but already crowded North Shore Rail Line (NWRL Project Team, 2011). As of 2014, the loading factor for morning peak services heading south down the North Shore Line and into the city are averaging at 90% (Transport For NSW, 2011). As such, there is extremely limited opportunity to provide extra capacity using the existing system. The main problem with this is during the morning peak. Reports indicate that approximately 20,000 passengers will alight the NWRL at Chatswood and expect to be able to continue to the CBD during the busiest hour

(7:30-8:30). This is an extremely large problem, and unless solved will result in a gross overcrowding of Chatswood Station. This will have several detrimental effects:

1. The platforms at Chatswood will become dangerously overcrowded. Overloading of this can result in serious injury due to the increased risk of being struck by oncoming trains. Likewise, overcrowding will present dangerous circumstances should an emergency evacuation of the station be required.

2. Overcrowding of the platforms means that passengers will need to wait for several trains to come and go before they can board a train to the city. North Shore Line trains can carry a maximum of 1300 persons per train, and are currently loaded to 90% capacity.

3. If the platforms are already well over loading capacity when a North-West Rail Link train terminates at Chatswood, alighting passengers may not be able to leave the train. This will have adverse effects on the running schedule of North-West Rail Link trains, and will result in delays for the network.

The NSW Government has developed a solution to this problem: The Second Harbour Crossing. The Second Harbour Crossing will comprise of a tunnel linking Chatswood that will go under the Sydney Harbour and down into the CBD. The line will then exit the CBD and terminate at Sydenham. However, this solution will be a case of “too little too late”. The North West Rail Link will be completed by early 2019, but funding for the Second Harbour Crossing has not been secured. Detailed analysis and planning has not been initiated. Preliminary geotechnical surveillance works have begun, but these are only extremely preliminary and present no major advance in the construction of the tunnel (The Daily Telegraph, 2015). As such, in a best case scenario of detailed planning beginning immediately and there be no delay in obtaining funding, construction for the Second Harbour Crossing could be complete by 2025 (Baird, 2015). This means that for 6 years between 2019 and 2025 there will exist a large bottleneck at Chatswood Station.

3.0 CREATING A SOLUTION

As such this report has a main focus of finding a solution to ease congestion at Chatswood Station between 2019 and 2025. The scope of this report is centred on finding a cost efficient and realistic solution to the Chatswood Station crisis.

3.1 OUTLINE OF INDIVIDUAL RESEARCH TASK

Various systems engineering tools are used in this portfolio to find the best solution to the Chatswood-City rail link overcrowding problem (Table 1).

Topic	Technique and Outcome
System Scoping	**System Boundary Chart:** Gained clear understanding of which elements are considered in our design
Requirement Engineering	**Design Requirements:** Determined the design requirements based off customer requirements
	Pairwise Analysis: Quantitatively ranked the importance of Design Requirements
System Function Definition	**Concept Generation Tree:** Generated design ideas including Light Rail, Busses and signalling upgrades
	Concept Comparison: Concepts were evaluated against design criteria to find best solution
Functional Flow	**FFBD:** Outlined functional steps of the system and identified key points
Subsystem Integration	**Functional Allocation:** Identifies which subsystems correlate to which functional step on the FFBD
	Requirements Mapping: Maps which subsystems meet each design requirement
Life-Cycle Phases	**Construction:** Outlined the importance of the order and timing of various physical constructions required for the project
	Usage: Outlined the large benefits of the system and minimal disturbance when the second harbour crossing opens
Design Communication	**Government:** Outlined importance of showing significance of the achievement of the proposed solution and the cost efficiencies
	Public: Outlined importance and methods of informing the public about the carriage segmentation system

TABLE 1: OUTLINE OF VARIOUS SYSTEMS ENGINEERING TOOLS USED

3.2 SYSTEM BOUNDARIES

In order to understand the full scope of the problem, system boundaries need to be created (Table 2).

