SELECTING THE MOST APPROPRIATE CONTAINER HANDLING INFRASTRUCTURE FOR DURBAN CONTAINER TERMINAL

By

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DECLARATION

I, Rowen Naicker, hereby declare that this dissertation, except where indicated in the text, is the candidate's own work and has not been submitted in part, or in whole, at any other University or University of Technology, and that it's only prior publication was in the form of conference papers and journal articles which are listed in Appendix A.

During the compilation, work was done solely by myself with the omission of plagiarism. Information extracted from sources was duly acknowledged.

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ABSTRACT

Transnet Port Terminals (TPT) is investing 33 billion rand to improve the infrastructure at terminals over the next seven years and the bulk of this expenditure will be invested in Durban Container Terminal (DCT). A plan to boost productivity to 3.3 million Twenty-Foot Equivalent Units (TEUs) per year at Pier 2 in DCT is targeted (Transnet Port Terminals, 2012). To achieve this target, advanced container handling infrastructure will need to be introduced. Seven new Zhenhua Port Machinery Company (ZPMC) ship-to-shore cranes have already been purchased for Pier 2 at DCT. Greve (2013), states that these cranes are expected to improve gross crane moves per hour (GCH) from 26 GCH to 33 GCH.

An in-depth literature review was conducted to examine various ports around the world and the type of technology that is currently being used before investigating the most appropriate container handling infrastructure for the Port of Durban (POD). Future plans for the POD were also taken into consideration.

This study established that the two most common pieces of equipment used for container handling in ports around the world are Straddle Carriers (SC) and Rubber Tyred Gantries (RTG). This is largely due to their flexibility and efficiency. Rail Mounted Gantries (RMG) were discussed very briefly, however were not considered as an option for DCT due to their exorbitant costs to construct, operate and maintain as well as the type of layout of the Port. The production outputs for Pier 1 and Pier 2 were obtained and reviewed to assist in selecting the most efficient piece of equipment from ship to shore. The world is currently leaning towards an environmentally friendly era therefore other options such as Electric-Rubber Tyred Gantries (E-RTG) and Automated Straddle Carriers (ASC) were considered in this study. The government’s National Development Plan (NDP) was then reviewed to determine if automation would be a viable option, considering the vision that South Africa (SA) has in reducing the rate of unemployment by 2030.

A visual assessment was carried out and the results were analyzed based on an evaluation of the current pavement to determine whether or not it would be sufficient to carry the loading of the proposed container handling options. An investigation was carried out to determine the possible causes of damaged panels that were discovered during the assessment and alternative solutions were proposed for repair.

To stimulate this study the author has presented papers in various renowned journals and conference proceedings.

In conclusion, this study deduced that the most appropriate container handling infrastructure would be manual handling RTGs due to their flexibility, reliability, cost effectiveness and efficiency.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AGV-	Automated Guided Vehicle
ASC-	Automated Straddle Carrier
BPA-	British Ports Association
CBR-	California Bearing Ratio
CF-	Condition Factor
DCT-	Durban Container Terminal
ERP-	Enterprise Resource Planning
ESWL-	Equivalent Single Wheel Load
FS-	Flexural Strength
GCH-	Gross Crane Moves Per Hour
GEAR-	Growth, Employment and Redistribution
GPR-	Ground Penetrating Radar
GVA-	Gross Value Added
MVII-	Maasvlakte II
NDP-	National Development Plan
POD-	Port of Durban
RMG-	Rail Mounted Gantry
RTG-	Rubber Tyred Gantry
SA-	South Africa
SC-	Straddle Carrier
STS-	Ship to Shore
TEU -	Twenty-Foot Equivalent Unit
TOS-	Terminal Operating System
TPT-	Transnet Port Terminals
TTU-	Tractor Trailer Unit
ZPMC-	Zhenhua Port Machinery Company

CHAPTER 1 – INTRODUCTION

1.1 Research background

Pier 2 in DCT is divided into North, East and South Quays. The Pier 2 container terminal was constructed around 1970. Originally, the pavement was designed to accommodate one over two SCs and two high stacking density. After an in-depth evaluation of other methods of construction, the Council for Scientific and Industrial Research (CSIR) decided that the most suitable paving system to adapt was in-situ concrete rather than asphalt and concrete block paving. The type of straddle to be used was unknown when the pavement design was carried out, therefore as a precautionary measure the paving was designed for 8-wheeled machinery. This overdesign was a good investment as the pavement is still in a fair condition approximately 35 years after construction with relatively low maintenance. Currently the pavement has exceeded its design life and more intense maintenance will be required. The current pavement is not capable of withstanding the loading that new container handling infrastructure that RTGs and SCs carry (Transnet National Ports Authority, 2013).

Young (2007) states that when there is limited space in terminals and volumes are growing, the factor that limits their ability to grow is the storage capacity and equipment (SCs, Tractor Trailer Units [TTUs], RTGs etc.) The landside and quay cranes may accommodate the increase in volumes but the equipment may not. The introduction of seven new Zhenhua Port Machinery Company (ZPMC) Ship-to-Shore (STS) cranes at DCT will boost gross cranes moves per hour, however the current equipment that is used in the terminal to transport these containers to the storage yard may not handle this increasing rate. Currently at DCT, when the new STS cranes offload ships, the single lift SC transports these containers to the storage yard. These straddles can only stack up to a maximum of 3 high (1 over 2). An urgent solution is required as the world is turning towards shipping as the most economical option to move goods, thus creating a demand for the use of efficient container handling infrastructure. DCT plays a major part in turning the economy in either a positive or negative direction, thus the selection of appropriate container handling infrastructure for this port needs careful evaluation.

1.2 Problem statement

The problem experienced at the DCT (Pier 2) concerns the escalating volume of containers being transhipped. The new ZPMC STS cranes are capable of accommodating the increase in volume. The current container handling infrastructure used in the terminal, however, cannot.

1.3 The research aim

The aim of this research is to determine the most appropriate container handling infrastructure that should be implemented at DCT to accommodate the rapid increase in container transhipment.

1.4 Objectives of the research

- To compare international terminals to DCT to determine which container handling infrastructure is suitable;
- To analyse the production outputs of the container handling infrastructure used from ship to shore in the POD and to study the advantages and disadvantages of the equipment;
- To study the conversion to automation;
- To evaluate the current pavement in the POD;
- To investigate the possible reasons behind current damaged panels and panel failures and to make recommendations so as to ensure proper workmanship to achieve the lifespan intended for the pavements as per original design;
- To compare costs between SCs and RTGs.

1.5 Research methodology

This research will be quantitative as it involves mathematical calculations and visual assessments that will determine whether the panels will fail under the load of new equipment.

The following activities will be carried out:

1) Comparison between RTGs and SCs by referring to other ports around the world to determine which are more commonly used and which will be the most appropriate for DCT. Their advantages and disadvantages will be discussed.
2) Analysis of current outputs from the RTG infrastructure used in Pier 1 and SCs used in Pier 2.
3) Visual assessments of current pavement conditions in the POD and determine the reasons behind panel failure, thereafter proposing solutions.
4) Design load calculations for SCs and RTGs will be done.
5) Cost comparison in terms of purchasing and installation of SCs and RTGs.
6) Cost comparison between concrete overlay and reconstruction.

Some of the information that will be gathered to carry out the above activities:

1) Information on the joints between the existing panels.
2) Design factors pertaining to the original pavement.
3) Properties of existing and proposed SCs and RTGs.
4) Loads imposed by stacking of containers.
5) Strength of the existing sub-base material.
6) Visual assessments on site at DCT.
7) Obtain RTG and SC outputs from the POD.
8) Historic thickness data.
9) Core and GPR thickness data.
10) Quantities for existing paving and slot drains.

1.6 Location and referencing

This study is based on the infrastructure used between the quay and stack area at DCT, Pier 1 and Pier 2. Figure 1, extracted from Google Earth, displays the locality map and detailed layout of the area covered by this study.

Figure 1: Layout map for DCT

1.7 Justification of this study

DCT is currently the busiest container handling port in Africa. Port congestion is a major problem both nationally and internationally, therefore the selection of appropriate container handling infrastructure is vitally important as ports play a major part in turning the economy in either a positive or negative direction. The fast growing sizes of ships in the world has led to the purchase and installation of seven tandem lift ZPMC STS cranes. These cranes cater for movements of either four 20 foot containers or two 40 foot containers loading or offloading. This idea was brilliant on the seaside but the vital question is: will this be accommodated by container handling infrastructure on the landside?

Some of the issues that could be experienced due to the introduction of the ZPMC cranes area are:

- Traffic congestion both on the road and sea, resulting in delays.
- Long turnaround times of both loading and offloading, resulting in customers turning to other countries to trade rather than SA.
- Frustration of employees and customers as targets need to be met which could lead to accidents on the roads and in the port.

1.8 Scope of the study

This study will focus on the evaluation and recommendation of the most appropriate container handling infrastructure for DCT. This will be properly addressed by gathering as much information as possible in order to get an in-depth knowledge of it across the world, and by means of physical assessment and critical review of the operating container handling systems in South Africa (SA).

1.9 Overview of chapters

This dissertation comprises six chapters. Chapter 1 introduces the research title, provides the background of the study, and highlights the problem statement, objectives and the scope of the study. Chapter 2 reviews the literature on the container handling infrastructure and future plans of the POD. Chapter 3 analyses the current equipment used from STS. Chapter 4 assesses the use of automation and whether or not it will meet the objectives of the NDP and Chapter 5 evaluates the current pavement at DCT to determine the required loading for the use of the proposed options. It also investigates the reasons that led to damaged panels and possible solutions to prevent reoccurrence. Finally, Chapter 6 presents conclusions and recommendations based on the results drawn from the study.

1.10 Conclusion

This chapter provided an overview of the chapters that follow. On this basis, the dissertation proceeds to the literature review in which the dominant theories that pertain to the study are explored.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

Boote and Beile (2015) state that “A literature review is an evaluative report of studies found in the literature related to your selected area and the review should describe, summarize, evaluate and clarify the research study.” This chapter, therefore, assesses the relevant literature related to this study and presents an overview of port container handling infrastructure across the world to SA right down to the local level. The review begins with a background to the study and the history of port infrastructure in Africa.

2.2 Background

The position or location that allows ships to dock and the transference of cargo either to or from the land is known as a port. The purpose of the selection of ports is to allow access to land. Port locations are selected to optimize access to land and maneuverable water, to meet the demands of the commercial industry. Ports that have deep waters can handle larger ships, but ports with shallow waters generally have to wait for high tide to haul the ships in by means of harbor pilots and tug boats. Containerized ports are very different from other types of ports such as passenger and petroleum terminals. The transshipment of cargo containers are transported through these terminals by means of various types of transport vehicles.

Once a ship is berthed or docked the cargo is then either loaded or offloaded through various container handling infrastructure, depending on the system the port has adopted. Some examples of systems ports use around the world are Tractor Trailer Units (TTU), RTG, SC or RMG.

2.3 Types of container handling infrastructure

Straddle carriers

The first straddle truck was developed by Mr. H.B. Ross in 1913 to replace horse driven carts used at lumber mills for the transportation of timber. The SC used for containerization was developed by Clark Van Carrier in the 1960s with a lifting height of 1 over 2 depicted in Figure 2 (Ham & Rijsenbrij, 2012).

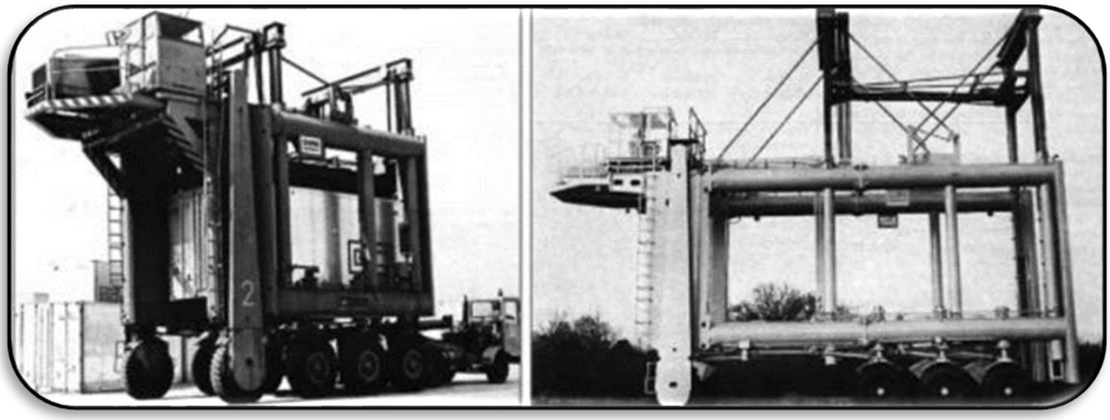


Figure 2: First straddle carrier

The SC is a very popular piece of equipment. These carriers can undertake a variety of handling operations such as loading, unloading, stacking and the transportation of containers between the landside and waterside. Its popularity is due to its space efficiency and flexibility. It can move containers from quay to stack area directly (and vice versa) and covers all kinds of horizontal and vertical movements. SCs can lift a container 1 over 2 and 1 over 3. This equipment stacks containers into rows, separated by a lane wide enough for the wheels of the SC (Mohseni, 2011). This type of stacking is referred to as block stacking (Figure 3).

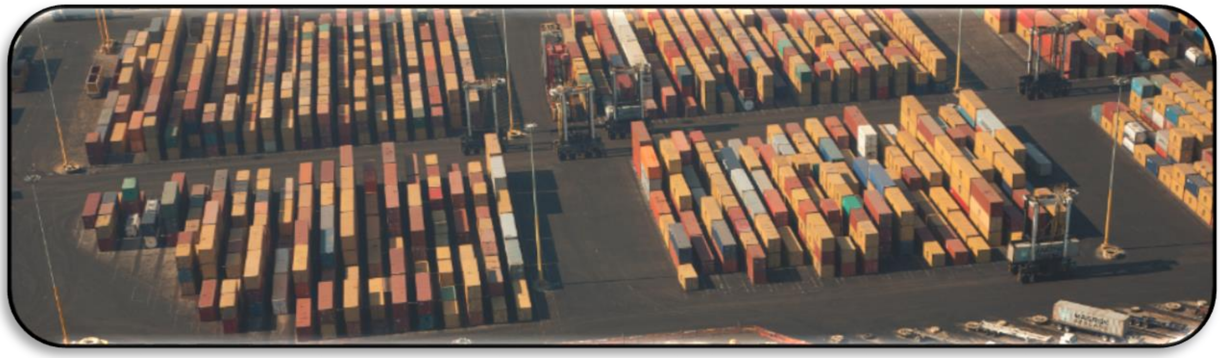


Figure 3: Block stacking

SCs are highly versatile and combine the function of both the TTU and the reach stacker. SC systems are often the optimal system for medium and large size terminals when high flexibility in the yard and accessibility of the boxes are required. With this system, it is fairly easy to alter the layout of the terminal. A STS crane requires an average of between 4 to 5 straddles. Some of the advantages of a SC are that containers can be dropped at the desired location without waiting. Furthermore, the system is flexible to changes based on operational requirements and terminal layouts can be simply altered, as SCs can be easily moved within the terminal since no pre-set routes or tracks are needed.

Rubber tyred gantries with tractor trailer units

A RTG is a mobile gantry crane used in intermodal operations to ground or stack containers. The STS gantry crane places the container on a TTU that transports the container to the storage area where the RTG crane stacks the containers in long blocks. Inbound containers are stored for future pickup by drayage trucks, and outbound are stored for future loading on to vessels. RTGs typically straddle multiple lanes, with one lane reserved for container transfers.

The system has a very high stacking density because of the high stacking capability and the block stacking. Long travelling distances on the terminal are less problematic as TTUs transport the containers. It can also be effectively used for the handling of containers on road trucks or rail cars. According to manufacturers, up to four tracks can be covered and containers can be stored at the side of the rail tracks. RTG cranes can be allocated from the yard to the landside operation and vice versa, if necessary.

Generally, 2 to 3 RTGs and 4 to 5 TTUs (depending on the distance between berth and stacking area) are required per STS crane. RTGs stacks the container in blocks 1 over 4 to 7-high and 5 to 8 container rows plus 1 lane for container handover lane (Brinkmann, 2011).

Ship-to-shore cranes

A STS crane is a type of large dockside gantry crane found at container terminals for loading and unloading intermodal containers from container ships. Container cranes consist of a supporting framework that can traverse the length of a quay or yard on a rail track. Instead of a hook, they are equipped with a specialized handling tool called a spreader. The spreader can be lowered on top of a container and locks onto the container's four locking points ("corner-castings") using a twistlock mechanism.

Seven new tandem lift STS cranes were delivered to DCT in 2012. These cranes can load and unload four twenty foot or two forty foot containers.

