

Simulation and Analysis of Container Freight Train Operations at Port Botany

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Abstract

Over two million containers crossed the docks at Sydney's Port Botany in 2011/12; a figure that is forecast to increase more than threefold by the end of the next decade. To cope with such large growth in volumes, the New South Wales (NSW) State Government plans to double rail mode share at the port by the year 2020. Conventional wisdom from industry and the media says that existing infrastructure cannot handle such volumes. In this paper, we use a combination of data analytics and simulation to examine operations at the port and evaluate the efficacy of current infrastructure to handle projected growth in volumes. Contrary to conventional wisdom, our findings indicate that current rail resources appear distinctly under-utilised. Moreover: (i) the peak rail capacity of Port Botany is 1.78 million TEU per annum, over six times higher than 2011/12 rail volumes; (ii) there are no infrastructural impediments to the achievement of peak rail capacity; (iii) operational changes, not infrastructural investment, are the key to unlocking the potential of the port; (iv) Port Botany is well positioned to handle projected increases in container volumes over the next decade and beyond, including the 28% rail mode share target established by the NSW Government.

Keywords: *Simulation, Data Analysis, Predictive Analytics, Capacity Analysis, Ports, Rail.*

1. Introduction

Port Botany is Australia's second largest container port, handling approximately one third of the nation's maritime container traffic. In 2011-12, total volumes at the port exceeded two million twenty-foot equivalent units (TEU), with 86% of all containers transported by road and the remaining 14% transported by rail. Container volumes are expected to increase annually over the next decade and projected to reach 3.6 million TEU by 2020, ~ 5 million TEU by 2025 and over 7 million by 2031 (Berejiklian & Gay, 2013). The New South Wales (NSW) State Government is concerned that future growth at the port will result in large numbers of additional trucks on Sydney's already congested roads. To handle the problem, the government has established a 28% rail mode share target for container freight at Port Botany by the end of the decade (Department of Premier and Cabinet, 2011).

The best way to achieve this goal is a contentious subject that has generated much discussion. For example, according to one recent analysis from industry media (Cameron, 2014), “Not only is rail capacity insufficient for current container demand, there is no rail capacity to meet future container demand. [...] Port Botany’s effectiveness is already impacted by inadequate road and rail infrastructure”.

In previous studies, commissioned by government and supported by industry, it has been suggested that rail at Port Botany has limited opportunities to benefit from economies of scale and that key components of its rail infrastructure are limiting factors. There are three widely held but largely untested perceptions arising from these studies:

1. Rail operations are bottlenecked by a 3km section of single track that provides access to and from the port (Keating, Cox, & Krieger, 2008; AECOM Australia, 2012).
2. The configuration of the DP World rail terminal is an impediment to increased rail volumes (Keating et al., 2008; AECOM Australia, 2012).
3. Port Botany would be better served in the future by consolidating rail operations at a new and centralised off-dock rail terminal (AECOM Australia, 2012).

Addressing any of these issues requires large-scale investment in new infrastructure. For example, the asked-for single-line track duplication has been estimated to cost \$210M AUD (Parliament of NSW, 2011). Given the scale of the expenditure, it is important to understand precisely how these different options compare, how they should be prioritised and when they should be enacted. In this paper, we aim to undertake a principled analysis of the factors that impede current rail volumes at Port Botany. Along the way, we also endeavour to test the veracity of each of these perceptions.

In the first instance, we undertake a data-driven analysis of current rail performance using six (6) months of operational data from the period September 2012 to February 2013. We study port performance using a range of metrics including (i) train timeliness; (ii) train utilisation; (iii) terminal utilisation; and (iv) yard congestion. We find that, contrary to popular beliefs from industry and from the media (e.g. (AECOM Australia, 2012; Cameron, 2014)), rail resources at Port Botany appear distinctly under-utilised. Moreover, the location and configuration of existing rail terminals is not an impediment to increased rail volumes.

Next, we construct a simulation-based model of Port Botany and measure peak rail capacity (in terms of container volumes) in a range of infrastructural case-studies. Our simulation focuses on a 20km “last-mile” rail corridor between the Sydney suburb of Enfield and Port Botany (Figure 1). The model we create is at the level of individual rail sections and sidings and includes detailed servicing operations at container terminals inside the corridor. Using this model we show that the current rail capacity of Port Botany is over 1.7M TEU; i.e. well above the levels needed to meet the NSW Government’s 28% rail mode share target over the medium term (cf. 1M TEU by 2020 and 1.4M TEU by 2025). These figures can be achieved without any investment in new infrastructure such as a centralised off-dock rail terminal or the planned duplication of 3km of rail track.

Our findings show that the key to unlocking the potential of rail at Port Botany lies not in infrastructural upgrades but rather operational changes such as dynamic train scheduling,