Endogenous	Exogenous	Outside
Existing North Shore line from Chatswood to central	Change of Governments	Track Alignment
Sydney Trains Staff	Government funding	NWRL Infrastructure
North West Rail Link Scheduling	Patronage	Manufacturing of trains
Track Upgrades	North West Rail Link Management	Natural Disasters

TABLE 2: THE SYSTEM BOUNDARIES CHART (DERIVED FROM PROBLEM SCOPING)

Sydney Trains related elements that can affect the running of any proposed solution are categorised in the System Boundary Chart above. The endogenous variables contain elements of the proposed solution which can be controlled and designed. The exogenous variables are the inputs and outputs of the system. Change of government is a part of the exogenous group because the long term solution (second harbour crossing) lies in the hands of the government. Outside variables affect the operation of the system but are outside of the scope of this project. Track alignment cannot be controlled for this is an immensely costly undertaking is far outside

the scope of designing a stop-gap solution for 2019-2025, as such has been included in the outside group.

3.3 KEY STAKEHOLDERS

The main stakeholders in the project are the newly formed NWRL Corporation, Sydney Trains, and the NSW Government along with the residents of Sydney's North West growth centre.

3.4 DESIGN REQUIREMENTS

Before any form of solution can be presented, it needs to be ascertained what exactly will make a good solution. As such, design requirements need to be formulated. These design require were obtained by perusing the various government reports and isolating the main design requirements. Since there are a variety of varying design requirements, it was decided that pairwise analysis would be used to determine the relative importance of each design requirements. The mapping of Customer Requirements to Design Requirements is presented in Table 3. This pairwise analysis technique is presented in Table 4.

Customer Requirements	Design Requirements	Requirement Identifier
Quick fix	Fully implementable by 2019	Completion
Low Cost	Cost of implementation is as low as possible	Cost
Minimal network disruptions	Construction does not impinge on existing Sydney Trains network	Disruption
Journey Time	Journey time from Chatswood to the City needs to be comparable to current North Shore Line Trains (15 mins)	Time
Move 20,000-25,000 people from Chatswood to the CBD between 7:30 and 8:30am	Increase throughput of existing North Shore Rail Line by 25,000 persons/hour	Throughput
Innovative and efficient in order to increase chance of government funding	Solution needs to be innovate and efficient, along with encapsulating the government's new motto of "NSW: The new state of business"	Innovative
Benefits beyond the 2019-2025 stop gap period	Multiple long term benefits beyond the primary objective of providing a solution to the Chatswood Interchange crisis between 2019 and 2025	Long-term

TABLE 3: MAPPING OF CUSTOMER REQUIREMENTS TO DESIGN REQUIREMENTS (DERIVED FROM REQUIREMENTS ANALYSIS)

Design Requirements	Completion	Cost	Disruption	Throughput	Innovative	Long-term	Time	Sum	Rank
Completion		1	1	1	1	1	1	6	1
Cost	0		1	1	1	1	1	5	2
Disruption	0	0		1	1	1	1	4	3
Throughput	0	0	0		1	1	0	2	5
Innovative	0	0	0	0		0	0	0	7
Long-term	0	0	0	0	1		0	1	6
Time	0	0	0	1	1	1		3	4

TABLE 4: PAIRWISE ANALYSIS OF DESIGN REQUIREMENTS FOR THE INTEGRATION OF THE NWRL WITH THE EXISTING SYDNEY TRAINS NETWORK (DERIVED FROM REQUIREMENTS ANALYSIS)

It can be seen from Table 4 that completing the project by 2019 and minimising cost are the two main design requirements. The NWRL will be complete in 2019, and it is imperative that the solution presented in this paper is fully implemented by that time. Following on, the government has already spent $8.3B on the NWRL, meaning that if this project wants to have a realistic chance at obtaining funding, the cost will need to be minimised as much as possible. As such these two requirements are the most important. Innovation is ranked as the least important requirement for it is not strictly imperative that this is included in the final solution. Whilst innovation would certainly encompass the Governments idea of "NSW: The New State of Business", from a purely functional perspective this is not important. In terms of trade-offs, it is likely that Time and Cost will be dramatically favoured, whilst Innovation and Long-Term may be sacrificed if need be.