Rail mounted gantries

RMG cranes are very popular in large-very large terminals as they are able to stack much wider and quicker, generally 12 containers wide and up to five boxes high. RMGs have the ability to maximise the storage space under the crane to a greater extent. The rails of the RMG can distribute loads better than wheels thus making it appropriate for use where the soil conditions are not ideal (Mohseni, 2011).

This option sounds like the solution for DCT to boost efficiency however there are some factors to be considered before settling on this option such as:

- Maintenance costs are high.
- It is not as flexible as other options like SC and RTG as it is fixed to where rails have been installed. The reconfiguration of terminals is practically impossible once RMGs have been installed.
- RMGs are more suitable for very large terminals. DCT is classified as a med-large terminal.

For the above reasons, this study focuses on either SC or RTG operations as an appropriate solution for DCT.

2.4 Other Ports

2.4.1 Port of Shanghai

The Port of Shanghai (Figure 4) is currently the world's busiest trading port which handles a staggering 32 million containers a year carrying 736 million tonnes of goods to far-flung places around the globe (Mail Online, 2013).

Figure 4: Container pier at the Port of Shanghai
Source: (Mail Online, 2013)

They have the most advanced technology and have adopted the system of RTG operation as this system is suitable for them. The Port of Shanghai reported an average crane handling efficiency at the rate of 30-35 moves/hour. Being aware of environmental protection, Port of Shanghai has launched a project of RTG cranes using electricity for energy consumption instead of diesel oil. The Port of Shanghai handles around 25.7% of the international trading volume in China. More than 2 000 container ships depart from the port every month. The Port of Shanghai has been recognized as the world's largest port in terms of container and cargo throughput for several consecutive years since 2010. On the 19^{th} July 2013 they handled a ship carrying 18 000 Twenty-Foot Equivalent Units (TEUs) (Shanghai International Port Group Co., 2013). The total value of Chinese imports and exports hit $3.87trillion (£2.45trillion) in 2012 – edging past the $3.82trillion (£2.44trillion) trade registered by the US.

2.4.2 Port of Singapore

The Port of Singapore refers to the collective facilities and terminals that conduct maritime trade handling functions in harbours which control Singapore's shipping. Currently the world's second-busiest port in terms of total shipping tonnage, it also trans-ships a fifth of the world's shipping containers, half of the world's annual supply of crude oil, and is the world's busiest transhipment port (Revolvy, n.d.).

Port of Singapore container facilities are as follows:

- Container berths: 57
- Quay length: 15 500 m
- Area: 600 hectares
- Max draft: 16 m
- Quay cranes: 190
- Designed capacity: 35 000k TEU

In 2014 the Port of Singapore was the first port in the world to have cumulatively handled 500 million TEUs. The port is equipped with 204 quay cranes and a number of RTGs. The quay cranes have twin-lift capability and can reach out across 22 rows of containers. The port handles around one-fifth of global container transhipment throughput.

2.4.3 Port of Shenzhen

The Port of Shenzhen is the gateway to Hong Kong and the Pearl River Delta, making it another key port as it connects China's southern hinterland to the world. The Port of Shenzhen is a collective name of a number of ports along parts of the coastline of Shenzhen, Guangdong Province, China. These ports as a whole form one of the busiest and fastest growing container ports in the world.

The port is home to 39 shipping companies who have launched 131 international container routes. There are 560 ships that call at Shenzhen port on a monthly basis and also 21 feeder routes to other ports in the Pearl River Delta region. Table 1 displays the volume produced in 2015 which indicates a slight improvement as compared to 2011 to 2014. The Port of Shenzhen has adopted the RTG system.

Table 1: Volume outputs of leading ports

Rank	Port	Volume 2015 (Million TEU)	Volume 2014 (Million TEU)	Volume 2013 (Million TEU)	Volume 2012 (Million TEU)	Volume 2011 (Million TEU)
1	Shanghai, China	36.54	35.29	33.62	32.53	31.74
2	Singapore	30.92	33.87	32.6	31.65	29.94
3	Shenzhen, China	24.20	24.03	23.28	22.94	22.57

Source: World Shipping Council (2015)

2.5 Port of Durban-DCT

The existing POD is the leading port in the Southern African Development Community (SADC) region and the premiere trade gateway between South-South trade, Far East trade, Europe and USA and East-West Africa regional trade. It occupies a focal point in the Southern Africa transport and logistics chain with 60% of all imports and exports passing through the POD. One of the crucial elements to manage logistics is to provide capacity to operate in advance especially in an environment that is extremely competitive. The problem experienced in POD is inadequate storage space and lengthy dwelling time for containers, according to the

Port Management Association of Eastern & Southern Africa (PMAESA) (KZN Top Business Portfolio, 2013).

DCT is currently divided into two piers namely Pier 1 and Pier 2. Pier 1 has berths 101-107 and Pier 2 has berths 108-205. Pier 1 has adopted a TTU and RTG combination, whereas Pier 2 has adopted a SC system. Seven new ZPMC ship-to-shore cranes have been installed in Pier 2 and these cranes have been designed to boost gross crane moves per hour by loading and overloading two 40 foot containers or four 20 foot containers. This new infrastructure needs to coincide with the current system adopted in Pier 2 and if not then a suitable system needs to be determined. This is the reason that this study was undertaken.

National production and trade trends

Figure 5 shows the export and import trends in SA from 2000 to 2011. During this time, imports and exports have grown by 12% and 11% respectively. Similarly, growth in production measured using Gross Value Added (GVA), has grown by 11% during this time. The trend lines in the graph below show how both the primary and secondary sectors correlate with the level of imports and exports (trade). Trade and production rely on each other. The majority of this trade is conducted through POD and therefore, as production increases, so will demand for the port (Urban-Econ, 2012).

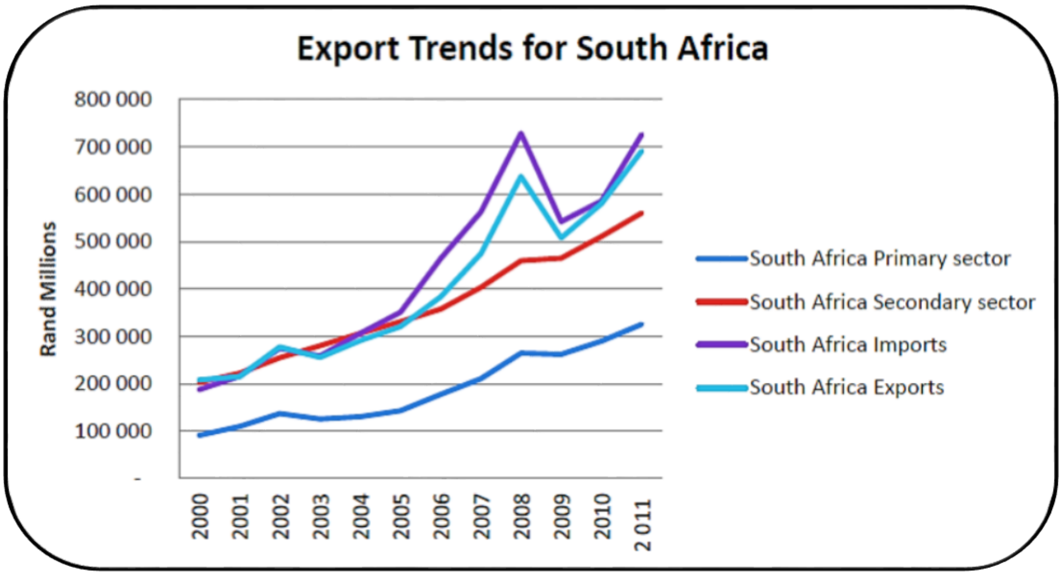


Figure 5: Export trends for SA, 2000-2011
Source: Urban-Econ (2012)

Table 2 extracted from the Economic Impact Assessment for the proposed deepening of berths 203, 204 and 205 of DCT, describes the average vessel and port turnaround time at Pier 2 from April to December 2012. It also shows the key performance indicators for each of these. The average turnaround time for a container vessel calling at Pier 2 is 60 hours (2 and a half days), and the average port turnaround time is 141 hours (just less than 6 days). However, the key performance indicator for both these is 40 hours (less than 2 days). It is vital for trade in SA that the port is efficient (Urban-Econ (PTY) Ltd, 2012).

Table 2: Average vessel & port turnaround time

Indicator	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Target
Vessel Turnaround Time	53.0	51.2	54.1	61.8	72.8	70.7	64.1	52.5	55.1	40 Hours
Port Turnaround Time	165.4	131.8	141.1	128.2	183.7	194.3	137.8	87.0	104.1	40 Hours

Source: Urban-Econ (2012)

Container volumes are expected to grow from 2.69 million TEUs per year in 2010 to between 9 and 12 million TEUs per year by 2040, in Durban alone. If cargo volumes continue to grow at current levels, the existing POD will run out of capacity by 2019 in spite of the expansion plans. Durban's resources in seaward land are extremely limited and the inability to handle growing cargo volumes will invariably have a knock-on effect on the region's competitiveness and on the national economy (Urban-Econ, 2012).

Table 3 shows the volumes of containers handled at POD across various categories in 2012. The total number of TEUs handled in 2012 was 2 720 915. Due to the recovery in the manufacturing sector and the KZN economy in general, the volume of containers (both shipped and landed containers) continues to grow. The proportion of TEUs shipped versus landed in 2012 was exactly 50/50 and the proportion of TEUs that were full was 76%, and empty was 24% (Urban-Econ, 2012).

Table 3: Volumes of containers handled at Durban Port in 2012

	FULL	EMPTY	TOTAL
LANDED:			
DEEPSEA	1 004 104	103 229	1 107 333
COASTWISE	2 753	6 125	8 878
TRANSHIPPED	200 933	43 094	244 027
TOTAL LANDED	*1 207 790*	*152 448*	*1 360 238*
SHIPPED:			
DEEPSEA	627 731	422 242	1 049 973
COASTWISE	13 457	12 814	26 271
TRANSHIPPED	217 725	48 708	266 433
TOTAL SHIPPED	*858 913*	*483 764*	*1 342 677*
GRAND TOTAL	*2 066 703*	*636 212*	*2 720 915*

Source: Urban-Econ (2012)

Future plans for the Port of Durban

SA is currently proposing a port expansion that will include the deepening and widening of berths 203 to 205 which will allow larger vessels to safely berth, thus increasing the overall economic production gained from the terminal (Urban-Econ, 2012). However, this expansion needs to take place urgently as the port is currently restricted to ships with a carrying capacity of less than 3 500 containers. Figure 6 and 7 show the current and future plans for the POD. The plans deal with the issue of capacity; however, this study deals only with the possible options for container handling infrastructure.

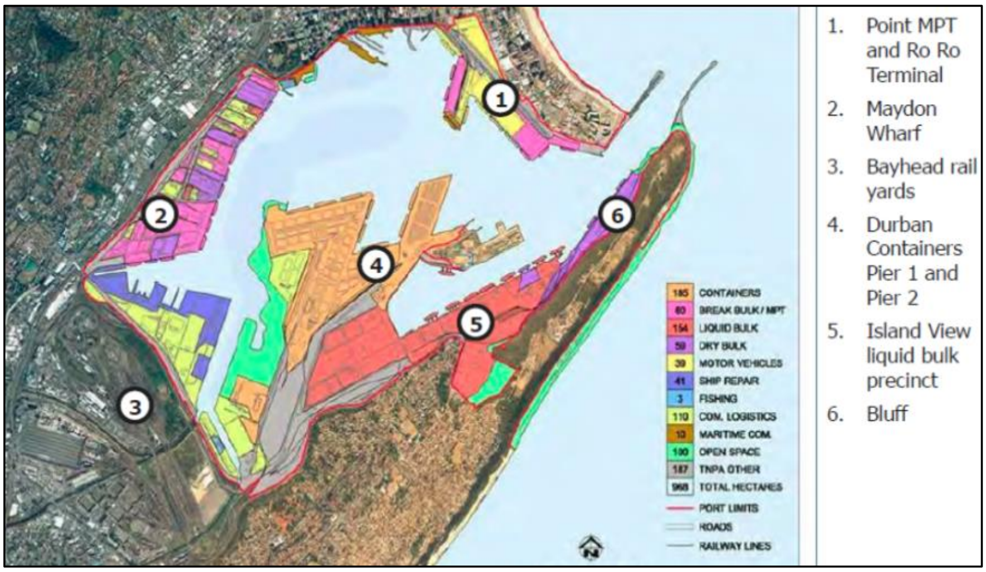


Figure 6: Current layout of the Port of Durban
Source: Urban-Econ (2012)

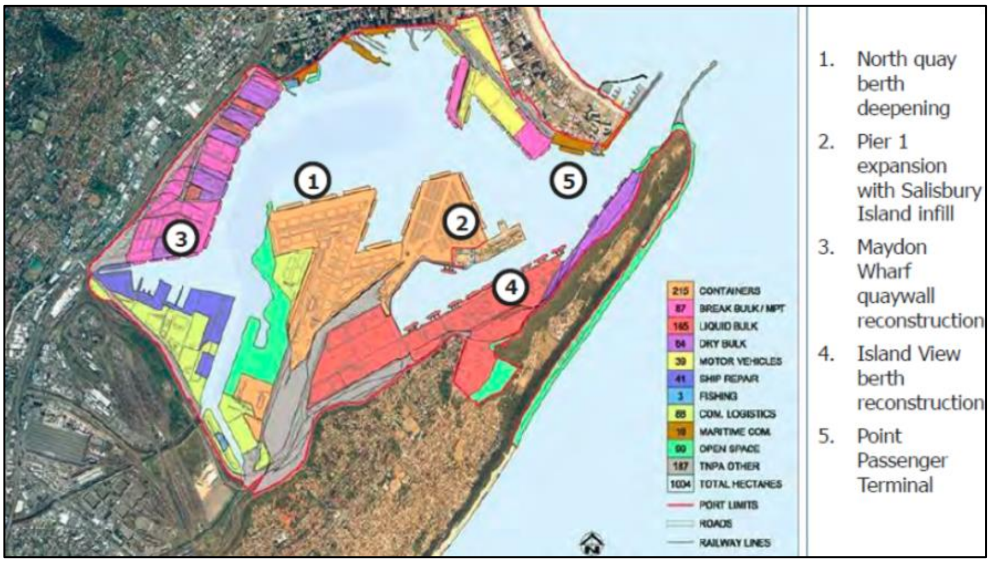


Figure 7: Short term layout (including Berth Deepening)
Source: Urban-Econ (2012)

2.6 Conclusions and recommendations

Terminals that have a lot of land will adopt SCs. Table 3 makes it evident that the comparisons made between various ports above favoured the RTG system of operation as the most efficient infrastructure; therefore, it is the recommended solution for POD as well. The preceding chapters will amplify this recommendation based on detailed research and analysis of the various alternatives that were explored.

CHAPTER 3 – ANALYSIS OF CONTAINER HANDLING INFRASTRUCTURE USED BETWEEN THE QUAY AND STACK AREA IN DCT

3.1 Introduction

DCT is currently the largest and busiest container terminal in Africa and handles about 2.7 million TEUs. DCT handles approximately 70% of SAs containers and generates 60% of SAs revenue. Regardless of demand for containers, ship sizes are increasing and will continue to do so in the near future to a point where 3 000 to 6 000 TEU range ships are phased out and replaced with medium and large sized vessels of 8 000 to 10 000 TEUs (Urban-Econ, 2012). Berths 203 to 205 of the Pier 2 Container Terminal have been identified to be widened, deepened and lengthened to be able to accommodate Super Post-Panamax container vessels of 9 200 TEU capacity with a draft of 14,5m CD. This expansion will allow larger vessels to safely berth, thus increasing the overall economic production gained from the terminal.

Currently Pier 2 is implementing SCs as the key infrastructure used between the quay and stack areas. The POD is currently assessing and introducing infrastructure to accommodate the rapid increase in export and import in the container terminal. The problem experienced at the DCT (especially Pier 2) is that the volume of containers being transhipped is increasing. Seven ZPMC tandem lift STS have been added to the fleet and can accommodate the increase in volumes, however the SCs used in the terminal cannot.

In this study, an assessment of container handling infrastructure currently used at the POD between the quay and stack area was carried out. The results were analyzed, conclusions were drawn and recommendations were made. The advantages and disadvantages for SCs and RTGs were investigated to assist in determining the most appropriate container handling infrastructure for DCT, Pier 2. The production outputs for SCs and RTGs were obtained from Transnet and analyzed. The results were plotted onto a graph to have a much clearer view on production rates and time wastage. The costs for operation, purchase and maintenance for SCs and RTGs were made available by Transnet. The costs were compiled in table format and compared before conclusions were made.

This chapter covers the following activities which were carried out during the course of this study:

1) Evaluation of the current infrastructure used at DCT, Pier 2.
2) A comparison of the infrastructure used in Pier 1 and Pier 2.
3) Investigation to determine if Pier 1 infrastructure between the quay and stack area would be suitable to be used in Pier 2.
4) Recommendations, based on the findings, on the best option to efficiently move containers from the quay to stack areas and vice versa.