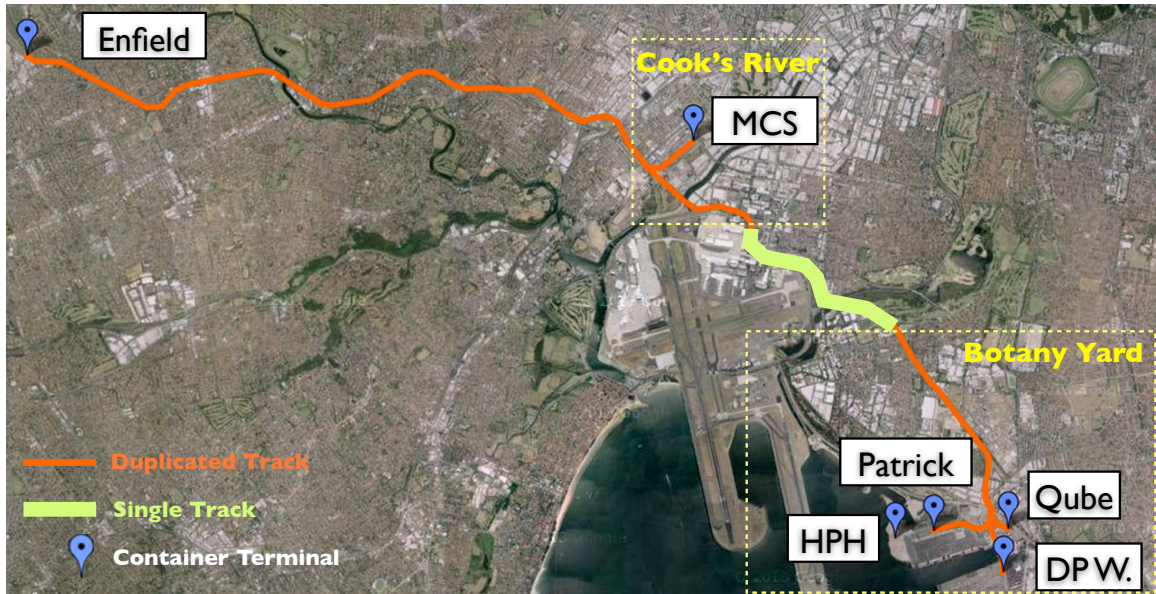


Figure 1: A map showing the extent of the Enfield-Botany rail corridor. Labelled are the locations of the four current rail terminals (DP World, MCS, Patrick and Qube) and the approximate locations of two new rail terminals due to commence operations in 2014 (Enfield ILC and HPH).

flexible servicing windows, improved staging practices, and “dedicated” train services that visit one stevedore per trip.

2. Methodology

We give a brief description of the main datasets used in for the analytical part of our study and an overview of the simulation model we employ thereafter.

2.1 Data Sources

Our analysis and results are informed by a range of primary and secondary data sources. The largest of these are two databases provided to us by Sydney Ports Corporation:

- A database of Daily Operations Plans (DOPs) which are compiled by Australian Rail Track Corporation (ARTC). This database contains information for 1992 separate freight services that operated at Botany Yard in the target six month period. Each DOP records details such as planned and actual arrival times, planned and actual departure times, planned and actual servicing times, and the point of origin and point of return for each train.
- A database of operational performance measures compiled by rail crews working at waterfront terminals. This database contains operational performance metrics for 1324 separate services (938 trains) across the target six month period. Recorded details include the scheduled number of lifts performed during a servicing operation,

the actual number of lifts, container type (import, export) and size (20' or 40') and the total lifting time for all containers.

In addition, we collected and analysed a wide range of supplemental data sources. Such data includes details of operational practices and constraints gathered during interviews with members of the port community (terminal operators, rail operators, rail network owners and others) and direct observations of train operations which were taken during several visits to Port Botany.

2.2 Simulator Overview

Much of this study is based on analysis of data from a discrete-event simulator that models rail operations inside the 20km dedicated freight rail corridor between Port Botany and Enfield. The purpose of our simulator is twofold: (i) to reproduce current rail operations at Port Botany and thus better understand the factors which impede rail productivity; (ii) to establish the peak rail capacity of Port Botany in a range of infrastructural case-studies.

The rail corridor, which is the focus of our simulation, connects Port Botany to the Sydney Metropolitan Freight Network. It is used primarily by container-carrying freight trains and is home to four (since 2015, five) intermodal rail terminals. Two of these terminals (since 2015, three) are on-dock stevedore terminals and two are empty container parks. With the exception of one 3km section, the system is comprised entirely of duplicated track, some of which is configured for bi-directional running. For further details of the physical infrastructure and operational procedures and constraints (See Section 3).

2.3 Simulator Design

Our simulator is constructed in the Java programming language and makes use of the freely available simulation library DESMO-J (Lechler & Page, 1999) (we use version 2.3.5, available from <http://desmoj.sourceforge.net>). Figure 2 gives a high level overview of the system. We briefly discuss each of its main components:

- The source and sink of the system is located at the Enfield Marshalling Yard. Trains originate at Enfield according to a pre-determined distribution or according to a fixed (e.g., historical) schedule.
- There are 5 intermodal rail terminals in the system, each having one or more available sidings where trains can be shunted, split (if necessary) and subsequently serviced. We model each terminal as a queue with capacity equal to one (1).
- Two sets of sidings, collectively known as Botany Yard and Cook's River, are used for staging trains before and after servicing. We model each of these yards as single queues with capacity equal to the number of physical sidings.
- A 3km section of single track connects Cook's River with Botany Yard. We model this section of track as a single queue with capacity equal to one (1).

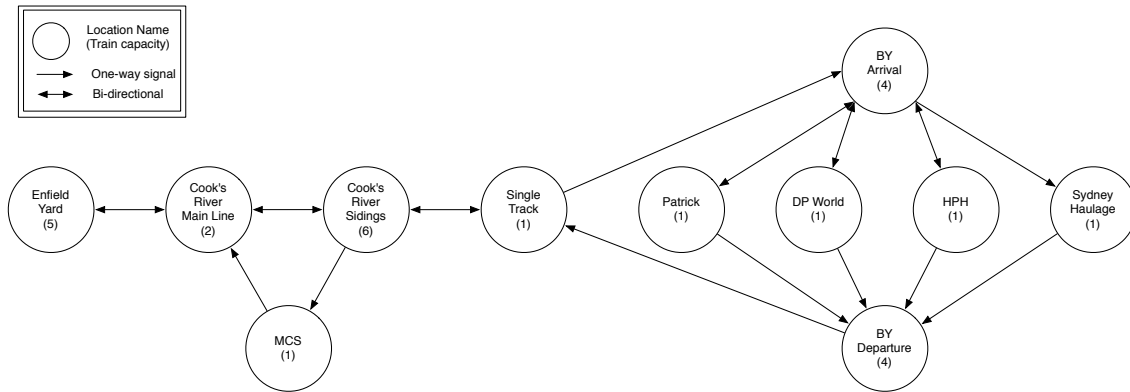


Figure 2: An overview of the architecture of our simulation model. Queues are represented by nodes. Their capacity is indicated in parentheses. Edges represent rail connections.