4.0 CONCEPT GENERATION

It can be seen in the Design Requirements (Section 3.4) that these requirements, at first glance, do not limit the scope of the project. That is, it seems reasonable to conclude that the Government is open to a variety of possible solutions. This idea of a wide range of solutions is actually encapsulated by the design requirement of "Innovation". The government has introduced a motto of "NSW: The New State of Business", and as such it is appropriate to generate and analyse a wide range of possible solutions to the problem. Several concepts were created in a Concept Generation Tree (Figure 2), then explored in more depth.

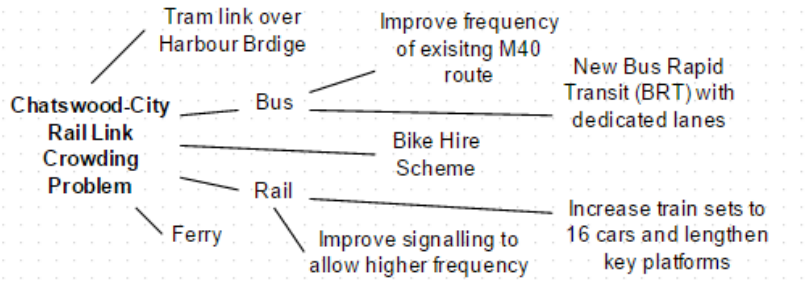

FIGURE 2: CONCEPT GENERATION OF POSSIBLE TRANSPORT LINKS BETWEEN CHATS AND THE CITY (LOGIC AND FUNCTION)

4.1 LIGHT RAIL

As such, it is proposed that a light rail line be constructed between Chatswood and the CBD (Figure 3). The system would almost entirely be on-road. This means that tram tracks will be laid down the left hand lane of each road, with catenary power poles being placed on the left hand side of the road to provide power.

Assuming a similar designed tram is used as what is currently employed on the L1 Dulwich Hill Line, each tram can accommodate approximately 200 passengers (Railway Technology, 2014). In order to transport the estimated 20,000 passengers from the Chatswood to the City in the morning peak, a tram will need to depart Chatswood every 36 seconds. This is extremely frequent and is rather unrealistic. Following on from this are significant problems with the journey time length. The M1 and Cahill expressway are notorious for morning peak hour jams. According to Google Maps, the trip will take 40 mins during the morning peak on a weekday. Currently, North Shore Line trains complete the journey in 15 mins. Another contributing factor is cost. Currently, the 14km route from the CBD to the Eastern Suburbs route announced in January 2015 will cost $2.2 Billion. Implementing Light Rail between Chatswood and the City is a comparable project both in terms of route length and complexity.

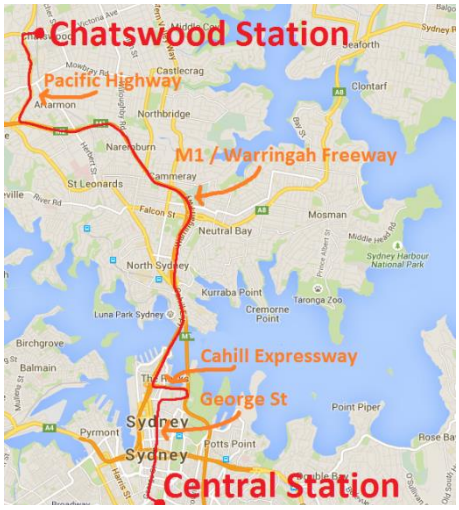

FIGURE 3: PROPOSED ROUTE FOR BOTH LIGHT RAIL AND BUS SERVICES

4.2 BUSSES

Busses could take on passengers at Chatswood station, then continue into the city via a similar route proposed for the Light Rail system (Figure 3). Assuming all busses used are of articulated form and are fully loaded, then each bus can accommodate 90 passengers (of which 26 are standing) (State Tranist Authority, 2012). In order to transfer the 20,000 passengers expected to board in the morning peak, a bus is required to depart every 16 seconds. This is extremely high frequency.