3.2 Evaluation of current container handling infrastructure between the quay and stack area-Pier 1

3.2.1 Pier 1: RTG operation

Previously, Pier 1 operations were based on a pure SC system and but were converted to a RTG system a few years ago (Figure 8). The STS gantry crane places the container on a TTU that transports the container to the storage area where the RTG crane stacks the containers in long blocks (Figures 9 and 10). A RTG can be used together with TTUs or road trucks. The size and structure of the RTG crane is determined according to the requirements of the terminal operator. Very heavy concrete paving is required in the wheel tracking areas to support the heavy wheel loads. Concrete/steel pads are necessary for turning purposes of the cranes to travel to adjacent storage areas (or blocks) to perform stacking operations. (Böse, 2011). RTGs are generally smaller and lighter than RMGs, therefore they are sometimes more favorable for terminals built on reclaimed marshland, where reinforced piling would be too costly (Brinkmann, 2011). DCT is built on reclaimed land so RTGs are suitable for this terminal. The current throughput of the terminal is provided as 770

000 TEUs. RTGs do not require a workshop like SCs. Table 4 displays specifications of the RTGs used at DCT Pier 1.

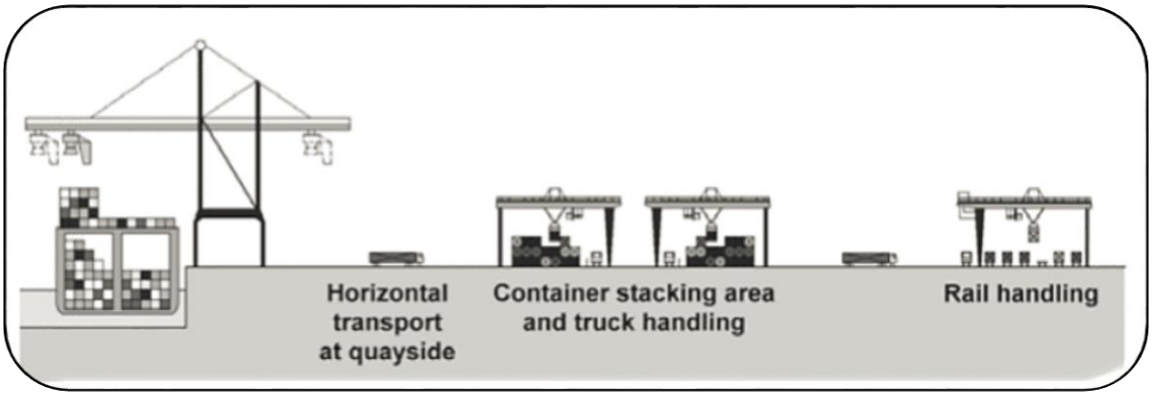


Figure 8: A typical layout of a RTG-TTU system
Source: Böse (2011)

Figure 9: RTG operation - DCT Pier 1

Figure 10: Block stacking at DCT Pier 1

Table 4: Specifications of the RTGs used at DCT Pier 1

Parameter	Value
Gantry speed	2.25 m/sec
Gantry acceleration	0.3 m/s²
Gantry deceleration	-0.3 m/s²
Trolley speed	1.16 m/sec
Trolley acceleration	0.3 m/s²
Trolley deceleration	-0.3 m/s²
Spreader max. speed (up until 15 tons of load)	50 m/min
Spreader max. speed (from 40 tons of load onwards)	22 m/min
Bumper to bumper distance	2 m

Advantages of RTGs

- Low space requirements in the stacking area because of the high storage capacity in a small area (high stacking density). The containers can be stacked up to 8-high (i.e. 1-over-7-high) without spacing for travelling lanes between the rows. To avoid reshuffling of the containers, an efficient administration of the yard is required.
- Relatively high flexibility as the RTGs can be transported to other storage blocks.
- Medium investment capital costs per piece of equipment.

- Due to their high efficiency, RTGs can handle successive lifting, lowering, and stacking operations for a larger number of containers.
- There is a high container space utilization ratio in cross-block operations.
- Thanks to the good mobility of RTGs, storage blocks can be used in a complementary fashion to promote operating efficiency.

  (Brinkmann, 2011)

Disadvantages of SCs

- Container transport between the STS crane and yard area require two handover procedures due to the use of different terminal equipment for transport and stacking tasks, and disturbances of TTU operations by trucks also being loaded/unloaded in the stacking area (mixed traffic).
- Diesel generator operation can lead to a high mechanical breakdown rate and high maintenance costs.
- Heavy fuel consumption can increase operating costs.
- Exhaust emissions and noise can cause environmental pollution.

  (Brinkmann, 2011)

3.2.2 Production of RTGs

Table 5 shows RTG-TTU moves per hour. The data was collected on 31 August 2014 at 5:51AM. If a comparison is done with the data collected in Table 6 (SC production) you will notice the rate of production for RTGs far exceeds that of SCs.

Table 5: EC statistics report

Moves by CHE and Hour of Day (ALL)

che	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	ttl	m/hr	adj m/hr
RTG1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	8	6	18	3.0	-
RTG10	4	6	1	3	8	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	6	52	6.5	-
RTG11	-	-	5	12	1	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	8	7	43	6.1	-
RTG12	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	10	26	8.7	-
RTG14	2	8	3	2	9	2	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	4	11	7	49	4.9	-
RTG15	13	-	4	10	6	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	8	45	6.4	-
RTG17	11	4	6	9	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	9	4	49	5.4	-
RTG18	1	2	-	3	5	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	12	11	48	6.0	-
RTG19	5	9	11	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	35	7.0	-
RTG2	7	4	6	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	11	42	7.0	-
RTG20	15	12	19	12	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	7	87	12.4	-
RTG21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	9	19	9.5	-
RTG22	14	-	7	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	7.3	-
RTG4	9	14	5	14	10	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	27	4	97	10.8	-
RTG5	9	14	9	5	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	12	63	7.9	-
RTG8	26	17	25	17	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	16	19	125	13.9	-
RTG9	5	5	2	1	17	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	11	4	61	6.8	-

RTG-TTU moves per hour

Source: Transnet National Ports Authority (2013)

3.3 Evaluation of current container handling infrastructure between the quay and stack area – Pier 2

3.3.1 Pier 2: SC operation

Figure 11 shows a typical layout of a pure SC system which Pier 2 has adopted.

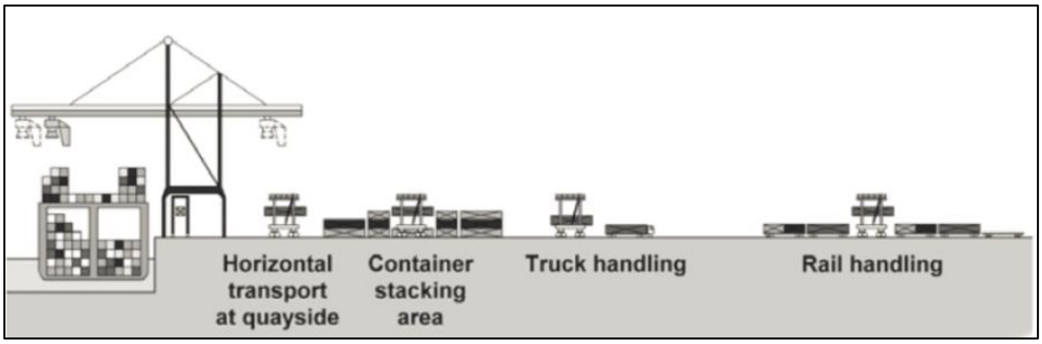


Figure 11: Typical layout of a pure SC system
Source: Böse (2011)

Advantages of SCs

- Improved utilization of land area for container stacking.
- Able to cope with high traffic volume of the future.
- Less spares to stock since only one type of equipment is used.
- Fewer personnel are required to operate the equipment.
- Much smaller wheel load.
- Greater manoeuvrability, visibility and ease of operation.

Disadvantages of SCs

- SCs collided with private trucks during loading and offloading of containers.
- They collide with each other (proving they have very poor visibility).
- SCs were a high priority when it came to safety concerns. Incidents vary from damaging of property to SCs overturning.
- Breakdowns are very common and the maintenance cost is extremely high. The terminal spends an average of 52 million rand on a yearly basis for maintenance only.
- Designated parking areas have to be assigned to SCs which poses an environmental hazard due to oil leaks and grease messing the parking areas.
- High area requirement in comparison to yard cranes as a result of lower stacking.
- Height and a large proportion of traffic (within the yard area).
- When travelling distances are far, SCs are not the first choice as they are considerably slower compared to TTUs, and more costly.
- SC workshops are required to carry out repairs.

Production of SCs at Pier 2

In this study SC production was monitored on the 28 August 2014 at Pier 2 and the data collected is displayed in Table 6. The weather was fairly good and it was observed that the highest number of boxes moved per hour was approximately 10 boxes/hour. This value is obtained by taking the highest total movement of boxes (76) divided by 7.75 hours. The data collected was then plotted on a graph to give an overview of the time wasted per straddle (Figure 12) and the total moves per straddle for that particular shift (Figure 13). It is clearly depicted that time wasted per straddle is substantially high compared to total moves per straddle. This could be caused by a number of factors such as poor pavement surfaces or fatigue.

Table 6: Production for a single shift

SC Name	Total Time Wasted	SC Name	Total Movements / 7.75hrs	SC Name	No of Yard Shift / Straddle	First Lift
SC133	00 Hrs:10 min	SC133	30	SC133	6	2014/08/28 16:52
SC102	00 Hrs:52 min	SC102	44	SC102	8	2014/08/28 14:42
SC125	01 Hrs:51 min	SC125	11	SC125	11	2014/08/28 17:10
SC136	00 Hrs:24 min	SC136	35	SC136	7	2014/08/28 16:08
SC137	01 Hrs:21 min	SC137	59	SC137	11	2014/08/28 14:53
SC140	01 Hrs:10 min	SC140	59	SC140	14	2014/08/28 14:47
SC141	01 Hrs:26 min	SC141	48	SC141	9	2014/08/28 14:42
SC143	01 Hrs:19 min	SC143	53	SC143	5	2014/08/28 14:59
SC144	01 Hrs:55 min	SC144	31	SC144	3	2014/08/28 17:24
SC145	02 Hrs:14 min	SC145	10	SC145	3	2014/08/28 14:48
SC68	01 Hrs:30 min	SC68	58	SC68	9	2014/08/28 14:50
SC70	01 Hrs:05 min	SC70	45	SC70	7	2014/08/28 14:43
SC72	00 Hrs:29 min	SC72	26	SC72	4	2014/08/28 18:07
SC79	00 Hrs:40 min	SC79	76	SC79	11	2014/08/28 14:47
SC80	01 Hrs:33 min	SC80	66	SC80	8	2014/08/28 14:33
SC82	01 Hrs:22 min	SC82	47	SC82	10	2014/08/28 14:41
SC84	01 Hrs:23 min	SC84	6	SC84	6	2014/08/28 15:14
SC86	01 Hrs:17 min	SC86	47	SC86	9	2014/08/28 14:39
SC91	01 Hrs:33 min	SC91	50	SC91	9	2014/08/28 14:52
SC92	02 Hrs:08 min	SC92	55	SC92	10	2014/08/28 15:21
SC99	00 Hrs:52 min	SC99	56	SC99	16	2014/08/28 14:41
SC105	01 Hrs:32 min	SC105	48	SC105	3	2014/08/28 15:14
SC131	01 Hrs:23 min	SC131	62	SC131	11	2014/08/28 14:35

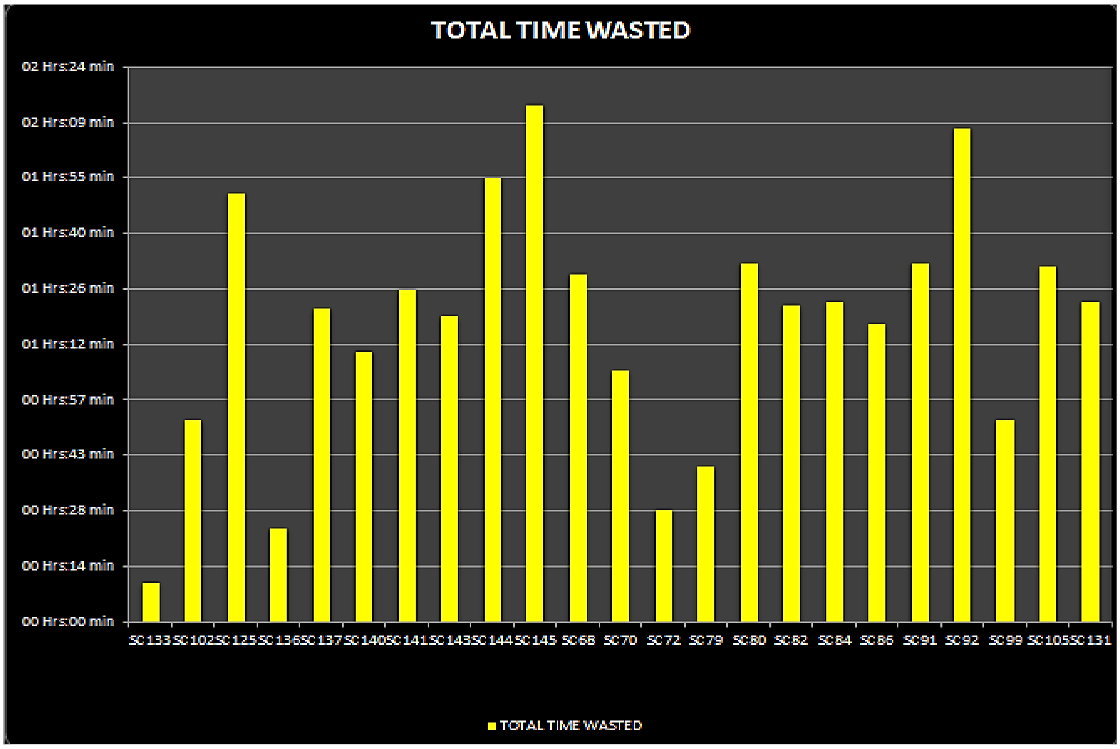


Figure 12: Total time wasted per straddle for that shift

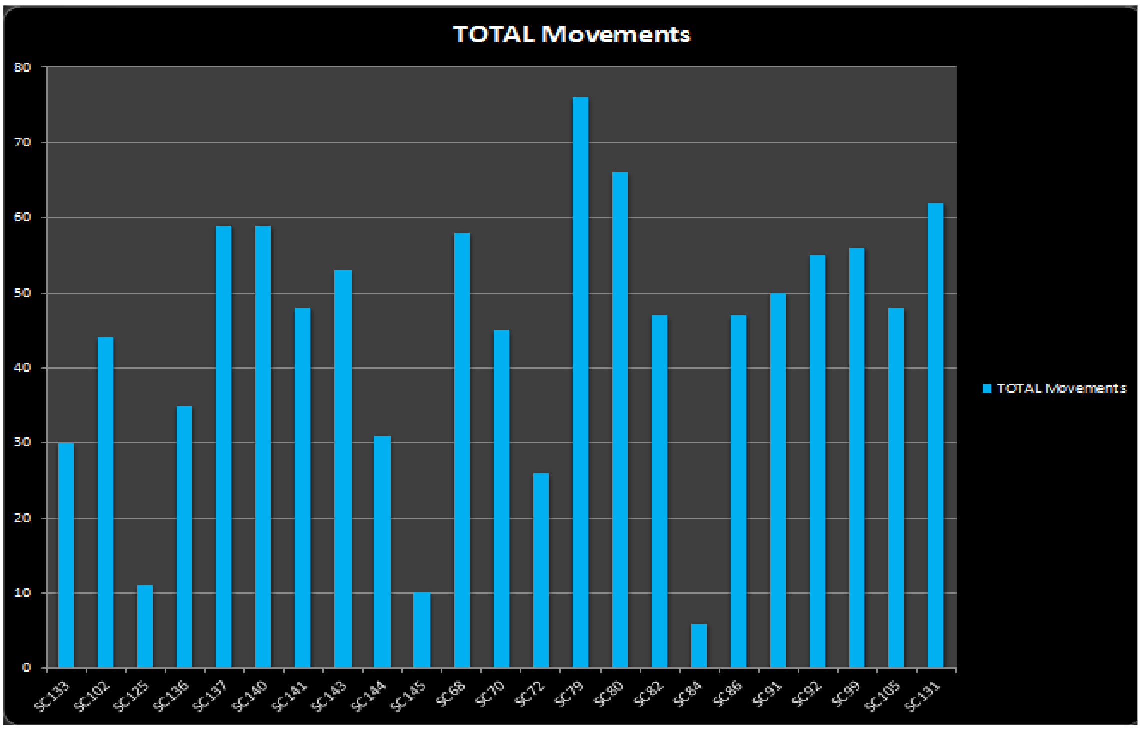


Figure 13: Total moves per straddle for that shift

3.4 Cost analysis of purchasing and maintaining RTGs and SCs

Table 7 provides an estimate of the cost to operate SCs and RTGs per hour. You will notice the cost to operate the RTG is slightly higher than a SC however the outputs in adopting the RTG system are much more efficient as shown in Table 5.