2.4 Simulator Inputs

To simulate train operations, we use a variety of empirical distributions computed from operational datasets described in Section 2.1. These distributions are used to determine: (i) stevedore lift rates; (ii) shunt in and shunt out time (i.e., the time required to propel trains both into and out of each terminal); (iii) variance between planned and actual number of containers carried on a train; (iv) possible delays between placement of a train and starting the service. Other parameters include headway time between trains and the period of time which is simulated (typically 365 days).

Each parameter can be adjusted. This flexibility allows us to simulate different scenarios and study, e.g., the impact of higher lift rates or peak capacity under ideal shunting operations. In the same way we can also add or remove infrastructure (e.g., add or omit a terminal) and modify the capacity of infrastructure (e.g., to simulate the effect of single-line duplication, the addition extra sidings in the corridor, or the impact of parallel train servicing operations).

2.5 Simulator Outputs

The output from the simulator is in the form of train attributes, train schedules, and stevedore performance data. In the case of trains, we record information such as the length of the train, the number of wagons, the number of planned containers, and the number of actual containers. We also generate a detailed record of train movements within the system and the times they occur (e.g., arrival to the Enfield Marshalling Yard, entry/exit at a stevedore terminal, lifting start/finish, etc.). In the case of terminals, we compute and record average, minimum and maximum servicing times, as well as number of trains serviced. We also calculate total servicing time and terminal utilisation. All queues in our model are traced, providing detailed logs and summary figures. Thus, additional information about infrastructure usage can also be obtained from the simulation, e.g., single line utilisation.

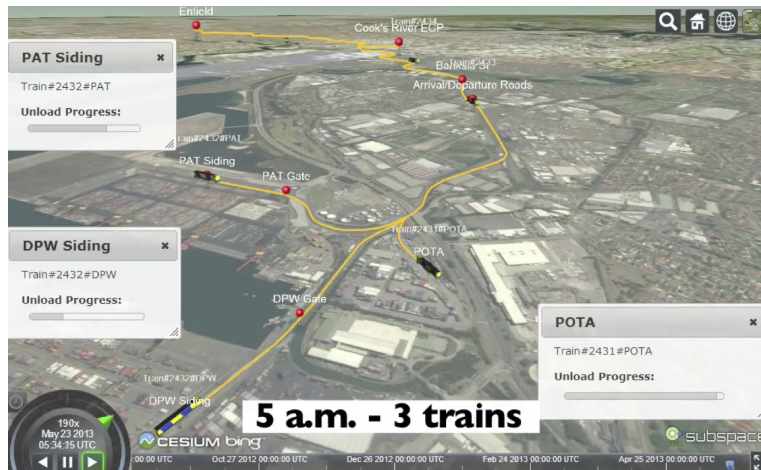


Figure 3: The visualisation component of our simulator.

2.6 Simulator Visualisation

As part of this work, we have also developed a visualisation component that allows us to more easily communicate the results of simulation-based analysis to our client stakeholders (Sydney Ports Corporation) and the members of the port community more generally. The visualiser is built on top of NICTA SubSpace; a freely available geospatial visualisation library (<http://subspace.nicta.com.au>). It takes as input a rail network map and a detailed train schedule. The output is an animation that shows trains moving through the system and being serviced at various terminals along the way. An example of this animation is shown in Figure 3.

3. An Overview of Rail Operations at Port Botany

The Enfield-Botany rail corridor (shown in Figure 1) is an approximately 20km section of (mostly duplicated) rail track connecting the Enfield Marshalling Yard and Port Botany. The corridor is dedicated freight and primarily used by trains carrying containers to and from intermodal terminals located in and around the port precinct. These terminals are:

- Patrick, DP World, and Hutchinson (HPH). These waterfront terminals facilitate the transfer of containers between ships and rail and road transport. They operate 24/7 with HPH due to commence rail servicing operations in 2015.
- Sydney Haulage and MCS. These are empty container parks operated respectively by Qube Logistics and Maritime Container Services. These terminals are used for storing and providing empty containers for lease and export, for unloading trains that have missed their stevedore windows, for refuelling services and for staging trains that are waiting for an outbound path.
- Enfield. This inland intermodal terminal, operated by Hutchinson, is planned to commence operations in the corridor in the near future.

Another important part of the rail infrastructure is Botany Yard. This collection of rail tracks and sidings, approximately 3km in length, is used to stage trains operating at waterfront terminals. The yard is divided up into 2 arrival roads and 2 departure roads. It can accommodate up to 8 trains of length 650m or less (2 per arrival and departure road) or 4 trains of length longer than 650m. Access to Botany Yard is by way of a 3km section of single-track (i.e. non-duplicated) between Mascot (near MCS) and the waterfront.

3.1 Train Operations

There are three categories of container trains operating in the Enfield-Botany rail corridor.