Currently, a similar route as depicted in Figure 3 called M40 runs express (no intermediate stops) from Chatswood to the City. Currently in the morning peak the journey time is 35 mins (Transport for NSW, 2015). There are expected to be major issues regarding the safe operation of these busses within the CBD, especially down George Street. Currently, over 1500 busses serve the CBD in the peak hour, with many roads already congested with busses (State Tranist Authority, 2012).

4.3 INCREASING LENGTH OF TRAINSETS

FIGURE 4: SEGMENTATION OF A 16 CARRIAGE TRAIN FOR CONCEPT 4.3

Currently all Sydney trains are 8 cars long and are of double-deck suburban style. It is suggested that the lengths of the trainsets are increased to 16 cars, which is achieved by coupling two 8 car trainsets together. Following on, platform extensions to handle 8 car trains will need to be made at Chatswood, St Leonards and Central. These stations were chosen because they are stations where large volumes of passengers will be exiting and alighting, as well as they have the room to be extended (North Sydney is underground and it is too costly to extend the platforms). The key to this idea is to segregate the train into different sections. Passengers will board the train and sit in a carriage depending on their destination. This can be seen in Figure 4.

Extending the trainset to 16 carriages will result in an increase of capcity of 1300 persons (Sydney Trains, 2012). At 20tph, this will result in an increase of 26,000 passenger movements per hour. This will require the procurement of approximately 30 8 car trainsets based on 2015 timetabling constraints. This extra capacity will be reserved for passegners travelling to the CBD (comprising of Wynyard, Town Hall and Central Stations). At Chatswood, St Leonards and Central, the full 16 carraiges' doors will open and passengers will board/alight. Then at Artarmon, Wollstonecraft, Waverton, North Sydney and Milsons Point Stations the centre 8 carraiges will pull up to the platform. This will serve the benefit of only having to extend the platforms of 3 stations.

4.4 IMPROVE SIGNALLING

Improve the existing timetabling and signalling aspects of the existing North Shore Line. Currently, the signalling implemented on the North Shore Line allows for a maximum thoroughfare of 20 trains per hour (tph) (Infrastructure NSW, 2012). Currently, the Victorian Line on the London Underground sees signalling that is capable of running 34 tph (Transport for London, 2013), whilst the City Loop tunnels in Melbourne are signalled to a capacity of 30tph (Mees, 2012). Thus it is suggested that the North Shore Line be upgraded to 30tph. Also, the timetable and scheduling of express and all station services be improved. Currently, there exists 4 platforms at North Sydney Station. Hence it would seem appropriate to ensure that North

Sydney Station is scheduled as the point where express trains from Chatswood heading to the city overtake the slower all station services heading to the city.

5.0 MAPPING CONCEPTS AGAINST DESIGN REQUIREMENTS

In order to choose the most suitable solution to the problem, each of the design requirements were compared to each potential solution generated (Section 4). This is evident in Table 5.

Design Requirements ↓	Relative Importance	Light Rail	Busses	Increasing Length of Trainsets	Improve Signalling
Completion by 2019	6	2	5	5	5
Cost	5	1	5	3	3
Journey Time	4	2	1	5	5
Throughput	3	2	1	5	3
Long-Term	2	3	1	5	5
Innovative	1	2	1	5	3
TPM (Score*Relative Importance) (High is better)		39	65	95	87
Rank		4	3	1	2

TABLE 5: DESIGN REQUIREMENTS VS CONCEPTS COMPARISON. 1 = VERY BAD, 5 = VERY GOOD. (LOGIC AND FUNCTION)

As can be seen in Table 5, the solution of using 16 car trainsets was deemed as most suitable. Firstly, increasing the length of the trainsets and 3 station platforms can easily be achieved by 2019. Cost wise, rough estimates are in the region of $500 million. This fits the cost requirement well considering the government just spent $8.3 Billion on the North West Rail Link. Journey time will remain as it currently is (15 mins), and as such scores very highly. Importantly, throughput will be increased by 26,000 per hour, and easily meets the requirement of 20,000. The solution is innovative in its nature due to the outside of the box thinking and resourcefulness, as well as providing permanent capacity increases on the North Shore Line. Even when the new Second Harbour Crossing is opened, there will be a requirement for this new capacity by residents north of Chatswood that aren't served by the NWRL.