Table 7 gives an approximate labour cost to operate the RTG and SC. Table 8 gives an approximate cost of purchasing a RTG as compared to a SC. As much as the costs to purchase a RTG are higher, the maintenance cost for a SC (as shown in Table 9) is quite substantial compared to RTGs.

Table 7: Labour costs

	Manning per equipment hour	Labour costs provided per hour (ZAR)
Quay Crane (STS)	2.28 (2)	116.9 (Pier 2)
SC (1 over 3)	2.36 (2)	103.4 (Pier 2)
RTG (eco)	2.36 (2)	149.8 (Pier 1)

Source: Urban-Econ (2012)

Table 8: Purchase cost

	Purchase costs provided by Transnet		International benchmark	relative difference
	(ZAR)	(euro)	(euro)	(%)
STS – single hoist	75,000,000	6,250,000	6,250,000	0%
STS – tandem hoist	100,000,000	8,300,000	8,300,000	0%
SC (1 over 3)	9,500,000	790,000	750,000	5%
RTG (eco)	17,000,000	1,400,000	1,350,000	4%

Source: Urban-Econ (2012)

Table 9: Maintenance cost

	Maintenance costs provided by Transnet		International benchmark	relative difference	Maintenance costs assumed for Transnet situation	
	(ZAR/hr)	(euro/hr)	(euro/hr)	(%)	(euro)	(ZAR)
Quay crane (STS)	1,280	106.7	95	4%	106.7	1,280
SC (1 over 3)					31.1	373
RTG (eco)	215	17.9	16	7%	17.9	215

Source: Urban-Econ (2012)

3.5 Conclusion and recommendations

It is quite evident that RTGs are much more beneficial to be used as container handling infrastructure rather than SCs. The outputs presented, advantages and disadvantages as well as cost comparisons, all favour RTGs as a preferred option for DCT.

CHAPTER 4 – AUTOMATION OF DCT

4.1 Introduction

Increasing the automation level of a terminal with products that automate a single part of the operation or the whole process is recognised as the next step towards improving performance at today's container terminals. The benefits of automation include lower operational costs as well as improved terminal productivity, capacity, safety and security. Automating an existing SC terminal is a complex project that requires deep expertise, careful planning, a capacity for wide-ranging systems integration and the ability to consider numerous factors beyond technical implementation. Besides the actual automated system, there is also extensive change management within the entire organisation of the terminal, as operating an automated terminal requires a thorough change of business processes as well as different skill sets for the people operating the terminal (Alho, et al., 2012).

ASCs are suitable for the same types of terminals as manual SCs (Figure 14). The main reasons to choose a SC setup compared to other terminal concepts include flexibility and simplicity. There are currently 113 manually handled SCs that are in operation at Pier 2. In a SC terminal, a single machine handles both stacking and horizontal transportation. Other horizontal transportation concepts, such as those built around Automated Guided Vehicles (AGVs), will always need another machine to stack the containers and load landside transport vehicles. A SC terminal can adapt easily to changes in terminal throughput. Excess machines are automatically parked away when not needed, and more equipment can be added on demand (Alho, et al., 2012).

An ASC terminal offers several clear advantages over a traditional manual SC terminal. The most immediate and most easily quantified gain is significant savings in terminal operating expenses such as labour and maintenance costs. Other direct benefits include increased efficiency, more predictable operations, higher availability, significantly improved occupational safety, better site security and longer equipment life spans. An often-heard remark from people seeing an automated terminal for the first time is how smooth the operation seems. No aggressive driving is seen, no containers are banging on the ground, and everything proceeds in a steady, systematic fashion. In an automated terminal, horizontal transportation and lifting equipment is always handled optimally. Collisions due to human error and unplanned repair tasks are eliminated (Alho, et al., 2012).

Automated equipment also conserves resources and contributes to the sustainability of resources. Significant fuel savings are realised through optimal driving patterns, a reduced need for air-conditioning, and consistent implementation of engine stop functionality during equipment idle time. An automated terminal also requires less lighting in the yard, which decreases power consumption and reduces the environmental impact of operations (Alho, et al., 2012).

Figure 14: ASC system
Source: Alho, et al. (2012)

4.1.1 Terminal implications

The time required for the conversion of a manual SC terminal to automated operation depends greatly on the specific design, needs, operational environment and business goals of the terminal. However, a typical timeframe for an automation conversion project can be 12 to 18 months (Alho, et al., 2012).

When planning the conversion timeframe, a key consideration is whether to optimise for maximum testing of new systems or for the swift adoption of the new processes and organisational culture required by automated operations. A slower transition will enable more thorough technical testing and training of operational personnel, but a quicker transition may be preferable for organisational reasons (Alho, et al., 2012).

In any automation project, a key priority is carrying out the conversion with minimal disruption to the existing operations of the terminal. This requires careful advanced planning as an automated SC terminal typically needs to be automated in one go. The transition will also likely require changes to the terminal layout and operating procedures. The procedures for STS operation, landside interface and reefer operation would be changed completely. Alternative processes may need to be introduced also to handle non-standard cargo that cannot be taken into the automated area, as well as for empty container handling. Change management of the workforce needs to be taken into account from the very beginning (Alho, et al., 2012).

The professional profile of the people operating and managing automated equipment will be markedly different from the staff running a manual terminal. Completely new skill sets are needed, and maintenance standards will need to be thoroughly revised (Alho, et al., 2015).

4.1.2 Infrastructure

An automated conversion will require changes to the entire infrastructure of the terminal. These changes need to be planned from a wider perspective, not just focusing on the horizontal transportation equipment. Areas to consider include:

- Terminal layout changes;
- Fencing, safety infrastructure, access control;
- Navigation infrastructure for the SCs;

- Automatic/manual interchange points (waterside interface, truck and rail handovers, maintenance areas, empty container interchange, handling of reefers);
- IT environment and wireless networks; and
- Yard lighting.

(Alho, et al., 2012)

The number one issue in an automated terminal is maintaining strict separation between automated operations and areas in which people work, and designing safe interfaces between the two. All non-standard cargo that requires manual handling has to be kept out of the automated operating area (Alho, et al., 2012).

When handling exceptions, for example, strict safety protocols must be developed for all activities that involve people moving in the same area as the horizontal transport equipment. Particular attention needs to be devoted to the establishment of safety procedures and access control in areas with mixed auto/manual operations (maintenance, refuelling, washing, reefers, etc.) (Alho, et al., 2012).

In a typical container terminal, the various facilities are spread out across the site, either by original design or simply due to the organic growth and evolution of the terminal over several years. In an automated terminal, all facilities requiring mixed auto/manual operation will need to be sited at or relocated to the perimeter of the automated zone, in order to keep the automated area to a practical shape and guarantee smooth access of people to the area without disturbing other operations. Access control, safety systems and physical fencing for these functions need to be considered when planning the automation conversion (Alho, et al., 2012).

4.1.3 Wireless infrastructure

An automated terminal will require navigation infrastructure for the automated equipment. Typically, this will be either radar beacons installed on lighting towers and buildings around the site, or magnetic markers embedded in the yard pavement.

Accurate and reliable position measurement for STS cranes also needs to be considered (Alho, et al., 2012).

4.1.4 Software integration

Automated equipment is only as good as the software controlling it. To obtain the desired performance from automated horizontal transport equipment, the terminal's Enterprise Resource Planning (ERP), Terminal Operating System (TOS) and other systems must be up to the task, and designed to seamlessly fulfil the required business processes while providing efficient ways to handle exceptions (Alho, et al., 2012). Figure 15 shows a typical ASC and the features it comprises of.

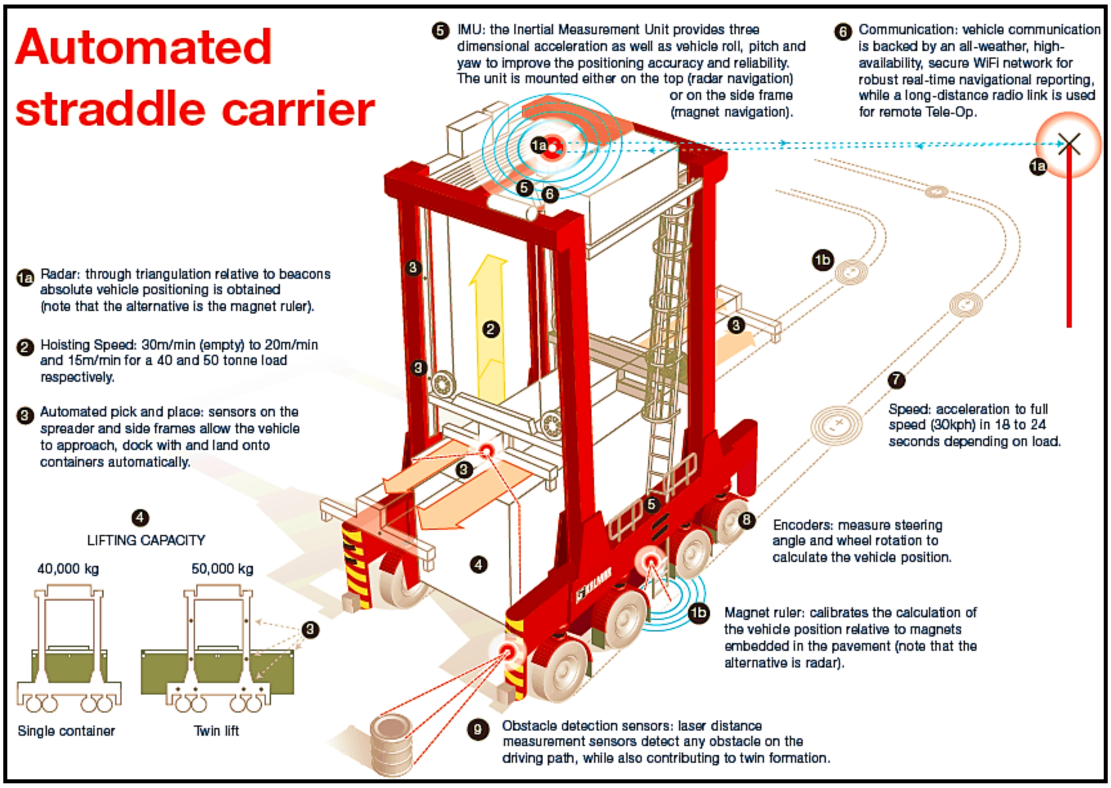


Figure 15: Automated SC
Source: (Alho, et al., 2012)

4.1.5 Safety and security

Safety is always paramount in any terminal operation. Automated terminals provide significant improvements in occupational safety by keeping people out of the operating area of moving heavy machinery. From the safety perspective, a SC terminal is relatively easy to automate since there are no manual truck lane operations as with an RTG terminal. However, in addition to infrastructure and terminal layout considerations, a different kind of safety mind-set will need to be instilled throughout the workforce. Adoption of safe working procedures for accessing the automated area is required. Employees will also need to be trained locally – a safety handbook in English is not enough. Furthermore, automatic driving eliminates collisions and accidents in the container yard, which will decrease the insurance premiums of the terminal.

Automated terminals improve the security of both cargo and personnel thanks to automated container handling and location tracking of all containers. Containers are not accessible by people in the automated zone and cannot be set down in unauthorised areas. Increased security contributes to customer trust and terminal competitiveness while reducing financial losses (Alho, et al., 2012).

4.1.6 Maintenance manual

Horizontal transportation systems will work even if the equipment is not in perfect condition, since human operators can usually compensate for the quirks and deficiencies of each individual piece of equipment. By contrast, automated equipment always needs to be in 100% working condition to deliver its full potential. This requires a major change in attitude for maintenance operations. With automated operations, the emphasis shifts to more frequent preventive maintenance. However, as this maintenance is usually done at planned intervals, the caused impact to the operation is minimal. As collisions and other accidents due to human error are eliminated, the need for ad hoc repairs is also reduced dramatically, bringing cost savings in the long term (Alho, et al., 2012).

4.1.7 Automating existing equipment

The actual automation of most SCs of recent models is relatively straightforward. Electric or hydraulic steering is controlled by on-board automation systems instead of from the cabin, while sensors and data links are added for control, monitoring and system diagnostics. In any automation project, third-party or mixed fleets can create challenges in, for example, the division of responsibility in maintenance questions, access to proprietary system data, as well guaranteeing performance levels for yard equipment. The best automation solution will always be based on the needs of the customer, but working with a fully integrated system from a single vendor – and upgrading the SC fleet when necessary – is often the most cost-effective solution for the terminal in the long run (Alho, et al., 2012).

4.2 Automation verses NDP

The industry move to automate is being driven primarily, though, by the need to efficiently handle big ships. This requires a step up in innovation. Increasing the automation level of a terminal with products that automate a single part of the operation or the whole process is recognised as the next step towards improving performance at today's container terminals. The benefits of automation include lower operational costs as well as improved terminal productivity, capacity, safety and security. Besides the actual automated system, there is also extensive change management within the entire organisation of the terminal, as operating an automated terminal requires a thorough change of business processes as well as different skill sets for the people operating the terminal. The biggest hurdle though is embedding this concept in SA ports, considering the fact that SAs NDP stipulates that government's desire to increase employment from 13 million in 2010 to 24 million in 2030 (National Planning Commission, 2012).

SA belongs to its entire people and the future of the country is a collective future. Making it work is a collective responsibility. All South Africans seek a better future for themselves and their children. The NDP is a plan for the country to eliminate poverty and reduce inequality by 2030 through uniting SA, unleashing the energies of its citizens, growing an inclusive economy, building capabilities, enhancing the capability of the state and leaders working together to solve complex problems (National Planning Commission, 2012).

Terminals, like DCT, that handle 1 million 20-foot container units, or more, per year must provide consistent, reliable and uninterrupted performance. However, as the day wears on, productivity can erode somewhat due to fatigue or other factors. An automated crane may do 30 moves per hour, but will perform at that level throughout the day. Unlike traditional quay cranes, in which the operator bends over and looks down at the containers as they are lifted off and on the vessel, the automated crane is operated remotely from the tower. The operator oversees the operation in front of a computer, and vision is not distorted by wind, rain or fog (National Planning Commission, 2012).

The biggest concern when implementing automated infrastructure at the POD is whether or not SA is ready to handle the new technology and how will this implementation affect the NDP's aim to create more jobs. An easily overlooked aspect of terminal automation is that it is in fact more of a cultural than technical issue. Whether creating a new automated terminal or converting a manual terminal to automated operation, change management is crucial. Equipment upgrades are usually planned carefully, but people-related issues are quite often overlooked, even though human behavior takes more time to adapt. Change is inevitable, so the question is how to manage it now (National Planning Commission, 2012).

4.2.1 The objectives of the NDP

- Increase employment from 13 million in 2010 to 24 million in 2030.
- Produce sufficient energy to support industry at competitive prices, ensuring access for poor households, while reducing carbon emissions per unit of power by about one-third.
- Interventions to ensure environmental sustainability and resilience to future shocks.

- Boost private investment in labour-intensive areas, competitiveness and exports, with adjustments to lower the risk of hiring younger workers.
  (National Planning Commission, 2012)

According to the NDP, in 2030 the economy should be close to full employment, equipping people with the skills that they need, ensuring that ownership of production is more diverse and able to grow rapidly, and providing the resources to pay for investment in human and physical capital (National Planning Commission, 2012).

4.2.2 Automation requirements

The most significant and immediate cost savings from automation are due to the drastically smaller number of operators required. For example, fleets of dozens of SCs can be handled by only a few highly skilled operators. Automation is where information technology meets engineering. In a traditional manual terminal, these are typically two separate teams that have little contact with each other. With an automation rollout, they need to start cooperating and form a joint team in which the skills and responsibilities of the people match each other and mutual responsibilities are clearly defined. An automated terminal requires a significantly different profile of employees.

Remote operation and exception handling are an integral part of automation that enables people to be separated from machines and moved from a dangerous and harsh working environment to the safety and comfort of a control room. The remote operation also creates an attractive working environment for the next generation of port staff and reduces absence (Henriksson, n.d.).

The terminals are run by a team of motion, logistics and maintenance specialists who handle the planning and manage exceptions together (Annala & Pettersson, 2015). A different level of maintenance engineer skills is also required for the stricter maintenance standards of automated equipment. In addition, automated operations will require new, different skill sets in several other areas, including:

- Data and fact-based usage and analysis compared to operators reporting faults in equipment;
- Data mining;
- Understanding the operating principles of automated equipment and systems;
- Competence in measuring and sensor technology that replaces the human senses; and
- Systematic planning of operation and maintenance work.