1. *Dedicated trains* that only visit one stevedore terminal (and possibly Sydney Haulage);
2. *Split trains* that visit both stevedore terminals (and possibly Sydney Haulage);
3. *Non-stevedore trains* that only visit Sydney Haulage or MCS.

Each train consists of one or more locomotives and a collection of wagons called a *rake*. When a train arrives into Botany Yard, the locomotive moves to the rear of the rake. This operation, known as a *run-around*, simplifies servicing operations and must occur before the train can enter any of the terminals.

Once the locomotive is positioned at the rear of the rake, the train waits in the yard until it is *called-up* by the terminal operator for servicing. The train is *shunted* (i.e., propels) into the appropriate *siding* and the wagons that are to be serviced are disconnected from the remainder of the rake. At this point, the train is said to be *placed* and servicing can begin. During servicing the remainder of the train (possibly just the locomotive) can either wait outside the entrance to the terminal or propel into another terminal.

Once servicing is finished, the train is *called-out* by the terminal operator. At this point the locomotive or the remainder of the train returns to pick up and re-attach the serviced wagons, the crew perform a safety inspection of the entire rake and the train *exits* (i.e. propels out) from the terminal and into the yard to wait; either for its next call-up or for its scheduled departure time from the yard.

3.2 Waterfront Operations

Each rail terminal offers pre-allocated and ad-hoc time windows for train servicing operations. In order to reduce risk and minimise delays, rail operators will pre-allocate windows; sometimes up to months in advance. A “standard” window is 90 minutes in length with 30 minutes of this time allocated for shunting the train in and out of the terminal and the remaining 60 minutes allocated for lifting containers on and off the train.

4. Current Performance (Data Analytics)

In this section, we evaluate the performance of container-freight train operations in the Enfield-Botany rail corridor. We analyse a six month period spanning September 2012 to February 2013, all inclusive. During this period, a total of 1992 container-freight trains visited Port Botany. We analyse the makeup and performance of these trains, the performance

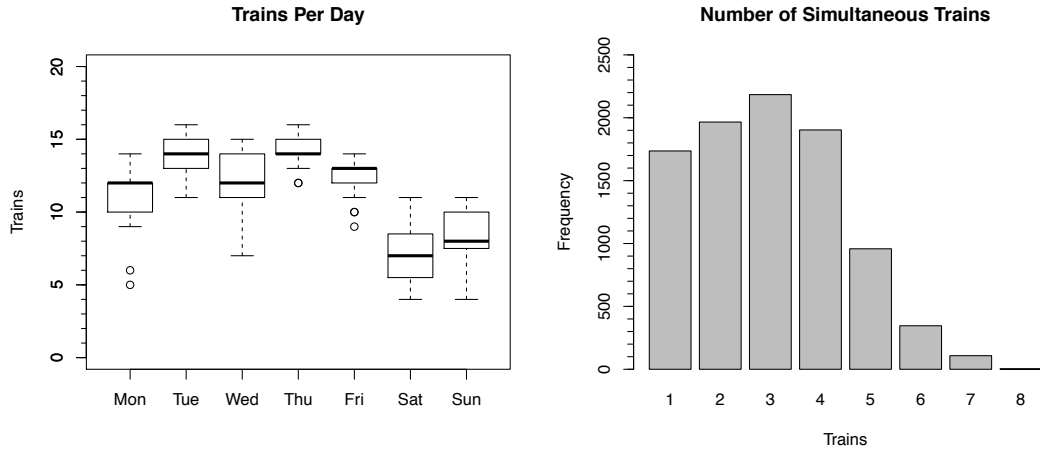


Figure 4: Distribution of daily arrivals in Botany Yard by day-of-the-week (left) and distribution of the number of trains operating simultaneously in Botany Yard (right).

of servicing operations at each of the two stevedore terminals and we look at the utilisation of Botany Yard. Additionally, we investigate three popular perceptions, originating within the port community, regarding rail operations at Port Botany: (i) the perception that Botany Yard is congested; (ii) the perception that the location and configuration of some current rail terminals is an impediment to increased rail volumes; (iii) the perception that the 3km single-track section to access the port precinct constrains rail volumes. In each case, we find that these perceptions are not accurate.

4.1 Perception 1: Port Botany has inadequate rail infrastructure

The perception that Port Botany does not have adequate rail infrastructure is one that has appeared in our discussions with members of the port community. It has also appeared in recent analysis by industry media (Cameron, 2014). We test this perception in two ways: (i) by measuring the current utilisation of available rail sidings, and thus congestion, in Botany Yard; (ii) by analysing the current utilisation of stevedore terminals.

Yard Congestion Botany Yard can accommodate up to $8 \times 650\text{m}$ trains in total across its two arrival roads and two departure roads. In addition, three more trains can be serviced in the yard – one at each of the two waterfront terminals and one at Sydney Haulage. The current capacity of Botany Yard is therefore $11 \times 650\text{m}$ trains. We compare this maximum figure with train volumes observed during the target six month period.

We begin with Figure 4 (left) which shows that, on an exceptionally busy day, up to 16 trains can arrive at the port during a 24 hour period. The expected figure is less; between 11 to 14 arrivals per weekday and 7 to 8 on weekends. In Figure 4 (right), we show a frequency count for the number of simultaneous trains operating in the yard at any one time. To compute this measure we count how many trains are in the yard each time the ARTC’s DOP indicates that a train movement has occurred. A movement can be a train arrival or departure, or a train entering or exiting a terminal.