The Light Rail option scores very low for completion by 2019. The CBD and Easter Suburbs Light Rail announced in January 2015 will be complete in 2019. Planning and analysis for this line commenced in 2011. As such, it is vastly unrealistic to have the planned Light Rail line from Chatswood to the CBD open by 2019. In terms of cost, the CBD and East Suburbs line is estimated at $2.2 Billion. Since the Chatswood to CBD line is of comparable length and subsequently comparable cost, this is extremely costly. Journey Time for the Light Rail option is a huge concern due to the congestion on the M1, resulting in a low score. Likewise, a light rail vehicle would be required to depart Chatswood every 36 seconds to transport 20,000 per hour, which is highly

unrealistic. Light Rail presents little innovation, and will become completely redundant once the second harbour crossing is complete. Hence it scores lowly on long-term benefits.

Busses are extremely quick to implement, with the only wait being the procurement of roughly 300 articulated busses. This results in a high score for project delivery by 2019. Each bus costs around $750,000, resulting in a project cost of about $300 million once extra bus stops are factored in (Scania, 2011). This is very reasonable and thus likely to obtain funding. However, journey times are likely to be around 40 mins, and thus busses score low in this area. Likewise, a bus will be required to depart every 16 seconds which is extremely unrealistic. Busses prevent little long-term benefits once the second harbour crossing is complete, and are highly un-innovative. Hence they score low in both these requirements.

Signalling improvements are easily implementable by 2019. Cost wise, estimates are in the region of $900 million (Transport for London, 2013). Thus scores for cost are lower at 3/5. However, as frequency increases, journey time will also be decreased. This results in a high score for journey time. Increased frequency results in increased throughput, however realistically frequency can only be increased by 10tph. This will result in an increase in throughput of 13,000 per hour. This does not fully meet the design requirement, resulting in a score of 3/5. Long term benefits are excellent, for even when the second harbour crossing opens in 2025, there will be growth in patronage on North Shore Line trains and improved signalling will cater for this growth. In keeping with the government motto of increased innovation, signally is not innovative and thus scores lowly.

6.0 SUBSYSTEM INTEGRATION

6.1 SUBSYSTEM FLOW ANALYSIS AND FUNCTIONAL ALLOCATION

In order to design the most efficient solution, the problem needs to be broken down into various subsystems. This will allow each subsystem to be tackled independently, then all the subsystems will be tied together to create a single system with efficient integration. To begin this, it is important to understand the different subsystems present in the Chatswood to City transport problem. Functionally speaking there are several main steps. These main steps can be seen in the Top Level of the FFBD in Figure 5. In analysing the FFBD in Figure 5, it is clear that there are multiple points in which the various subsytems integrate with eachother. For exmple, when a passenger is waiting on a platform (item 3 in Figure 5), the user is simultaneously using the

Platform Management System (item 3.1.1) along with the Boarding / Alighting Subsystem (item 3.1.2).