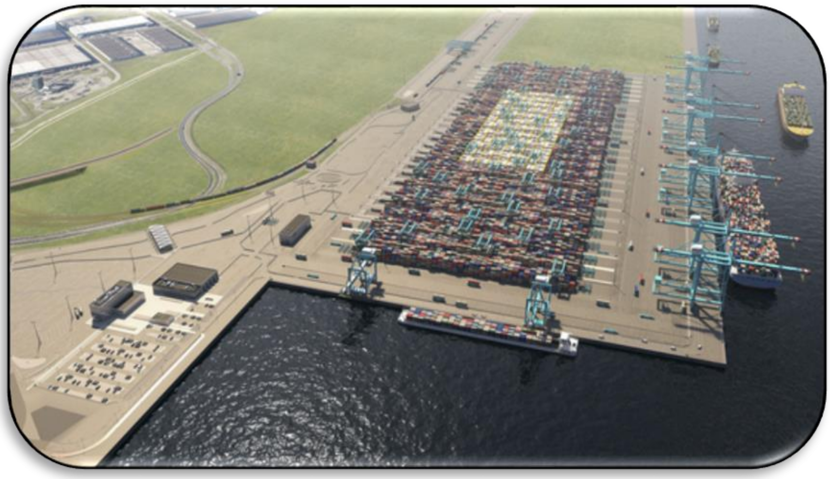


Figure 16: Fully automated terminal in Maasvlakte II Container Terminal
Source: Churchill (2014)

APM Terminals' Maasvlakte II (MVII) container terminal in Rotterdam has constructed a fully automated terminal (Figure 16). It was officially opened in April 2015. About 300 people work at MVII, almost all of them outside the container yard. And of the 74 machines in the yard, 63 run on their own with no human intervention. There are 26 rail-mounted gantry cranes that manage the container stacks with the computer systems sending them specific tasks throughout the day (Churchill, 2014). The STS are operated remotely using a joystick and multiple viewing screens where cameras mounted on the cranes provide different viewing angles (Figure 17). The terminal's equipment is powered by wind generated electricity for zero carbon emissions (Barnard, 2015).

Figure 17: Remotely controlling Ship-to-Shore cranes
Source: Barnard (2015)

New jobs that will need to be outsourced or insourced include automation system specialists; system optimisation engineers; IT system service and maintenance professionals; and instructors for internal staff and external parties. On the other hand, significantly fewer employees will be required for basic container operation and traditional maintenance tasks. Conditions, legislation and industry labour norms differ greatly from geography to geography. In many locations, limited availability of skilled personnel – even at competitive salaries – can also be a challenge. Automation resolves this issue, but also changes the profile and structure of the terminal staff. Successful change management requires an open dialogue with all relevant parties. Human resources need to be taken into account from the beginning. Automation provides new job opportunities, but also places additional demands on the workforce. The significant workforce impact of automation needs to be considered and planned carefully, working in cooperation with local labour organisations and other stakeholders (Barnard, 2015).

The procedures for STS operation, landside interface and reefer operation will be changing completely. Alternative processes may need to be introduced also to handle non-standard cargo that cannot be taken into the automated area, as well as for empty container handling. Change management of the workforce needs to be taken into account from the very beginning. The professional profile of the people operating and managing automated equipment will be markedly different from the staff running a manual terminal. Completely new skill sets are needed, and maintenance standards will need to be revised thoroughly (Alho, et al., 2012).

An often overlooked or underestimated fact is that automation is first and foremost a major culture change in how a terminal operates. For an automation deployment to be successful, managing this culture change is more crucial than the technical implementation. The job profile of the workforce will be transformed, a new maintenance approach is required, IT and engineering operations will need to converge, and business processes will need to be mapped and planned more carefully than before. Whether creating a new automated terminal or converting a manual terminal to automated operation, change management is critical (Alho, et al., 2012).

Eliminating human error is one of the main benefits of an automated system. The result is a marked improvement in workplace safety (Alho, et al., 2012).

Benefits of automation

- Fully automated infrastructure can operate all day, every day and cut labour costs. The unmanned automated infrastructure can operate 24/7 in almost any weather conditions, ensuring smooth flow of cargo and significant cost savings (Alho, et al., 2012).
- Unstaffed operations cut labour costs in the terminal. Machine hours are minimised by employing automatic shutdown, which reduces idle time costs to zero. Additionally, as automated operation do not require night-time lighting, energy savings in a 40-hectare terminal can be significant (Alho, et al., 2012).
- Safety is always paramount in any terminal operation. Automated terminals provide significant improvements in occupational safety by keeping people

out of the operating area of moving heavy machinery. Collisions and other accidents due to human error are eliminated (Alho, et al., 2012).

- The quay and yard cranes can be electric, which means zero emissions and no noise. The electricity can be generated locally by wind. The cranes also generate power on the downward cycle of the crane movement (Barnard, 2015).
- Reduce and possibly eliminate strike action. On 16 August 2012, SA saw the most gruesome killing of workers post-apartheid in Marikana during the Lonmin mineworkers' illegal strike. Thirty-four mineworkers were gunned down by police in what will go down in history as the 'Marikana massacre'. Demonstrators were calling for salary hikes from about US$ 500 (ZAR 4,000) to US$ 1 500 (ZAR 12,500) among other grievances of better working and living conditions and lack of concern for workers by management (Dhliwayo, 2012).
- An automated terminal also requires less lighting in the yard, which decreases power consumption and reduces the environmental impact of operations.

Disadvantages

- Unfortunately, automation is dreadfully expensive. In order to justify such an investment, container throughput is key. It is difficult to estimate how much volume is needed to achieve an adequate return on investment for automated terminals around the world because operating conditions and labour costs vary, but in countries with higher labour costs, such as SA, a throughput of at least 1 million TEUs a year is required (Alho, et al., 2012).
- Manual systems will work even if they are not in perfect conditions, since human operators can usually compensate for the quirks and deficiencies of each individual piece of equipment. To deliver their full potential, automated equipment and the entire system always need to be in 100% working condition.

4.3 Conclusion and recommendations

Automation provides new job opportunities, but also places additional demands on the workforce. There are very few prospects for growth in employment in the country in the near future as the World Bank has further lowered the economic growth estimates in 2012 from 3.1% to 2.5%. This is not good news for SA as the high unemployment rate may lead to civil unrest which will deter investment and further cripple the economy. SA has an unemployment crisis at hand that threatens to cripple the Rainbow Nation. The unemployment rate in the second quarter of 2012 was 24.9% with a labour absorption rate of 40.9%. No other middle-income country has such an unprecedented rate of unemployment (Dhliwayo, 2012). With the Eskom crises the electricity demand on automated infrastructure will be ridiculously high.

Labour savings cannot be denied as a number of longshore jobs are eliminated due to automation. The Port of Los Angeles released a study that said automation at the TraPac terminal will eventually reduce jobs by 40 to 50 percent (Mongelluzzo, 2014). As warehouse workers have become operators of automated warehouses, and engine mechanics have become engineers who can calibrate integrated sensor systems, so will port workers need to become skilled professionals in SA with sophisticated automated systems. The SA Government has been promising to create jobs since 1994 but the Government cannot sustainably provide jobs and this should not be its mandate. The implementation of the Growth, Employment and Redistribution (GEAR) strategy in 1999 failed to bear fruit in the labour market until 2003 when labour absorption began to increase but progress was deterred with the beginning of recession in late 2008 as job losses increased. Instead, Government should focus on providing an environment that encourages entrepreneurship and job creation (Dhliwayo, 2012).

SA has an education system that has been heavily criticised for being below standard and a for lack of skills development. In the 2012/2013 Global Competitiveness Report by the World Economic Forum, SA was ranked 140 out of 144 countries in the quality of educational system category. This has resulted in the creation of a large uncompetitive labour force that becomes structurally unemployed (Dhliwayo, 2012).

The long-term benefits of automation are clearly evident, but these benefits come with widespread changes that will need to be addressed in a comprehensive way. Automation is the answer to boost efficiencies at the port, however the present issues in SA like unemployment and education must first be addressed as automated operations require radically different skill sets compared to traditional terminals.

CHAPTER 5 – CONTAINER TERMINAL PAVEMENT EVALUATION

5.1 Introduction

Based on the preceding chapters, it was concluded that there would be a great advantage if DCT switches over to RTG. In this chapter different scenarios were evaluated, considering single/twin lift SC and RTG as options.

- Scenario 1: Current operation using single lift SCs and 3-high row stacking;
- Scenario 2: Mixture of single and twin lift SCs and 3-high row stacking;
- Scenario 3: RTG operation, stacking in blocks and 5 high; and
- Scenario 4: RTG operation, stacking 3 high (as a possible interim strategy).

An evaluation of the concrete container pavement facility of the DCT, Pier 2 at Berths 108 and 109 was conducted. This represents an area of approximately 300 000 m². During this exercise, available testing data and interpretation of all available data regarding the structural capacity of the existing facility under current loading conditions as well as under projected loading conditions, was assessed. In addition, the need for structural improvement was investigated. An evaluation of the structural capacity of the concrete pavement facility in the area of Berths 108 and 109 as well as the area west of Berth 109 was conducted.

A visual assessment for Berths 108 and 109 was conducted to determine the percentage of structurally defective slabs. A further investigation was carried out on possible reasons for panel failures, and recommendations were made based on past experience at the port. Previous projects that were executed at the port were referred to. Historic Thickness Data, together with 35 cores and Ground Penetrating Radar (GPR) test results were obtained from an outsourced company and analysed. Design load calculations were carried out using various scenarios for SCs and RTGs. Traffic wheel load repetitions were obtained from (Transnet Limited, 2011) to determine traffic loading estimates for straddle way traffic and traffic estimates for stacked areas. After analysing this information the daily repetitions of the design wheel load was used to express the capacity or life in terms of years. A quasi-static loading regime was investigated in order to express container stacking capacity in terms of years. The calculations are based on the assumptions provided and do not include any factors to account for highly channelized movements. The structural capacity for handling plant was investigated using the traffic loading estimates. Analyses were performed at both 85% and 95% reliability levels, and Condition Factor (CF) and Flexural Strength (FS) approaches were used. Typical restoration techniques that were adapted from (Knapton, 2007) were presented to indicate the type of repairs that can be carried out. The British Port Association (BPA) Manual for The Structural Design of Heavy Duty Pavements for Ports and Other Industries, 4th edition (referenced in this study as Knapton, 2007) was used extensively for the calculations.

In this chapter options such as overlays and reconstruction was explored and thereafter a cost estimate exercise was carried out.

5.2 Background

5.2.1 Location and referencing

DCT, Pier 2, is located in the central area of the Durban Harbour. Figure 18 is a satellite image (courtesy of Google Earth) of the harbour area showing the boundary of the evaluation area.

Because the terminal was constructed and upgraded in different portions at different times, with limited availability of as-built information, the methodology adopted in this study focussed on evaluation of short subsections rather than construction sections. Selection of the survey route was based on a practical layout and stacking considerations. Table 10 summarises the stacks and survey routes with approximate survey lengths representing the different facilities. The stack codes are used by DCT for operational planning and the survey routes were selected for referencing during this investigation. Figure 19 shows the location of the stacks and survey routes.

Figure 18: Project location and project boundary

Table 10: Referencing and representativeness of evaluation

Stacks	Stack Survey Lengths (m)	Survey Route/ Travel Ways	Survey Route Length (m)
RR2	203	A	107
JJ5	220	B	126
HH5	233	C	163
HH6	116	D1	141
GG5	209	E	162
M10-12	117	F	125
		D2	125
FF5	203	G	250
FF6	122	N	161
		D3	127
		H	249
EE6	64	J	353
888 (M)	101		
178	75		
ED1	320	O	207
ED2	241	P	240
EC1	267	Q	211
EC2	100	R	181
		S	196
Total for stacks	**2,591 m**	**Total survey route**	**3,124 m**
Approximate total representative length of all facilities surveyed			**5,715 m**
Note: Aggregations of stacks and survey routes only used in this table to indicate relative vicinity of measurements and do not necessarily represent subsections used for data analysis			

5.3 Pavement condition assessment

5.3.1 Visual assessment

As part of the fieldwork, a visual assessment was performed. All survey routes and selected stack rows were visually inspected. For survey routes (essentially travel ways) visual data were sampled two slabs wide, while two different rows (approximately one slab width each) were sampled in stacks. The location and extent of survey routes and stacks are furnished in and Figure 19 and Table 11. During the assessment, defects exhibited by slabs within the defined sampling arrangement were noted and analysed, with the main objective being to determine the percentage of structurally defective slabs. In general, the condition of slabs can be classified as good, fair or poor based on the criteria described in Table 11. Table 11 summarises the overall visual condition of the subsections evaluated. Figures 20 to 22 are photographs which illustrate the appearance of good, fair and poor. Based on this data, the Berths 108 and 109 area is generally in a good to fair condition, while the area east of Berth 109 is in a visually fair to poor condition.

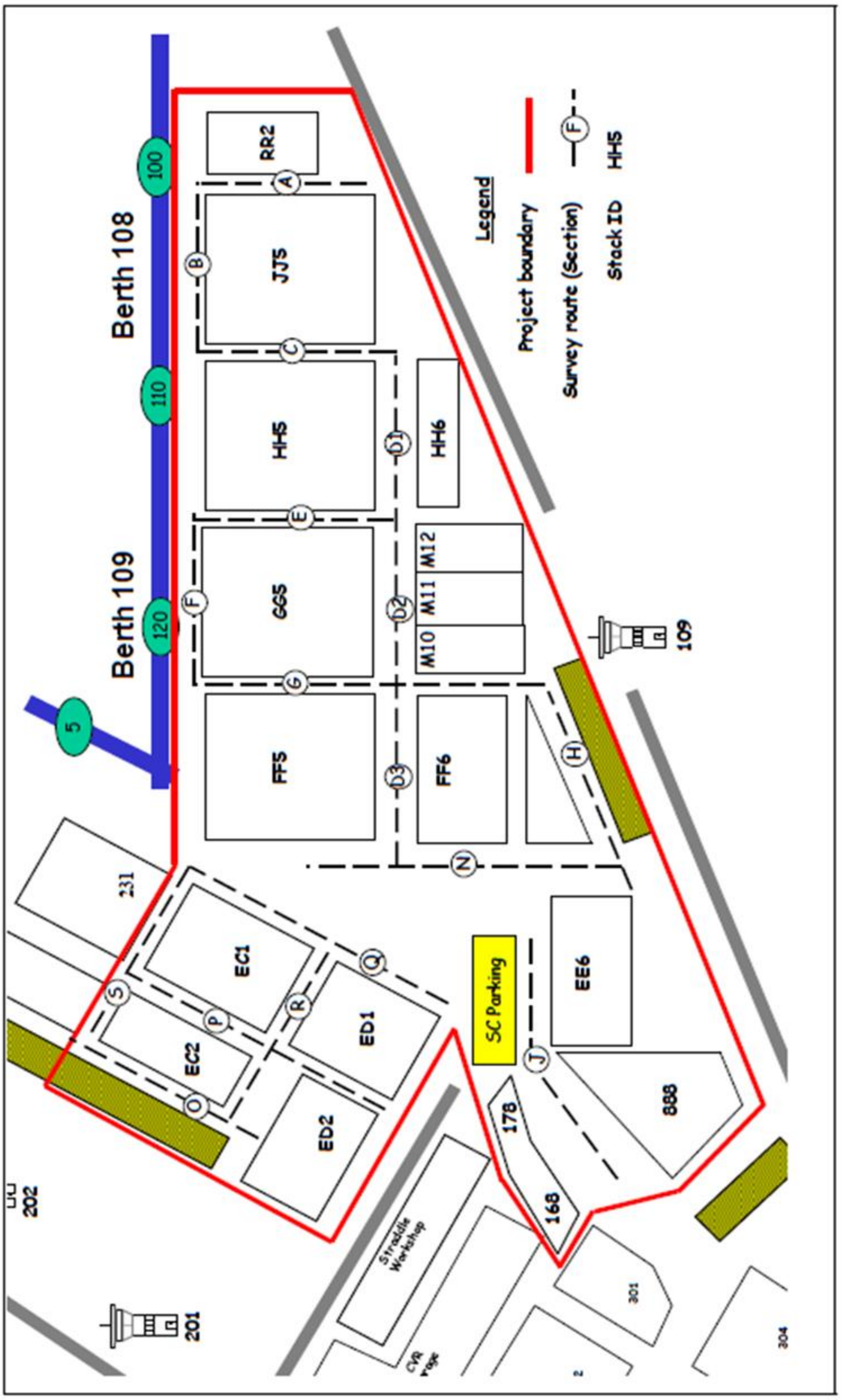


Figure 19: Detailed stack layout

Table 11: Visual condition summary

Survey Routes					Stacks				
Section	Good	Fair	Poor	Rating	Section	Good	Fair	Poor	Rating
A	24	26	50	POOR	RR2	93	5	3	GOOD
B	83	13	4	FAIR	JJ5	80	12	8	FAIR
C	83	10	5	FAIR	HH5	76	12	12	FAIR
D	78	14	8	FAIR	HH6	100	0	0	GOOD
E	94	2	4	GOOD	GG5	77	20	2	FAIR
F	100	0	0	GOOD	M10-12	100	0	0	GOOD
G	86	14	0	FAIR	FF5	100	0	0	GOOD
H	92	8	0	GOOD	FF6	100	0	0	GOOD
J	89	11	0	FAIR	EE6	100	0	0	GOOD
N	82	12	6	FAIR	178	100	0	0	GOOD
O	55	20	25	POOR	888	100	0	0	GOOD
P	74	10	15	POOR	ED1	56	40	4	FAIR*
Q	76	12	12	FAIR	ED2	68	32	0	FAIR*
R	64	7	30	POOR	EC1	59	35	6	FAIR*
S	59	14	27	POOR	EC2	59	35	6	FAIR*
Note:* Since the percentages imply that more than 30% of the slabs will require either localised repairs or routine maintenance, a POOR rating may be waranted.									