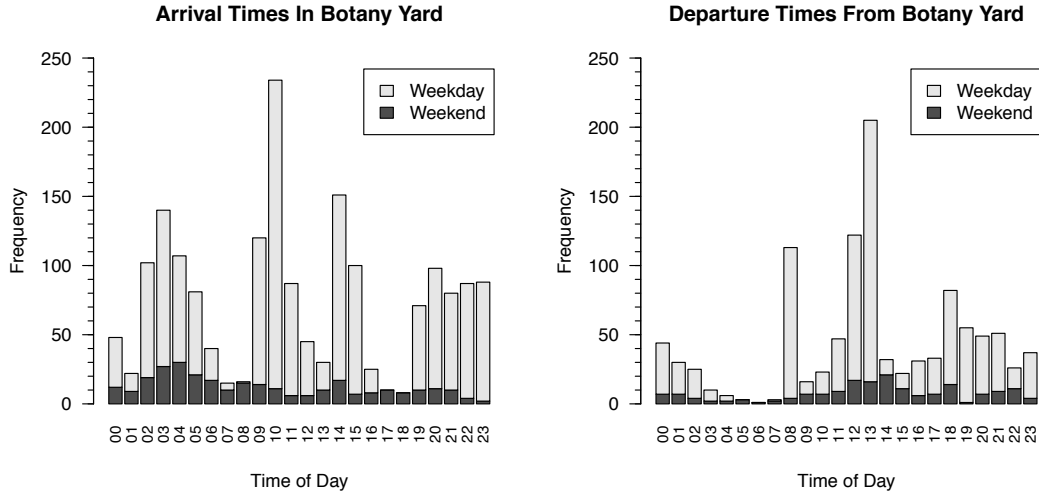


Figure 5: Frequency plot of arrival times (left) and departure times (right) for trains operating at Botany Yard. Note that our available data only indicates a departure time $\sim 71\%$ of all cases. This means we count fewer departures than arrivals.

We find that in the vast majority of cases, there are only between 1-6 trains operating simultaneously in the yard. This suggests that the current utilisation of rail track resources in Botany yard is between 9-55%. The analysis is similar if we account for the length of each train and not just the total number. We find that, in 89% of cases, there are no more than $6 \times 650\text{m}$ sidings in use at any one time. Although trains of length greater than 650m account for 17% of all rail traffic, they do not often operate in the yard in large numbers at the same time.

Our analysis thus far suggests that Botany Yard is not a source of congestion for rail traffic. However this finding appears contrary to perceptions held by some members of the port community. For an alternative perspective consider Figure 5. Here we give the frequency of arrival and departure times for trains operating in the yard. We can see that there are significant peaks during the day, often around the start and end of the freight curfew on Sydney’s passenger network. Depending on specific arrival, departure, and servicing times, it is entirely plausible that trains can incur delays. e.g., due to simultaneous demand for shunting operations at the terminals. We will come back to this issue later on.

Terminal Utilisation Next, we analyse the perception that Port Botany has inadequate rail infrastructure from the point of view of available resources at waterfront terminals. We distinguish between two activities: lifting and waiting. Lifting is the time between the first and last lift, as reported by stevedores. Waiting is the amount of servicing time that remains and includes both shunting time and idle time (e.g., waiting for the locomotive to return). We omit detailed performance data for reasons of confidentiality.

During the six month study period a total of 2348 servicing operations were carried out by stevedores. In one terminal trains are serviced at a (near) constant lift rate, largely independent of the number of containers the train is expected to carry. Waiting times at this

terminal are between 20-35%, most of which is shunting (i.e., during servicing operations the terminal appears well utilised). At the other terminal the number of lifts per hour is highly variable and increases or decreases with the number of expected containers. Waiting times are between 30-60% (i.e. during servicing this terminal appears under-utilised).

For a clearer picture, we also compute the total proportion of time that each terminal spent servicing a train (i.e. lifting or waiting) during the study period. Using this measure the two terminals have a utilisation rate of 43% and 66%; i.e. both appear under-utilised.

4.2 Perception 2: Rail sidings at the DP World terminal are an impediment

The DP World rail terminal is configured with $3 \times 350m$ sidings. Trains longer than 350m require more complicated shunting operations when accessing this terminal as the train needs to be split across two or more sidings prior to servicing. This situation has led some within the port community to conjecture that a bottleneck exists within the terminal (Keating et al., 2008; AECOM Australia, 2012).

To investigate this perception, we analysed six months of DOP data, recorded by ARTC. The data indicates when a train moves into and out of each stevedore terminal. On first analysis, we find that shunting into and out of the DP World terminal can indeed take 4-5 minutes longer than shunting into and out of the Patrick terminal. Further investigation however reveals the issue is more complex.

As part of our study, we engaged directly with railway engineers from ARTC and undertook on-site visits to their monitoring facility at Port Botany. These discussions reveal that shunt in and shunt out times recorded by ARTC correspond to the times when a train leaves the track circuits and when it re-appears on the track circuits (railway tracks at Botany Yard are instrumented with sensors and the location of each train is precisely monitored by ARTC). At DP World, the track circuits end approximately 300m before the stevedore gate whereas at Patrick the circuits end very close to its gate. A typical port train takes 1 minute to traverse 100m of siding. If we adjust (i.e., subtract) this travel, the shunt time difference between the two terminals vanishes almost entirely. This finding is consistent with direct observations that we made while visiting both rail terminals. In particular, we have seen that splitting at DP World can be very fast. The crossover track is located next to the gate and the train can propel quickly from one siding to the other. We measured the overhead at one minute, which is consistent with our data analysis.

We conclude that there is no appreciable difference between shunting in and shunting out at either terminal despite the additional splitting operation at the DP World terminal. We believe this perception stems from the fact that, in practice, shunting time and lifting time might be similar for trains carrying only few containers.