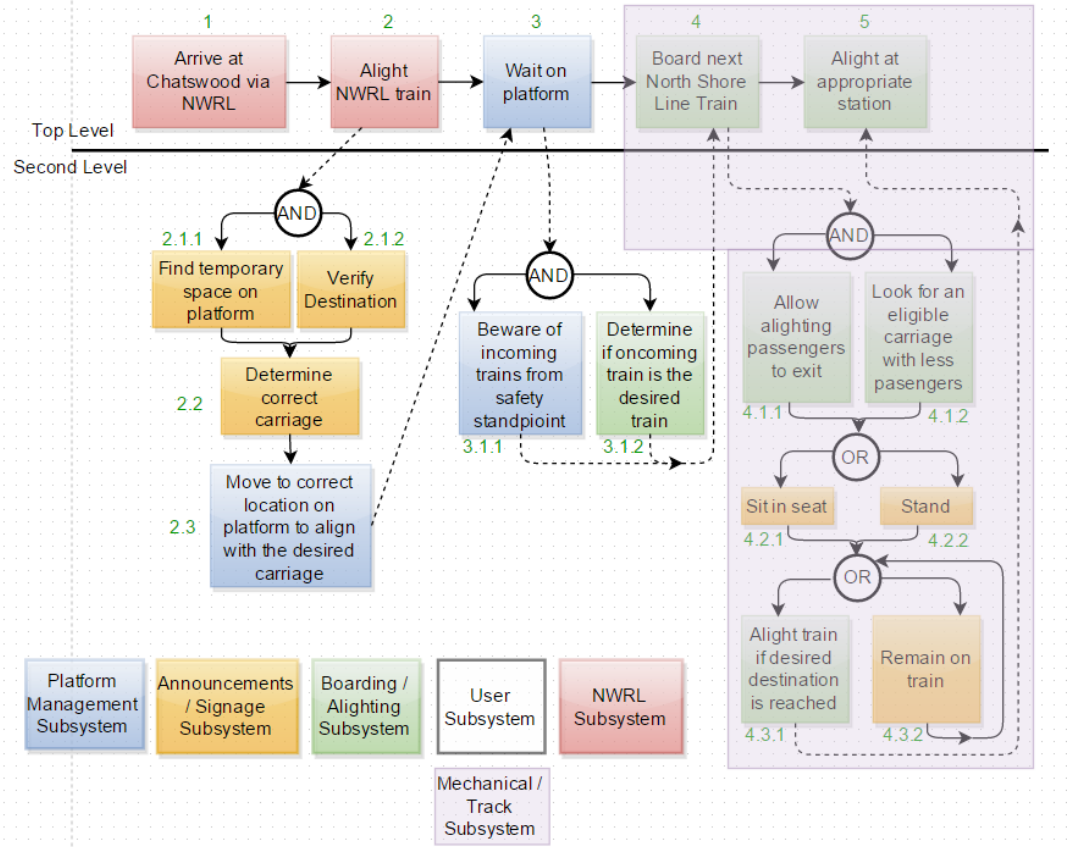

FIGURE 5: FFBD OF THE PROPOSED CHATSWOOD TO CITY RAIL MODIFICATIONS. THIS IS ADAPTED FROM FUNCTIONAL ALLOCATION IN THE SUBSYSTEMS INTEGRATION SECTION.

6.1.1 PLATFORM MANAGEMENT SUBSYSTEM

This subsystem deals with efficient and safe management of crowds at key stations. 3 stations will have their platforms increased to be compatible with 16 car trains – Chatswood, St Leonards and Central Stations. At each of these stations, the platform will be able to accommodate approximately 2000 passengers at any given time (based on a density of 1 persons/m^2 and the platform measuring 330m long by 5m wide) whilst still allowing critical flow passages to be retained. Station entry/exit points will be relocated to serve both ends of the platform, as well as the middle. Passengers will use the subsequent entry/exit points that correlated closest to the location of their train carriage (depending on their desired destination). Sydney Trains Staff will be on the platform at several key locations. They will ensure that overcrowding does not occur, as well as preventing passengers from moving in front of the yellow line and getting too close to approaching trains.