GOOD: No visible cracks or cracks less than 2 mm aperture (Figure 20). No, or only minor spalling along panel edges not affecting the riding surface. Joint seal in good condition.

Figure 20: Good – no visible cracks or cracks with less than 2mm aperture

FAIR: Cracks with apertures between 2 mm and 10 mm (Figure 21). Spalling along panel edges to a depth in the order of 50 mm to 100 mm resulting in a locally uneven riding surface. Joint seal either damaged or non-existent. The condition suggests localised repairs/partial slab replacement and/or routine maintenance.

Figure 21: Fair – cracks with aperture between 2 mm to 10mm

POOR: Cracks with aperture greater than 10 mm and panels with a general appearance of being completely broken into independent pieces (shattered slabs) (Figure 22). Spalling to a depth greater than 100 mm. The condition suggests slab replacement.

Figure 22: Poor – cracks with aperture greater than 10 mm

5.4 Investigation into the reasons for panel failure in DCT Pier 2

Concrete panel failure in the vicinity of the stack area can pose serious safety risks for SC drivers. An investigation into the reasons for panel failure in DCT was carried out during various pavement rehabilitation projects and is presented in this chapter. The results were analyzed, conclusions reached, and recommendations were made.

The existing pavement throughout the terminal is in-situ, unreinforced concrete slab, generally 375 mm deep. Much of the paving has been in use for 35 years and is at or near the end of its design life. The paving is drained by continuous slot drains, generally running the length of the terminal. Pavement rehabilitation is ongoing at DCT. The most recent pavement rehabilitation project entailed 585 panels that needed to be demolished, 68 654 m of joint sealing, 695 partial repairs and 3 850 m of slot drain cleaning. Data was collected from this project as well as previous projects to identify various causes of panel failure.

This chapter is based on data collected during various pavement rehabilitation projects within the vicinity of Berths 108 to 205.

5.4.1 Reasons for panel failure at DCT

- Improper placement of dowel and tie bars

Dowel bars are commonly made of round, smooth, epoxy coated steel bars. Tie bars are made of deformed epoxy coated steel. Figure 23 shows what happens when neither dowel nor tie bars are used when severe loading is imposed onto concrete pavement. The purpose of dowel bars is to transfer load from one slab to another and to reduce joint faulting and corner cracking (Figure 24). The purpose of tie-bars is to prevent lane separation and differential deflections (Figure 25). Tie-bars also reduce transverse cracking (Khazanovich, 2011).

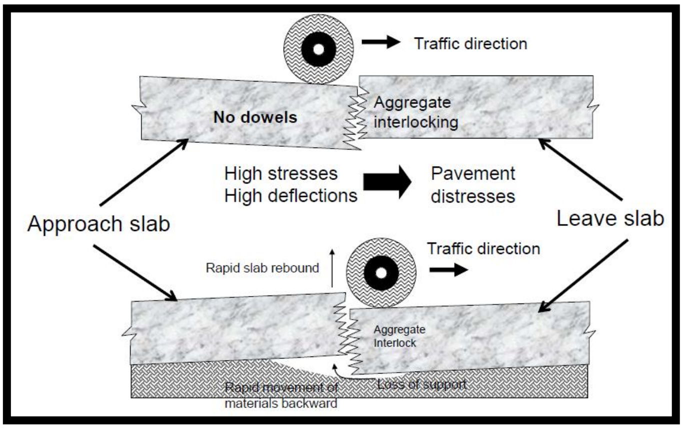


Figure 23: No dowels
Source: Khazanovich (2011)

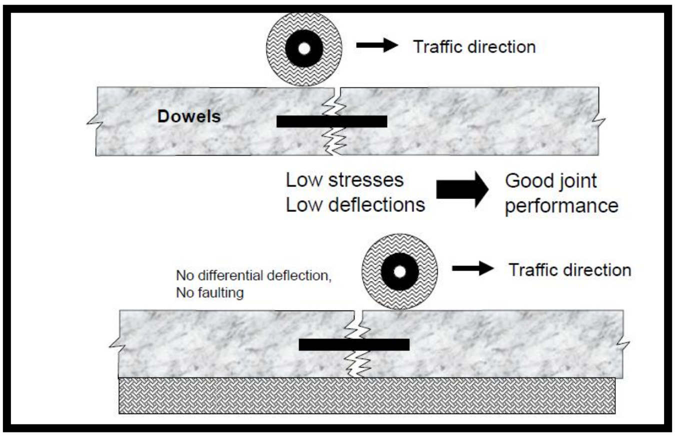


Figure 24: Purpose of dowel bars
Source: Khazanovich (2011)

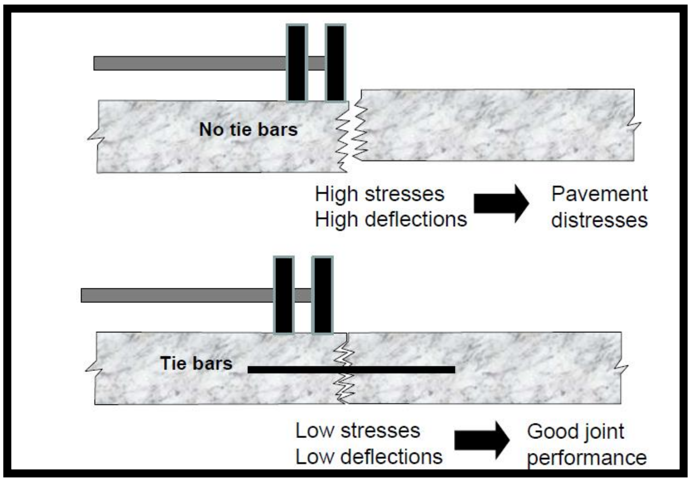


Figure 25: Purpose of tie bars
Source: Khazanovich (2011)

Placing bars at incorrect depths

Dowel bars provide load transfer across joints which reduce stress and deflections, thereby reducing faulting at joints and slab cracking. To ensure proper functioning of the dowels, however, proper placement is critical. Figure 26 displays an example of a dowel bar that was placed incorrectly which resulted in spalling, due to insufficient cover (Khazanovich, 2011).

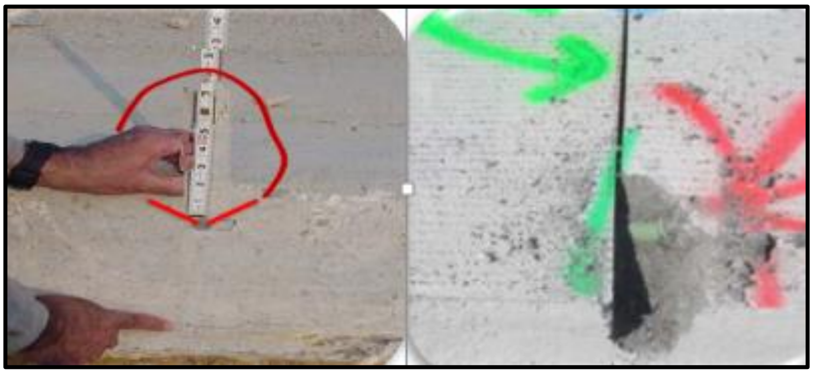


Figure 26: Bars placed at incorrect depths resulted in spalling

Clashing of bars

Clashing of the bars will result in spalling and cracking. The tie bar pointed out in Figure 27 will not be effective in preventing lane separation and deflections due to clashing of the bars. This will ultimately lead to panel failure (Khazanovich, 2011).

Figure 27: Clashing of bars

- Fly ash used as infill material

Fly ash is inconsistent in terms of thickness and quality and is therefore not graded or classified as G6, G7, G8 or G9. Sometimes you do get decent material, but it is very fine and cannot be compacted (similar to cake flour). Concrete pavements rely on the lower layers for support (imagine a sheet of glass on a mattress vs it being on a table). The concrete can withstand a certain amount of flexure as it is unreinforced, but as soon as there are “soft spots”, differential settlements occur which results in premature failure. There were serious panel failures in the areas that contained fly ash material in Pier 2.

- Damaged stormwater pipes

Damaged stormwater pipes were one of the common problems that contributed towards panel failure at DCT. Due to the loss of sand through various cracks on the pipe (Figure 28), the layer works above the stormwater pipe destabilized which subsequently resulted in panel failure.

Figure 28: Damaged storm water pipe

- Slot drains not maintained

Slot drain cleaning plays a pivotal role in ensuring concrete panels maintain their life expectancy period and must be practiced on an ongoing basis. When slot drains are blocked (Figure 29), water will pond on the surface of the concrete and will eventually seep into joints where the sealing has been omitted or has become old and requires replacement. Thereafter the water will begin to undermine the slab by weakening the layer works underneath, which eventually leads to a panel failure.

Figure 29: Blocked slot drain

- Unsuitable backfill material

It was noticed that unsuitable backfill material (Figure 30) was used in some areas in Pier 2. This resulted in hard and soft spots (Figure 31) being formed in the vicinity, causing a high rate of panel failure due to the lack of compaction and subgrade uniformity of the material.

Figure 30: Rubble used as backfill

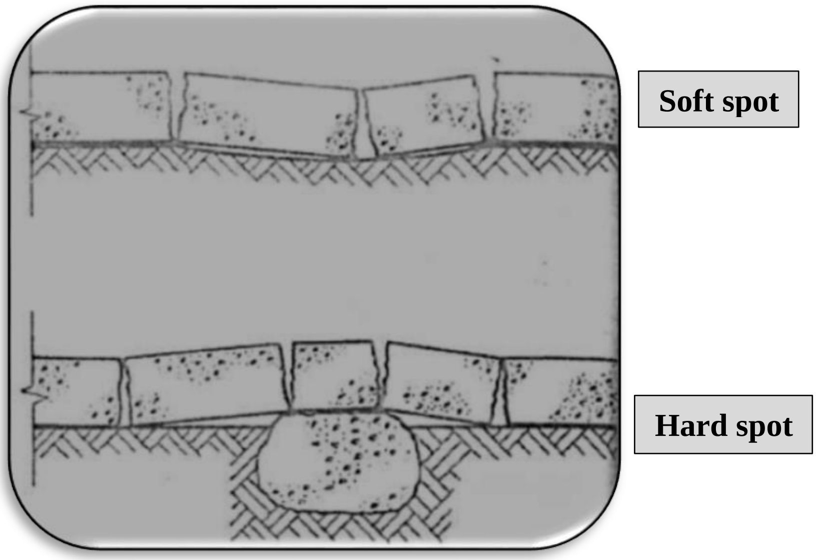


Figure 31: Hard and soft spots
Source: Khazanovich (2011)

- Joints not maintained

One of the major causes of panel failure is the lack of maintenance of joints. When water ponds on panels due to insufficient surface runoff or slot drain blockages, it eventually seeps through joints if the joint sealing is worn, omitted or sealed using improper techniques (Figure 32). Eventually the water will undermine the slab by weakening the subgrade and will ultimately lead to panel failure.

Joint sealing prevents incompressible materials from getting lodged in the joint space, which can cause spalls. Sealant materials must be able to withstand repeated expansion and compression as the pavement slabs expand and contract with temperature and moisture changes. There are three different categories of sealants: hot-poured liquid sealants, cold-poured silicone sealants, and preformed compression sealers (Grove & Brink, 2006).

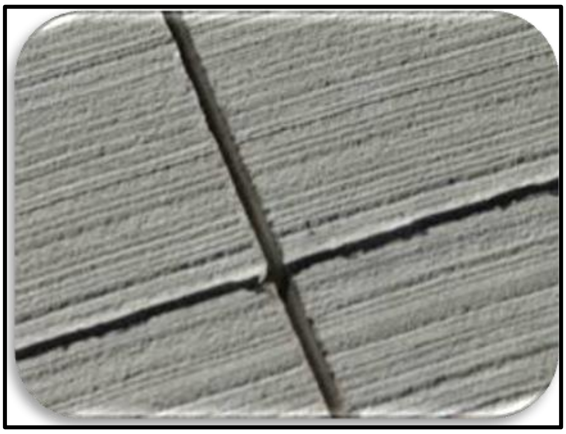


Figure 32: Absence of joint sealing

- Failure along quay wall

There was an increase in panel failure along the quay wall therefore an investigation was carried out and it was discovered that the existing marine sand was seeping through the joint of the quay wall during high tides. Failure of the road and concrete panels resulted from the destabilization of the layer-works, which occurred over a protracted period (Figure 33). Water pumps had to be used when repairing due to high tides (Figure 34).

Figure 33: Destabilization of the layer-works

Figure 34: Water pumps used.

5.5 Pavement layer thickness evaluation

Detailed as-built records were not available to verify basic structure information. Design drawings for portions of the area under consideration and with indications of likely concrete thickness were made available by Transnet. Table 12 summarizes the available information. The data from this table suggests that the majority of the pavement included in the evaluation area is approximately 14 years old.

Table 12: Summary of historic thickness data

Relevant Area	Dwg date	Information obtained from drawings
FF5	1997	375 mm Jointed Plain Concrete (JPC) with thickened edge 450 mm where applicable. 150 crushed stone subbase
FF6	1997	375 mm JPC with thickened edge 500 mm where applicable. 150 crushed stone subbase
EE6	1996	380 mm JPC
888	1996	375 mm JPC with thickened edge 500 mm where applicable. 150 crushed stone subbase
Cross Berth at Quay Wall	1996	375 mm JPC with thickened edge 600 mm where applicable. SPT N-values of 30-50 reported suggest dense layer in horizon below concrete.
RR2	2005	375 mm JPC with thickened edge 550 mm where applicable. 100 mm G3 crushed stone subbase

Source: Transnet National Ports Authority (2013)

A total number of 35 cores were drilled by an outsourced company and details made available to the researcher by Transnet to determine or verify current as-built concrete thicknesses (Table 13). In order to obtain more continuous thickness data which would complement the analysis of deflection tests, data from a GPR survey that was conducted by the same outsourced company was used in this investigation.

Table 13: Core and GPR thickness data

Core ID	Core Thickness (mm)	GPR Thickness (mm)	Comments on Support
A1	430	389	No subbase core (no close inspection)
A2	435	403	Loose material from subbase (no subbase core)
B1	370	-	Loose material from subbase (no subbase core)
C1	380	363	Residue of cemented material at bottom of slab – no core
D2	360	-	Loose material from subbase
D3	380	-	Double slab, no DCP performed
F1	350	380	Loose material from subbase (no subbase core)
F2	390	430	Residue at bottom, but no subbase core
G1	380	-	Loose material from subbase
H2	405	402	Loose material from subbase
J2	385	390	Loose gravelly material extracted
J3N	380	365	Loose material with cementitious agglomerations – no core
J3S	370	385	Residue at bottom but no subbase core
O1	370	387	Loose subbase material
P1	390	439	No subbase core (no close inspection)
Q1	390	450	Residue of stabilised subbase – no core
R1	435	-	Double slab – no DCP
S1	390	400	No subbase core (no close inspection)

Core ID	Core Thickness (mm)	GPR Thickness (mm)	Comments on Support
RR2	400	350	Loose material from subbase – No core
JJ5/1	390	-	Loose material from subbase – No core
JJ5/2	390	400	No subbase core (no close inspection)
HH5/1	400	400	Loose material from subbase – No core
HH6/1	390	380	Cemented agglomerations visible bu no core possible
GG5/1	410	370	Subbase broken up – No core
GG5/2	390	400	Residue of cemented material but coring not possible
M10/1	390	390	Subbase cemented but deteriorated – No core
FF5/1	380	460	Loose material from subbase
FF6/1	395	-	Loose gravelly material extracted from subbase
178/1	430	370	Residue of stabilised material at bottom of slab – No core
M1	380	387	No subbase core (no close inspection)
ED1	350	480	Only partially intact (80-100mm) subbase core
ED2	430	415	Lower slab (different concrete) of ±75 mm evident
EC1/1	350	380	No subbase core (no close inspection)
EC1/2	390	430	No subbase core (no close inspection)
EC2	415	-	Double slab – No DCP

Source: Contest Concrete Technology Services (2011)

5.6 Pavement loading conditions

In this section, current and projected loading conditions are presented and design load assumptions formulated. Loading on the DCT Pier 2 pavement facility is mainly induced by:

- Containers, both 12 m and 6 m in length; and
- 8 Wheeled, 1 over 3 SCs (40 ton capacity).