4.3 Perception 3: The 3km single-track accessing Port Botany is a bottleneck

A 3km section of single-track connects Botany Yard to the dedicated freight line from Enfield. This contentious piece of infrastructure is often identified as a bottleneck and an impediment to the growth of rail (Keating et al., 2008; AECOM Australia, 2012).

ARTC (the rail network owners), estimate the maximum capacity of this line at 36 return train-trips per day, on average (Ormsby, 2013). ARTC's figure is a conservative estimate that takes into account infrastructure stress and maintenance requirements and

also considers minimum time separation between trains crossing the single line. Recall (from Figure 4) that, on an exceptionally busy, day up to 16 trains can arrive at the port. In this case, single-line utilisation is 44%. The expected figure is even less; 31-39% on weekdays and 19-22% on weekends. It is easy to see from this simple analysis that the single-line track is not a current operational bottleneck and any infrastructural investments at Port Botany should be directed elsewhere (e.g., increasing the capacity of rail terminals which are saturated long before the single-line track, as we show in the next section).

We believe the single-line track is regarded as a bottleneck because it can become over-subscribed for short periods each day. In particular, train arrivals and departures tend to be clustered immediately before and immediately after the curfew period imposed on freight trains crossing Sydney’s passenger rail network (see Figure 5). Again, an improved scheduling system for port trains would result in better utilisation of this section and help mitigate the perception of congestion.

5. Peak Capacity (Simulation and Predictive Analytics)

In this section, we use a simulation-based approach to investigate the container-carrying capacity of rail infrastructure in the Enfield-Botany rail corridor. The outputs from such an analysis, together with forecasted growth in container volumes, will allow us to clearly see when the port is likely to become saturated and will help us identify which pieces of infrastructure will be impacted first. Such information is necessary to guide long-term infrastructural planning and to prioritise investment at the port.

Our simulation model is described in Section 2.2. Unless otherwise noted, we use a common set of ideal but not unrealistic operational parameters. These parameters are described in Appendix B. As part of our analysis, we undertake several operational and infrastructural case studies. These case studies are:

- Port Botany with current rail infrastructure.
- Port Botany with longer sidings at the DP World terminal.
- Port Botany with a single centralised rail terminal.

A key finding from our analysis is that the peak capacity of current rail infrastructure at Port Botany is as high as 1.780M TEU per annum; i.e., over six times higher than actual rail volumes in 2011/12 and well above the levels necessary to meet the NSW Government’s 28% rail mode share target for the year 2020 (i.e., 1M TEU).

5.1 Capacity Case Study 1: Port Botany with current infrastructure

We developed multiple scenarios to explore the annual peak capacity of rail at Port Botany. Scenario 1 (the “As-Is” model) represents the current configuration of the port, i.e., there are only two stevedore terminals offering rail services. Scenario 2 (the “Soon-to-Be” model) represents the configuration of the port in the near future, i.e., all three stevedore terminals offer rail services. Table 1 summarises our main findings.

For the As-Is scenario, we observe that peak capacity of 1.121M TEU per annum can be reached using two terminals servicing 16 trains per day on average. The amount of rail

Metric	Scenario 1: As-Is		Scenario 2: Soon-to-Be	
	80% Current Max	Unchanged	80% Current Max	Unchanged
Lifts Per Hour				
Avg. Trains per day	16	13.11	25.4	21.3
Time (% Lifting)	85.8%	88.5%	86.5%	87.7%
Time (% Shunting)	14.2%	11.5%	13.5%	12.3%
Peak Volume (TEU)	1.121M	0.919M	1.780M	1.493M

Table 1: Peak capacity at Port Botany. We simulate two scenarios: Scenario 1 represent an As-Is model of the port (with two rail terminals) and Scenario 2 represents a Soon-to-Be model (with three rail terminals). For each scenario, we present results assuming that: (i) each terminal lifts at a constant 80% of current maximums; (ii) lifting performance at each terminal remains unchanged.

traffic in this case is similar to the level currently experienced at Port Botany during a “busy” weekday. In the Soon-to-Be case, a peak capacity of 1.780M TEU can be attained with three terminals servicing 25.4 trains per day, on average. For context, under the NSW Government’s 28% rail mode share target, Port Botany will need to rail 1M TEU per annum by 2020 and 1.4M TEU by 2025.

It is important at this stage to discuss the lift rate performance of stevedore terminals. Currently lift performance at Port Botany can vary from day to day and train to train. Chiefly these variations are due to operational uncertainty; e.g. differences in the number of planned vs actual train arrivals and differences in the actual vs planned number of containers of each train. Such uncertainties can affect the size of the rail crew on the day and the amount and type of equipment available to service the train. To model this variation, we analysed six months of operational data collected from each terminal operator. We constructed from the data empirical distributions for lift rates based on recorded performance stripping and backloading rakes of length 650m or similar. There are two such distributions, one for each terminal. We assume that the third operator will be comparable to the current best observed performance at the port. We used these distributions during simulation to establish a peak capacity figure for the system under the assumption that there are no changes to terminal operations in the foreseeable future.

If we assume no operational changes take place at Port Botany’s terminals (i.e., stevedore lift rates are unchanged), the capacity of the port is 16-18% lower: 0.919M TEU in the “As-Is” scenario and 1.493M TEU for the “Soon-to-Be”. In both cases, peak figures are very close to the stated 28% rail mode share targets established by the NSW Government but we can see the system is saturated and stevedore resources are exhausted. In order to deal with projected growth for the year 2020 and beyond, Port Botany will need to incentivise terminal operators to lift at higher and more consistent rates than currently. Essentially, this can be achieved by reducing operational uncertainty (e.g., through better communication in the rail supply chain) and better allocation of existing resources to rail.