6.1.2 Announcements / Signage Subsystem

This is a very critical subsystem. Unlike any other rail service in Australia, the proposed solution using segmented carriages. Communication with the end user is paramount in order to not confuse passengers. The 16 car trainsets will be colour coded. That is, a vinyl wrap (much like used for exterior train adverts) will be applied to the top windows of each train carriage. For example, the front 4 carriages (Figure 6) will have a blue streak, whilst the next 4 carriages will have a hybrid blue/orange streak. This will serve as a visual confirmation to boarding passengers that they are indeed entering the correct carriage. By only applying the colour scheme on the top windows, the base windows can be retained for advertisements. Next, there needs to be efficient announcements alerting customers to which carriages have free seats. Currently, all Waratah trains (A sets) have load measuring cells on each axle (AusRAIL, 2012). This means that the approximate loading of each carriage can be determined. It is proposed that this data is fed in real time to key stations such as Chatswood. Announcements over the PA system such as "Carriage 4 is mostly empty" will then guide users to the train carriage that has the freest space. This will result in more even distribution of passenger's along the length of segmented carriages. Another aspect of this subsystem will be in carriage announcements. Each carriage will have a unique PA announcement, such as "This carriage will serve Wynyard/Central. Please move forward 2 carriages if you wish to alight at any other station". Again, this is to reassure the user that they are on the correct carriage for their destination.

Figure 6: Segmentation of a 16 carriage train depicting carriage colour schemes

6.1.3 Boarding / Alighting Subsystem

The boarding / alighting subsystem deals with efficient, safe and timely boarding / alighting of trains. This is important because Sydney Trains has identified station dwell times (the time taken to board / alight a train) as a major issue contributing to late running and delays (Sydney Trains, 2015). When a train arrives, an announcement saying "Please stand clear and allow alighting passengers to leave the train" will be played through both the station PA speakers and the internal speakers on the train. Painted arrows on the ground of the platform will create "clear zones" for alighting passengers to enter the platform. This is similar to systems used in London on the Jubilee Line and has been proven to speed up boarding and alighting times (Transport for London, 2015).

6.1.4 NWRL SUBSYSTEM

The NWRL subsystem consists of services that will run on the NWRL from Rouse Hill to Chatswood. It is to be noted that this subsystem is, for the most part, outside of the scope of control for this project. As such, it is classified as an exogenous element (Table 2).

6.1.5 MECHANICAL / TRACK SUBSYSTEM

This subsystem incorporates all of the mechanical aspects of the proposed solution. This includes the new procurement of 30 8 car trainsets, as well as the proposed platform lengthening at Chatswood, St Leonards and Central Stations.

6.2 ENSURING SUBSYSTEMS MEET THE DESIGN REQUIREMENTS

It is absolutely imperative that the subsystems of the chosen solution all work together to meet the design requirements. The most appropriate way to ensue this is to show the relationships between the design requirements and the various subsystems by means of a subsystem map (Table 6). The Mechanical/Track subsystem aids in meeting all of the design requirements, mainly because it single handed forms the backbone of the proposed solution. Boarding/Alighting and Announcements/Signage subsystems increase the efficiency of the proposal, and thus meet the design requirements of Journey Time and Throughput. Cost wise, all subsystems excluding NWRL (which is exogenous) are very cost efficient and help to meet the design requirement of cost efficiency. The extension to 16 cars with segmented carriages (mechanical subsystem) and intelligent platform management subsystems are very innovative and help to meet the design requirements of innovation.

Subsystems → / Requirements ↓	Platform Management	Announcements / Signage	Boarding/ Alighting	NWRL	Mechanical / Track
Completion by 2019				x	x
Cost	x	x	x		x
Journey Time	x	x	x		x
Disruption					x
Throughput	x	x	x		x
Long-Term				x	x
Innovative	x				x

TABLE 6: MAPPING OF DESIGN REQUIREMENTS AGAINST SUBSYSTEMS. THIS IS AN ADAPTED FORM OF REQUIREMENTS MAPPING

7.0 CONSTRUCTION & USAGE OVERVIEW

Construction is of significant importance to this project because it has the capacity to significantly affect already critical transport infrastructure. The importance of minimizing construction impact is exemplified as it is the 4th most important design requirement. The first major step that will need to be undertaken is the procurement of 30 new 8 car Waratah trainsets. The government brought 78 of the sets in 2008, and the first was delivered in 2010 (Reliance Rail, 2010). As such,