Containers are generally stacked 3 high and placed in row stacking arrangements. In order to increase the stacking density, it is proposed to change the primary container stacking equipment to 8 wheeled, 1 over 5 RTG cranes with 40 ton loading capacity. Use of RTG vehicles will enable a stacking height of 5 containers. The recommendations and principles related to loading conditions contained in "The Structural Design of Heavy Duty Pavements for Ports and other Industries, Edition 4", originally known as BPA manual was used in this dissertation. All design loads are based on the Equivalent Single Wheel Load (ESWL) concept where load inference is accounted for by the use of proximity factors.

5.6.1 Handling plant

Basic design load assumptions are provided in Table 14 and further details follow in Tables 15 to 20. Where containers being handled comprise 100 percent 12 m containers the critical load is commonly 22 tons, and 20 tons where only 6 m containers are handled. A value of 21 tons is recommended where mixes of 12 m and 6 m containers are handled (Knapton, 2007). For twin lift SCs, which can handle two fully loaded 6 m containers (each 30.48 tons), the critical container weight is doubled to 40 tons.

It is assumed that RTGs will mainly travel unloaded, and that the distances and occurrences travelling with containers are insignificant. The equivalent wheel load used for this plant is the dynamic unloaded case exhibiting a maximum value of 284 kN. Although this assumption has been confirmed and agreed upon, it is recommended that dynamic factors be investigated during the detailed design stage for the case when the plant handles containers while in a stationary condition (i.e. dynamic effects induced when the troll moves with a container).

Table 14: Summary of container handling plant design load assumption

<table>
<tr><th>Single Lift Straddle Carrier (3-high)</th><th colspan="2">Loaded: Mixed Containers</th><th colspan="2">Unloaded</th></tr>
<tr><td>Critical Container Weight
Effective Static Wheel Load
Dynamic Factor
Equivalent Single Wheel Load (ESWL)*
ESWLs/vehicle</td><td colspan="2">21 000 kg
108 kN
1.5
161 kN
1.57</td><td colspan="2">0 kg
80 kN
1.5
161 kN
0.51</td></tr>
<tr><th rowspan="2">Heavy Twin Lift Straddle Carriers
& Single Lift Straddle Carrier (3 high)</th><th colspan="2">Heavy Twin Lift Straddle</th><th colspan="2">Single Lift Straddle</th></tr>
<tr><th>Loaded: 100% 2x6m Containers</th><th>Unloaded</th><th>Loaded: 100% 12m Containers</th><th>Unloaded</th></tr>
<tr><td>Critical Container Weight
Effective Static Wheel Load
Dynamic Factor
Equivalent Single Wheel Load (ESWL)*
ESWLs/vehicle</td><td>40 000 kg
154 kN
1.5
231 kN
1.58</td><td>0 kg
101 kN
1.5
231 kN
0.32</td><td>22 000 kg
109 kN
1.5
231 kN
0.43</td><td>0 kg
80 kN
1.5
231 kN
0.13</td></tr>
<tr><th>Rubber Tyre Gantry (5 high, 6 wide)</th><th>Loaded Dyn.: Mixed Containers</th><th colspan="2">Loaded Static: Mixed Containers</th><th>Unloaded</th></tr>
<tr><td>Critical Container Weight
Effective Static Wheel Load
Dynamic Factor
Equivalent Single Wheel Load (ESWL)*
ESWLs/vehicle</td><td>21 000 kg
268 kN
1.3
284 kN
3.30</td><td colspan="2">21 000 kg
268 kN
1
284 kN
2.41</td><td>0 kg
222 kN
1.3
284 kN
1.53</td></tr>
<tr><td colspan="5">Note:* ESWL represents the design wheel load for the plant under consideration for any loading situation and is not necessarily related to the dynamic factor for a specific loading situation</td></tr>
</table>

Table 15: Design load calculations for mixed containers

Kalmar CSC340			
LOADED: MIXED CONTAINERS			
Wt	Unladen weight of plant	60	t
M	Total number of wheels on plant	8	
Tw	Track width	4452	mm
X1	Wheel base	3500	mm
X2	Wheel spacings	2100	mm
Wc	Weight of critical container	21000	kg
U	Wheel load of unladen plant	7500	kg
W	Static wheel load of laden plant	10125	kg
SG_{CBR}	Subgrade CBR	50	%
De	Effective Depth	1236	mm
Proximity Factor from Table 19 (Interpave, 2007)			
Xs	1800		
De1	1000	1.00	
De2	2000	1.19	
PF	Interpolated proximity factor	1.04	
Xs	2400		
De1	1000	1.00	
De2	2000	1.02	
PF	Interpolated proximity factor	1.00	
PFf	Final interpolated PF	1.08	
Wes	**Effective static wheel load**	**107.5**	**kN**
fdb	Dynamic factor for braking	50	±%
fdbi	Effective dynamic factor for braking on inner wheels	22.7	±%
fda	Dynamic factor for acceleration	0	%
fdai	Effective dynamic factor for accelaration on inner wheels	0.0	
fdc	Dynamic factor for cornering	0	%
fdu	Dynamic factor for uneven surface	0	%
W1fo	Front outer wheel load + dynamic effects	161.31	kN
W2fi	Front inner wheel load + dynamic effects	132	kN
W3ri	Rear inner wheel load + dynamic effects	83	kN
W4ro	Rear outer wheel load + dynamic effects	54	kN
ESW1		1.00	
ESW2		0.47	
ESW3		0.08	
ESW4		0.02	
ESWL	Equivalent single wheel loads per vehicle	1.57	
DF	Dynamic Factor (incorporated)	1.50	

Table 16: Design load calculations for SC without containers

Kalmar CSC340 [without container]			
EMPTY			
Wt	Unladen weight of plant	60	t
M	Total number of wheels on plant	8	
Tw	Track width	4452	mm
X1	Wheel base	3500	mm
X2	Wheel spacings	2100	mm
Wc	Weight of critical container [without container]	0	kg
U	Wheel load of unladen plant	7500	kg
W	Static wheel load of laden plant	7500	kg
SG_{CBR}	Subgrade CBR	50	%
De	Effective Depth	1236	mm
Proximity Factor from Table 19 (Interpave, 2007)			
Xs	1800		
De1	1000	1.00	
De2	2000	1.19	
PF	Interpolated proximity factor	1.04	
Xs	2400		
De1	1000	1.00	
De2	2000	1.02	
PF	Interpolated proximity factor	1.00	
PFf	Final interpolated PF	1.08	
Wes	**Effective static wheel load**	**79.7**	**kN**
fdb	Dynamic factor for braking	50	±%
fdbi	Effective dynamic factor for braking on inner wheels	22.7	±%
fda	Dynamic factor for acceleration	0	%
fdai	Effective dynamic factor for accelaration on inner wheels	0.0	
fdc	Dynamic factor for cornering	0	%
fdu	Dynamic factor for uneven surface	0	%
W1fo	Front outer wheel load + dynamic effects	119	kN
W2fi	Front inner wheel load + dynamic effects	98	kN
W3ri	Rear inner wheel load + dynamic effects	62	kN
W4ro	Rear outer wheel load + dynamic effects	40	kN
ESW1	(expressed in fully loaded ESWL)	0.32	
ESW2	(expressed in fully loaded ESWL)	0.15	
ESW3	(expressed in fully loaded ESWL)	0.03	
ESW4	(expressed in fully loaded ESWL)	0.01	
ESWL	Equivalent single wheel loads per vehicle	0.51	
DF	Dynamic Factor (incorporated)	1.50	

Table 17: Design load calculations for loaded 12 m containers

Kalmar CSC340			
LOADED: 100% 12m CONTAINERS			
Wt	Unladen weight of plant	60	t
M	Total number of wheels on plant	8	
Tw	Track width	4452	mm
X1	Wheel base	3500	mm
X2	Wheel spacings	2100	mm
Wc	Weight of critical container	22000	kg
U	Wheel load of unladen plant	7500	kg
W	Static wheel load of laden plant	10250	kg
SG_{CBR}	Subgrade CBR	50	%
De	Effective Depth	1236	mm
Proximity Factor from Table 19 (Interpave, 2007)			
Xs	1800		
De1	1000	1.00	
De2	2000	1.19	
PF	Interpolated proximity factor	1.04	
Xs	2400		
De1	1000	1.00	
De2	2000	1.02	
PF	Interpolated proximity factor	1.00	
PFf	Final interpolated PF	1.08	
Wes	**Effective static wheel load**	**108.9**	**kN**
fdb	Dynamic factor for braking	50	±%
fdbi	Effective dynamic factor for braking on inner wheels	22.7	±%
fda	Dynamic factor for acceleration	0	%
fdai	Effective dynamic factor for accelaration on inner wheels	0.0	
fdc	Dynamic factor for cornering	0	%
fdu	Dynamic factor for uneven surface	0	%
W1fo	Front outer wheel load + dynamic effects	163	kN
W2fi	Front inner wheel load + dynamic effects	134	kN
W3ri	Rear inner wheel load + dynamic effects	84	kN
W4ro	Rear outer wheel load + dynamic effects	54	kN
ESW1		0.27	
ESW2		0.13	
ESW3		0.02	
ESW4		0.004	
ESWL	Equivalent single wheel loads per vehicle	0.43	
DF	Dynamic Factor (incorporated)	1.50	

Table 18: Design load calculations for a loaded heavy Twin Lift SC

NSC 644E Heavy Twin Lift Straddle (3-High)			
LOADED: 100% 2x6m CONTAINERS			
Wt	Unladen weight of plant		76 t
M	Total number of wheels on plant		8
Tw	Track width		4440 mm
X1	Wheel base		3700 mm
X2	Wheel spacings		2000 mm
Wc	Weight of critical container		40000 kg
U	Wheel load of unladen plant		9500 kg
W	Static wheel load of laden plant		14500 kg
SG_{CBR}	Subgrade CBR		50 %
De	Effective Depth		1236 mm
Proximity Factor from Table 19 (Interpave, 2007)			
Xs		1800	
De1		1000	1.00
De2		2000	1.19
PF	Interpolated proximity factor		1.04
Xs		2400	
De1		1000	1.00
De2		2000	1.02
PF	Interpolated proximity factor		1.00
PFf	Final interpolated PF		1.08
Wes	**Effective static wheel load**		**154 kN**
fdb	Dynamic factor for braking		50 ±%
fdbi	Effective dynamic factor for braking on inner wheels		24.0 ±%
fda	Dynamic factor for acceleration		0 %
fdai	Effective dynamic factor for accelaration on inner wheels		0.0
fdc	Dynamic factor for cornering		0 %
fdu	Dynamic factor for uneven surface		0 %
W1fo	Front outer wheel load + dynamic effects		231 kN
W2fi	Front inner wheel load + dynamic effects		191 kN
W3ri	Rear inner wheel load + dynamic effects		117 kN
W4ro	Rear outer wheel load + dynamic effects		77 kN
ESW1			1.00
ESW2			0.49
ESW3			0.08
ESW4			0.02
ESWL	Equivalent single wheel loads per vehicle		1.58
DF	Dynamic Factor (incorporated)		1.50

Table 19: Design load calculations for an empty heavy Twin Lift SC

NSC 644E Heavy Twin Lift Straddle (3-High)			
EMPTY			
Wt	Unladen weight of plant	76	t
M	Total number of wheels on plant	8	
Tw	Track width	4440	mm
X1	Wheel base	3700	mm
X2	Wheel spacings	2000	mm
Wc	Weight of critical container [without container]	0	kg
U	Wheel load of unladen plant	9500	kg
W	Static wheel load of laden plant	9500	kg
SG_{CBR}	Subgrade CBR	50	%
De	Effective Depth	1236	mm
Proximity Factor from Table 19 (Interpave, 2007)			
Xs	1800		
De1	1000	1.00	
De2	2000	1.19	
PF	Interpolated proximity factor	1.04	
Xs	2400		
De1	1000	1.00	
De2	2000	1.02	
PF	Interpolated proximity factor	1.00	
PFf	Final interpolated PF	1.08	
Wes	**Effective static wheel load**	**101**	**kN**
fdb	Dynamic factor for braking	50	±%
fdbi	Effective dynamic factor for braking on inner wheels	24.0	±%
fda	Dynamic factor for acceleration	0	%
fdai	Effective dynamic factor for accelaration on inner wheels	0.0	
fdc	Dynamic factor for cornering	0	%
fdu	Dynamic factor for uneven surface	0	%
W1fo	Front outer wheel load + dynamic effects	**151**	**kN**
W2fi	Front inner wheel load + dynamic effects	125	kN
W3ri	Rear inner wheel load + dynamic effects	77	kN
W4ro	Rear outer wheel load + dynamic effects	50	kN
ESW1		0.20	
ESW2		0.10	
ESW3		0.02	
ESW4		0.00	
ESWL	Equivalent single wheel loads per vehicle	**0.32**	
DF	Dynamic Factor (incorporated)	**1.50**	

Table 20: Design load calculations for a RTG

Kalmar RTG 422318-2040C				
	20 ton troll position 3			
	Corner 1		Corner 2	
	Outside	Inside	Outside	Inside
Static	266	247	234	234
Dynamic	336	240	223	223
ESWL	1.0	0.29	0.22	0.22
ESWL/RTG	1.72			
	30 ton troll position 3			
	Corner 1		Corner 2	
	Outside	Inside	Outside	Inside
Static	287	270	256	256
Dynamic	361	266	248	248
ESWL	1.0	0.32	0.25	0.25
ESWL/RTG	1.81			
	21 ton troll position 3			
	Corner 1		Corner 2	
	Outside	Inside	Outside	Inside
Static	268	249	237	237
ESWL	0.42	0.32	0.26	0.26
ESWL/RTG	1.26	(338 kN)		
Dynamic	338	243	225	225
ESWL	1.0	0.29	0.22	0.22
ESWL/RTG	1.73	(338 kN)		
	0 ton troll position 3			
	Corner 1		Corner 2	
	Outside	Inside	Outside	Inside
Static	222	204	191	191
Dynamic	284	192	172	172
DF	1.28	0.94	0.90	0.90
ESWL	0.52	0.12	0.08	0.08
ESWL/RTG	0.80	(338 kN)		
	21 ton troll position 3			
	Corner 1		Corner 2	
	Outside	Inside	Outside	Inside
Static	268	249	237	237
ESWL	0.80	0.61	0.50	0.50
ESWL/RTG	2.41	(284 kN)		
Dynamic	338	243	225	225
ESWL	1.91	0.55	0.42	0.42
ESWL/RTG	3.30	(284 kN)		
	0 ton troll position 3			
	Corner 1		Corner 2	
	Outside	Inside	Outside	Inside
Static	222	204	191	191
Dynamic	284	192	172	172
DF	1.28	0.94	0.90	0.90
ESWL	1.00	0.23	0.15	0.15
ESWL/RTG	1.53	(284 kN)		

5.6.2 Containers

Container loads are induced onto the pavement through four corner castings with dimensions 178 mm x 162 mm. Since it is unlikely that all containers in a stack will be fully laden, the BPA manual recommends reductions in the maximum gross weights for different stacking heights (Knapton, 2007). Disregard of this fundamental design assumption typically leads to impractical concrete slab thicknesses in the order of one (1) metre. Table 21 provides a summary of the design load assumptions for both the primary design scenarios to illustrate the concept.

Table 21: Summary of container design load assumptions

Description of Load Characteristic	Current	Projected
Stack height	3	5
Stacking arrangement	Row	Block
Stack spacing: Door-to-door	200 mm	340 mm
Side-to-side	1700 mm	350 mm
Reduction in gross weight	20%	40%
Design load	366 kN	914 kN

5.6.3 Load repetition/ traffic demand

Handling plant traffic and associated wheel load repetitions are based on DCT container throughput estimates for Berths 108 and 109. Assumptions made to produce the traffic demand, in terms of wheel load repetitions are included in Appendix B. This data was obtained from TPT (Transnet Limited, 2011). Using these assumptions, the daily repetitions of the design wheel load can be used to express the capacity or life in terms of years. Container stacking is traditionally considered as a static loading regime, and expressed in terms of the allowed stacking height. A quasi-static loading regime was investigated.