Our simulation shows that stevedores operating at the port are able to meet the NSW Government’s rail mode share targets for 2020 and beyond with only changes to operational practices (i.e., consistent lift performance) and no investment in new infrastructure. Further

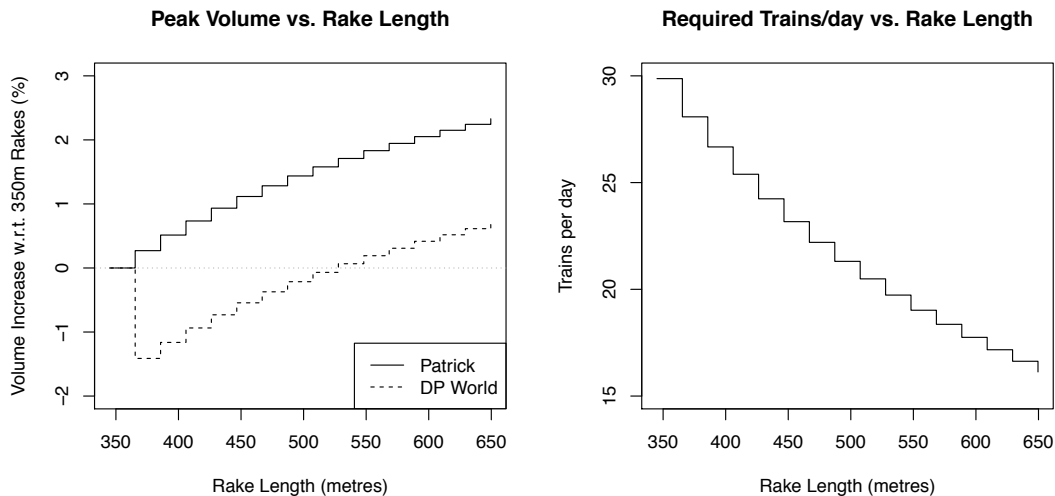


Figure 6: Left: Peak Rail Volume (two stevedores) vs. Rake Length. Values are indicated as the relative variation w.r.t. the suggested ideal length of 350m to maximise volumes at the DP World terminal. Right: Trains per day vs. Rake Length. We observe that maximising volumes with shorter configurations requires a number of trains close to the maximum number of trains that can traverse the single-line section according to ARTC (i.e., 36 trains/day).

our simulation shows that there are also no bottlenecks or other impediments that prevent the achievement of these figures and targets (e.g. single-track or siding lengths).

5.2 Capacity Case Study 2: Longer siding lengths at the DP World terminal

Within the port community, a range of alternative rake lengths have also been proposed to maximise rail throughput. For example, because the DP World rail terminal comprises $3 \times 350\text{m}$ rail sidings, it has been suggested that trains with 350m rakes are optimal with respect to maximising container volumes. We analysed the impact on peak capacity from operating container trains with rakes of length other than 650m. We explored a range of such alternative configurations; from rakes that comprise a single wagon (20.3m in length) to rakes of up to 32 wagons (650m in length). We focus our discussion on rakes of 17 wagons (350m in length) or longer, as shorter configurations are less effective.

Figure 6 (left) gives the result of this analysis in terms of relative container volume variation with respect to the suggested 350m rake length. We find that 650m 32-wagon rake configurations maximise volume both across the entire operation and also at each terminal. At the DP World terminal we can observe that there is less than 1% difference in volume between 350m vs. 650m rakes. This observation runs counter to suggestions from industry who argue that volumes at DP World can be increased by running shorter rakes with reduced shunting time. Moreover, Figure 6 (right) shows that the number of train services per day required to achieve projected volumes rapidly increases for shorter rake

lengths. We observe that, to obtain maximum volumes with 350m rakes, 30 trains need to access the port daily, while only 16 trains per day are required with 650m rakes.

Our analysis of operational data showed that splitting operations at DP World introduce only a small overhead to total shunting time. We have also shown, in our analysis of alternative rake lengths, that operating 350m rakes at the DP World terminal is marginally less efficient than operating longer 650m rakes. A logical recommendation would be to extend DP World sidings to accommodate 650m rakes, aiming at eliminating the shunting and splitting overhead. However, we quantified the impact of such infrastructure upgrade at 0.4% increase in peak rail volume, suggesting that investment should be directed elsewhere in order to obtain bigger gains.

5.3 Capacity Case Study 3: A single centralised off-dock rail terminal

It has recently been suggested that, in order to overcome terminal limitations and to increase rail capacity at Port Botany, it will be necessary to consolidate stevedoring operations at a single common-user off-dock rail terminal (AECOM Australia, 2012). Such a scenario has two potentially compelling advantages: (i) improvements in peak capacity from standardised shunting and lifting operations and (ii) the elimination of delays for non-dedicated train services that are currently split between Port Botany's rail terminals. We modelled the proposed facility as follows, on advice from Sydney Ports Corporation:

- There exist three separate rail sidings, each of length 900m.
- All shunting operations into or out of the terminal are non-conflicting.
- Shunting operations are streamlined and faster than at current rail terminals. The proposed improvement is achieved through changes to the current interface agreement between terminal operators and rail operators. In this scenario train crews do not disconnect the locomotive from the rake during servicing and do not need to wait outside the terminal during servicing.
- All train rakes are 900m in length, carry 136 TEU, and require 88 lifts to fully strip or load.
- Trains are serviced at a constant lift rate equal to 80% of current max at Port Botany.