if the order for 30 new trains was placed this year, then delivery would begin in early 2018. This would suit the timeline of the project well. The next construction aspect is the extension of the platforms at Chatswood, St Leonards and Central. Any form of platform extension will require the closure of the rail line. However, the existing Epping-Chatswood underground rail link will close during the first half of 2018 in order to allow for the track to be replaced and infrastructure upgraded to accommodate the new NWRL. This means that trains will not be servicing 2 of the 4 platforms at Chatswood Station during this time, and the North Shore Line in general will see reduced passenger numbers due to bus replacements to facilitate the works. Hence, it is proposed that during this time construction of the lengthened platforms at Chatswood and St Leonards takes place. As seen in Figure 7, platforms 1&2 can be lengthened (see yellow arrows in Figure 7) if trains are re-routed onto platforms 3&4 (blue lines in Figure 7). Likewise, platforms 3&4 can be lengthened if trains are rerouted onto platforms 1&2.

FIGURE 7: TRAIN ROUTE MODIFICATIONS TO ENABLE CONSTRUCTION OF LENGTHENED PLATFORMS AT CHATSWOOD

The proposed solution also features very good usage patterns when the project is in full use in 2019-2025. Once staff are trained on how the system works and are confident in their knowledge, no new training will be required. The system will remain unchanged from opening to when the second harbour crossing opens around 2025. When the second harbour crossing does open, the only change to the system will be the reduction in the frequency of 16 car services. The same number of trains (signalled at 20tph) will continue to run, except some will run at 8 car sets. 16 car sets will still run the majority of the time for by 2025 the North Shore Line will be experiencing severe overcrowding even after the second harbour crossing opens (Transport For NSW, 2015). This reduction in frequency of 16 car sets will have no impact on staff training or staff duties.

8.0 DESIGN COMMUNICATION

Successful communication is paramount to the success of this project. Firstly, the benefits and operation of the proposed system need to be effectively communicated to Government officials. These officials (most like Transport for NSW representatives) need to be convinced that the solution will meet all of the requirements. This will accomplished by producing a more in depth report that will build upon the main strengths of the proposed solution outlined in this paper. In the meeting with the representatives, it needs to be explicitly stated that the proposed solution will double capacity whilst requiring minimal investment. Plans to double the North Shore Line have been floated for years, with many aiming at quadruplicating the track (Transport Sydney, 2014). Hence the proposed solution solves an age old problem using minimal investment.

However, whilst communication is important to obtain funding, the real test of communication is educating the general public on how to use the segmented carriage system. When the system is first introduced, people are going to be overwhelmed and excited at the newly finished NWRL. However, when they alight at Chatswood, they need simple and efficient instructions to choose the correct carriage to board based on their destination. One major solution to solving a lack of communication is to have unified colour branding for each of the carriages, with this colour scheme being brought across into the various advertising methods. Please refer to Section 6.1.2.

8.1 POP-UP SHOPS

Pop-up shops will be placed in shopping malls throughout the North-West area. The shops will feature large diagrams of a 16 car train (Figure 6) with a large emphasis on colour branding. Sydney trains representatives will be on site to aid with enquiries.

8.2 TRAIN ADVERTS

Large print adverts with the distinctive 16 car train (Figure 6) will be placed on the interior of every Sydney Trains carriage in the feet. These adverts will also be placed aboard Sydney Busses and Sydney Light Rail trams. They will also be displayed at train station on the North Shore Line. This will ensure that all passengers (both current and future) will be exposed to the changes well ahead of implementation.

8.3 PRINT MEDIA

Small adverts in key newspapers such as the SMH will be employed. These will feature the same 16 car carriage (Figure 6), along with a brief explanation of the changes.

9.0 CONCLUSION

This portfolio uses a systems engineering approach to design a solution to the Chatswood-City rail link overcrowding problem. Initially, extensive background information is presented, then design requirements and various concepts are presented. These concepts are then mapped against design requirements, with in depth functional analysis and subsystem identification used. As the design grows in maturity, detailed subsystem analysis takes place, along with a detailed outline of construction steps and operational details. Throughout the paper it is demonstrated that the proposed solution of extending trainsets to 16 cars in length meets the design requirements in a superior fashion. The paper concludes outlining steps taken to communicate the proposed changes with the general public in innovative manners.

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