We find that such a centralised terminal is capable of rail volumes of up to 2.052M TEU per annum; i.e., 15% higher than the peak rail volume established in our Soon-to-Be scenario where separate waterfront rail terminals are operating at Port Botany. It is clear that a centralised terminal appears to provide some gains in peak rail volumes vs. simply retaining and operating three on-dock rail terminals. However, if we assume the same consistent lift rates across all three waterfront terminals in the Soon-to-Be scenario, we find that rail volume increases up to 1.97M TEU per annum; i.e., a difference of 4% which can be largely attributed to faster shunting times and reduced shunting due to longer rakes at the centralised facility. Besides offering only marginal gains a single centralised rail terminal has significant disadvantages: (i) it requires significant investment in new infrastructure; (ii) it may require additional resources to ship containers from the facility to the waterfront.

Our study shows that a centralised terminal is not necessary to meet the NSW government’s rail mode share targets over the medium term. The principal advantages of such a facility (better lift rates, faster shunting times) appear to be equally achievable through operational changes and better utilisation of existing rail terminal infrastructure (e.g. 650m dedicated train services, revised interface agreements between rail operators and stevedores and an emphasis on achieving more consistent lift rates). In short, operational rather than infrastructural changes seem to be the key to unlocking the rail capacity of Port Botany .

6. Conclusions

In this paper, we analysed the efficacy of rail at Port Botany and inside the 20km Enfield-Botany rail corridor. Our objective was twofold: (i) to evaluate the current performance of rail in and around the waterfront and; (ii) to investigate the peak rail capacity of both current and proposed infrastructure and working practices. In the course of our study, we analysed six months of operational data collected at the port over the period September 2012 to February 2013. We worked with Sydney Ports Corporation and members of the port community through the Port Botany Landside Improvement Strategy (PBLIS).

In the first instance, we employed data analytics to evaluate the current performance of rail resources at Port Botany. We found that Botany Yard and its associated stevedore terminals appear to be distinctly under-utilised. Particular problems that we identified include under-utilised trains, unproductive staging practices, and peak-hour congestion stemming from poor train scheduling and unbalanced allocation of rail resources.

Next, we employed predictive analytics and discrete-event simulation to study the potential of the rail system. We found that, under a set of ideal (but not unrealistic) operating conditions, the peak capacity of rail at Port Botany is 1.780M TEU per annum. This result is achieved through operational changes only and is significantly higher than previously reported estimates (e.g. (AECOM Australia, 2012)) which assume costly investment in additional infrastructure. We also investigated the potential of such investments including: the duplication of the Mascot-Botany line, the extension of rail sidings at the DP World rail terminal and replacing Port Botany’s existing on-dock rail terminals with a single off-dock centralised facility. In each instance, we found that new infrastructure is either not necessary or that investment can be deferred in favour of changes to operational practices. As a conclusion from our study, particular changes that we recommended are: (i) replacing fixed servicing windows by dynamic train scheduling; (ii) staging trains at the Enfield Marshalling Yard instead of Botany Yard; (iii) replacing non-dedicated non-standard metro/regional traffic with dedicated and standard 650m trains; (iv) the introduction of a minimum rake utilisation policy that prevents low-volume trains from accessing the port.

Our work focused only on the operational aspects of rail. We have not evaluated the economic impact of our results nor attempted to construct any cost model. Our results do show however that Port Botany is well positioned and adequately equipped to achieve the NSW State Government’s stated rail mode share targets for the year 2020 and beyond. The key to unlocking the potential of Port Botany over the next decade and beyond lies not in new infrastructure but better utilisation of existing rail resources. These findings run contrary to conventional wisdom within the port community, and industry media, which purports

that Port Botany suffers from limited rail resources and requires additional investment in new infrastructure.

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Appendix A. Rail Operations Terminology

Call-out. Order to proceed shunting a train out terminal sidings.

Call-up. Order to proceed shunting a train into terminal sidings.

Path. Set of rail resources and time schedule to run a train between two places in the rail network over a given time-period.

Placement. Operation consisting of shunting a train into a siding and detaching the locomotive to start servicing operations within a terminal.

Rake. A set of wagons coupled together.

Road. A railway route connecting two or more places in the rail network.

Run-around. Operation consisting of detaching a locomotive from its train, driving it to the other end of the train and re-attaching it. This operation is performed before shunting into a terminal.

Shunting. Operation consisting of moving trains to or from sidings, as well as dividing trains in sidings. Shunting operations are often performed at low speeds.

Shuttle. A train that runs back and forth, usually over a relatively short distance, between two locations in the rail network.

Siding. A section of track off the main line. Sidings are often used for staging or servicing trains.

Staging. Holding a train, normally at a siding or within a yard.

Yard / Marshalling Yard. A complex set of rail tracks used for storing, sorting, or loading/unloading, rakes and/or locomotives. A *marshalling yard* is a type of yard used to separate and rearrange rakes.

Appendix B. Peak Capacity Simulation Parameters

To evaluate peak capacity we simulate rail operations at the port under a set of operational parameters which we found to be ideal. Some of these parameters have been suggested previously (e.g. (Brereton, 2005; AECOM Australia, 2012)) but to the best of our knowledge they have never been analysed holistically. These parameters are:

- All trains are dedicated 650m shuttles and visit one Stevedore only.
- Trains are scheduled dynamically and originate at the Enfield Marshalling Yard.
- Trains are staged inside Botany Rail Yard prior to servicing.
- Trains are full when they arrive and fully backloaded when they depart.
- All train rakes are homogeneous, comprise 32 wagons and have a capacity of 96 TEU.
- Shunting operations at stevedore terminals proceed without delays.
- Stevedores operate 24/7 and lift at a constant rate equal to 80% of current max performance.