5.6.4 Wheel load repetitions

For each operational scenario, Low, Medium, and High estimates are presented. Tables 22 to 23 contain the traffic loading estimates (see Appendix B). These figures are used in subsequent sections to interpret the results from the structural capacity analysis.

Table 22: Straddle way traffic

Daily	ESWL Factor	Repetitions Berth 108 & 109			Repetitions West of 109		
		Low	Medium	High	Low	Medium	High
Scenario 1A: Current Single Lift Straddles (3-high)							
Loaded	1.57	246	1007	1419	153	277	1303
Unloaded	0.51	246	1007	1419	153	277	1303
Daily ESWL Reps.		*513*	*2095*	*2952*	*319*	*577*	*2710*
15 Years		2.8×10^6	11.4×10^6	16.6×10^6	1.7×10^6	3.2×10^6	14.8×10^6
20 Years		3.7×10^6	15.2×10^6	21.5×10^6	2.3×10^6	4.2×10^6	19.8×10^6
30 Years		5.6×10^6	22.9×10^6	32.3×10^6	3.5×10^6	6.3×10^6	29.7×10^6
Scenario 2A: Straddle Carrier Mix (3-high)							
HTL Loaded	1.58	62	252	355	38	69	326
HTL Unload.	0.32	62	252	355	38	69	326
SL Loaded	0.43	123	504	710	77	139	652
SL Unloaded	0.13	123	504	710	77	139	652
Daily ESWL Reps.		*186*	*761*	*1071*	*116*	*209*	*984*
15 Years		1.0×10^6	4.2×10^6	5.9×10^6	0.63×10^6	1.1×10^6	5.4×10^6
20 Years		1.4×10^6	5.6×10^6	7.8×10^6	0.84×10^6	1.5×10^6	7.2×10^6
30 Years		2.0×10^6	8.3×10^6	11.7×10^6	1.3×10^6	2.3×10^6	10.8×10^6

Table 23: Traffic estimates for stacked areas

Daily	ESWL Factor	ESWL Repetitions		
		Low	Medium	High
Scenario 1B: Current Single Lift Straddles (3-high)				
Loaded	1.57	16	32	32
Unloaded	0.51	16	0	32
Daily ESWL Repetitions		*32*	*50*	*66*
15 Years		0.81×10^5	0.27×10^5	0.36×10^5
20 Years		0.24×10^5	0.36×10^5	0.48×10^5
30 Years		0.36×10^5	0.55×10^5	0.73×10^5
Scenario 2B: Straddle Carrier Mix (3-high)				
HTL Loaded	1.58	4	8	8
HTL Unload.	0.32	4	0	8
SL Loaded	0.43	8	16	16
SL Unloaded	0.13	8	0	16
Daily ESWL Repetitions		*12*	*19*	*24*
15 Years		0.07×10^5	0.11×10^5	0.13×10^5
20 Years		0.09×10^5	0.14×10^5	0.18×10^5
30 Years		0.13×10^5	0.21×10^5	0.26×10^5
Scenario 3: RTG (5-high)				
Loaded	2.41	9	28	47
Unloaded	1.53	9	28	47
Daily ESWL Repetitions		*37*	*111*	*186*
15 Years		0.20×10^5	0.61×10^5	1.02×10^5
20 Years		0.27×10^5	0.81×10^5	1.35×10^5
30 Years		0.41×10^5	1.22×10^5	2.03×10^5
Scenario 3: RTG (3-high) – Only for analytical purposes				
Loaded	2.41	6	17	28
Unloaded	1.53	6	17	28
Daily ESWL Repetitions		*24*	*67*	*110*
15 Years		0.13×10^5	0.37×10^5	0.60×10^5
20 Years		0.17×10^5	0.49×10^5	0.80×10^5
30 Years		0.26×10^5	0.73×10^5	1.21×10^5

The number of repetitions is based on the following considerations:

Stacks: SCs

- Each container generates two loaded and two unloaded trips;
- A wheel path is shared between two containers;
- Low: One loaded and one unloaded repetition (second trip uses opposite direction);
- Medium: Two loaded repetitions (unloaded plant moves in opposite direction); and
- High: Two loaded and two unloaded repetitions (typically for containers positioned close to one end of stack).

Straddle ways

- Each container generates two loaded and two unloaded trips;
- Loaded and unloaded trips do not follow the same path;
- Low: Straddle way shared between two stacks;
- Medium: Straddle way that serves a large portion of the area (point of accumulation/ diversion); and
- High: The total throughput. Although conservative, it is assumed that a transfer area is dedicated to the total of Berths 108 and 109 and therefore experiences all the traffic.

Stacks: RTGs

- Each container generates two loaded and two unloaded trips;
- The gantry will remain in one position/ bay as long as possible;
- At least 6 (Low) containers but ideally 30 containers (High) are stacked while stationed at a bay; and
- Depending on the stacking efficiency, each bay generates:
  - ✓ Two dynamic unloaded: to stack with 50% chance of a repetition;
  - ✓ Two dynamic unloaded: to un-stack with 50% chance of a repetition; and
  - ✓ Two static loaded movements.

It should be noted that the traffic estimates furnished in Tables 22 and 23 are purely based on the assumptions provided above and do not include any factors to account for highly channelized movements. The design curves provided in Edition 4 of the BPA manual include a safety factor of 1.5 applied to critical stresses during the development of the curves (Knapton, 2007). The PCA method suggests the application of a safety factor of 1.7 to 2.0 (to calculated stresses) to accommodate channelization. The BPA manual does not provide specific guidance but merely states that in certain extreme cases it is recommended that the number of (design) repetitions be enhanced by a factor of five (Knapton, 2007).

5.6.5 Quasi-static container loads

Similar to the design of post loads induced on industrial floors, loads under container castings are considered as static loads and non-repetitive due to the nature of and time delay between loads. For this reason, a limit state approach is followed by applying safety factors to limit the effect of loading to a state where failure will not occur during the expected life span of the facility. This approach is therefore purely one of eliminating the risk of failure and the concept of "life" is vague, essentially non-existing.

- In this analysis, it is assumed that the curves included in the BPA manual for repeated wheel loads represent the relative deterioration that will take place under container loads (Knapton, 2007).
- It should be understood that the critical stresses used to calibrate the performance curves represent levels required to produce incremental damage caused by dynamic loads (even though a static model is used to calculate the stresses). In comparison, container loads are static although the impact of "continuous" impact stacking loads and removal of containers at a certain position below and up to the maximum operational stack height, and repetition of this process every 4 to 7 days, may perhaps be interpreted as a quasi-static loading regime.
- The life in terms of repeated loads obtained from the wheel load curves can therefore not be used "as-is" and only serve as a relative performance

indicator. The apparent daily repetitions therefore need to be calibrated to provide a realistic estimate of remaining life expressed in years. The allowable load repetitions were obtained for each stacking configuration, for each subsection.

- To calibrate the model, the new and existing life in terms of repetitions for the current stacking configuration were obtained using the BPA wheel load graph for selected sections, and the calibrated daily container load repetitions determined over a period of 15 years (Knapton, 2007). While it is known that the stack layout has changed once over this period, the damage caused over the total period need to be accounted for. Based on the variability encountered, Low, Average, and High values were determined.

5.7 Structural capacity analysis

The objectives of this part of the assessment were:

- To determine remaining structural capacities of facilities based on current loading conditions, and
- To determine the remaining structural capacities based on projected loading conditions.

The information presented in previous sections indicates that the container terminal facilities in the vicinity of Berths 108 and 109 typically consist of approximately 375 mm concrete generally supported by an unbound granular sub-base (or equivalent) and a good subgrade. The data also showed high variability in subgrade conditions which is partly due to a deteriorated stabilised sub-base encountered in some areas. Since the subgrade strength is not an explicit input into the BPA design procedure, but based on a minimum requirement (before application of the design curves), subgrade areas that do not meet this requirement have to be identified and accounted for. It is expected that the typical support in the evaluation area consists of a subgrade with California Bearing Ratio (CBR) of approximately 15 and a 150 mm crushed stone sub-base (CBR 80) which is equivalent to a composite modulus of subgrade reaction (k-value) of 75 MPa/m. The back calculated k-values presented in

Table 24 were obtained from (Transnet Limited, 2011) and are in line with this basic illustration. The model used to develop the design curves is based on a subgrade with minimum CBR of 5 and a 150 mm crushed stone sub-base which equates to a composite k-value of 50 MPa/m. In the analysis, therefore, areas where the k-value falls below this level were accounted for by adjusting the equivalent concrete thickness accordingly.

Table 24: Back calculated k-values

Subsection	Slab Thickness (mm)	Jointed Plain Concrete		k-value (MPa/m)	Estimates of % Structural Defected Slabs	
		Elastic Modulus (MPa)	Flexural Strength (MPa)		Visual	FWD
A	420	24 392	4.4	78	50	25
B	375	27 025	4.9	57	4	0
C	372	35 416	6.4	53	5	10
D	365	31 956	5.8	63	8	10
E	400	23 026	4.2	52	4	12
F	380	25 979	4.7	73	0	0
G	380	25 515	4.6	70	0	0
H	395	25 374	4.6	63	0	7
J	378	29 592	5.4	72	0	0
N	372	25 275	4.6	67	6	10
O	400	22 356	4.1	67	25	40
P	375	30 272	5.5	71	15	16
Q	390	24 585	4.7	76	12	11
R	375	26 935	4.9	89	30	33
S	390	20 870	3.8	88	27	27
RR2	425	30 027	5.5	67	3	4
JJ5	380	29 735	5.4	80	8	15
HH5	385	28 337	5.2	66	12	4
HH6	375	36 318	6.6	65	0	0
GG5	388	24 511	4.5	75	2	5
M10-12	385	29 172	5.3	81	0	0
FF5	375	30 303	5.5	71	0	0
FF6	380	31 353	5.7	86	0	12
EE6	380	31 631	5.8	95	0	0
178	380	26 843	4.9	91	0	0
888	380	29 787	5.4	78	0	0
ED1	375	25 862	4.7	85	4	27
ED2	400	20 676	3.8	91	4	36
EC1	410	10 894	2.0	120	6	65
EC2	385	18 254	3.3	111	6	38

Source: Transnet Limited (2011)

Due to the key contribution of slab thickness to bearing capacity, efforts have been made to deduce reliable and representative thickness values. With the release of the 4th edition of the BPA manual for heavy duty pavements, a procedure has been incorporated to take the condition of existing pavement into consideration. This procedure makes use of CF that rate the condition of the existing surface or pavement component essentially based on visual inspection and as-built information.

This design produces qualitative information on the in-situ characteristics of the concrete and support. Two approaches were therefore followed:

1) Condition Factor Approach (CFA): A condition factor of 1, 0.8, 0.5 or 0.2 is assigned representing "as new", "slightly cracked", "substantially cracked" and "fully cracked", respectively. The thickness is multiplied by this factor in the conversion to an equivalent C10 (standard lean concrete with compressive strength of 10 MPa) material before using the design curves.
2) Flexural Strength Approach (FSA): Back calculated flexural strength is used to select an equivalent material that represents the current condition of the material. This material is then converted to an equivalent C10 before using the design curves.

5.7.1 Pavement structural capacity for handling plant

In this section, the effect of repeated wheel loads induced by container handling plant is investigated. Structural capacity is therefore expressed as the maximum allowable wheel load repetitions that a pavement facility can handle until "failure" occurs. The definition of structural failure in the context of jointed plain concrete pavements is normally related to the occurrence of shattered slabs and associated secondary defects. Shattered slabs eventually result in deformation that causes a poor riding surface which results in increased plant operating cost and so hampers production. Other distresses such as faulting are related to defects such as load transfer deficiency which ultimately leads to slab deterioration and a rough surface. In this evaluation, it is assumed that edge and corner deficiencies will be restored.

It is important to note that interpretation of structural capacity in terms of the remaining life (in years) is dictated by the traffic loading estimates provided in Tables 22 and 23. The model pavement structures developed as described in the previous section to evaluate stacking capacity was analysed by assessing the impact of different equivalent wheel loads on these pavements. Analyses were performed at both 85% and 95% approximate reliability levels using the CF and FS approaches (or models). A safety factor can be applied to traffic in stacks to reflect the impact of channelization. Since a Safety Factor of 1.7 to 2.0 is generally applied to the calculated critical stress in concrete, the effect was tested using stress data provided in the BPA manual (Knapton, 2007). This exercise indicates that for a Safety Factor of 2, the associated factor that should be applied to the traffic varies between approximately 1.7 and 3.5 for higher design traffic situations (typically > 8 million repetitions) and low design traffic situations (typically below 1.5 million repetitions), respectively. Although a value of 3.5 may be considered during a detailed design stage, a value of 5 was selected during this preliminary evaluation. Detailed results were obtained from (Transnet Limited, 2011) and are attached in Appendix C. Table 25 summarises the results for the 85% reliability structural capacity analysis which is believed to be an acceptable level of interpretation for this facility. The pavement generally exhibits high remaining life, typically in excess of 15 years. Table 25 highlights areas with lower capacities and provides an indication of the expected lower remaining life. Some of these areas contain failed slabs and it is assumed that these will be replaced. In addition, it is assumed that routine maintenance will be performed.

Table 25: Structural capacity to accommodate handling plant

Scenario	Estimated Remaining Life (85% "Reliability")	Critical Areas
1A: Straddle Ways (current)	Generally ≥ 15 years; Critical areas 7 to 10 years	A, HH5, O, P, Q, R, S, ED1, ED2, EC1, EC2
2A: Straddle Carrier Mix (Single + Twin Lift) stacking 3 high	Generally ≥ 15 years; Critical areas 10 to 15 years	A, HH5, O, P, Q, R, S, ED1, ED2, EC1, EC2
1B: Straddles in stacks (current)	Generally ≥ 15 years	-
2B: Straddle Mix in stacks	Generally ≥ 15 years	-
3: RTGs stacking 5 high	Generally ≥ 15 years; Critical areas 5 to 10 years	A, HH5, O, P, Q, R, S, ED1, ED2, EC1, EC2
4: RTGs stacking 3 high	Generally ≥ 15 years; Critical areas 7 to 15 years	A, HH5, O, P, Q, R, S, ED1, ED2, EC1, EC2

The data suggest that Scenario 2A presents an attractive alternative to the current operations. Although associated with higher wheel loads, albeit not excessive, such an operation generates fewer trips due to the twin lift system. In general, the number of repetitions in stacks is significantly less than traffic experienced in travel ways even if a channelization factor is applied to the traffic. From an evaluation of the remaining life of the critical areas, it was deduced that the RTG operation (5-high) represents the most critical condition which is aggravated by the application of a channelization factor (in stacks) of 5 in the analysis.

5.7.2 Pavement structural stacking capacity

The loads induced by containers on these facilities are essentially static in nature and pavements are subjected to crushing, shear, and bending forces. In this context, structural capacity is normally defined in a different way from facilities where repetitions of rubber tyre wheel loads are the main concern. Two aspects are addressed in this section of the report:

- Structural capacity in terms of the maximum allowable stacking height; and
- Estimated structural capacity expressed in terms of years.

The design curve for container stacking was updated from the 3rd to the 4th editions of the design manual. In the 4th edition, a safety factor was applied which results in more conservative stacking capacity estimates. While this adaption may be warranted, the 4th edition states that appropriate use of past manuals has led to 100% successful pavements (as far as the manual's author is aware). Both methods are used in the analysis, but more attention should be given to the results produced using the 4th edition during interpretation.

In this assessment, the maximum stacking capacity is defined in terms of the stacking arrangement and stack height. Assessment of the capacity was conducted at approximate 85% and 95% reliability levels by considering the spatial variability of the data sets. Apart from the condition factor (which is the same for the two reliability levels), only thickness affects the variability of the CFA output. Thickness in this analysis alone is not sufficient to cause a significant difference between the two reliability levels. The 95% reliability is very conservative and normally used to design highways where the highest level of riding comfort is required. In a slab replacement programme, most of the positions that dictate the 95% reliability output will be replaced. For this reason, the 85% reliability analysis is adopted. The FSA, however, shows a significant difference between the results associated with the two reliability levels. It should further be noted that the CF Approach is inherently more subjective than the FS Approach and results should be viewed taking this difference into consideration. The results of the stacking capacity analysis are shown in Figures 35 and 36.

Inspection of Figures 35 and 36 confirms that the Berths 108 and 109 area has performed better than the area west of Berth 109. In addition, the areas close to the key side exhibit lower structural capacities than those areas further away. The latter suggest that areas more likely to be utilised (close to the key side), i.e. those that are experiencing higher traffic volumes, are generally in poorer condition compared to areas further away. This observation is also corroborated by visual data. Table 26 summarises the estimated stacking capacity in terms of stack height as well as years if subjected to various container load conditions.

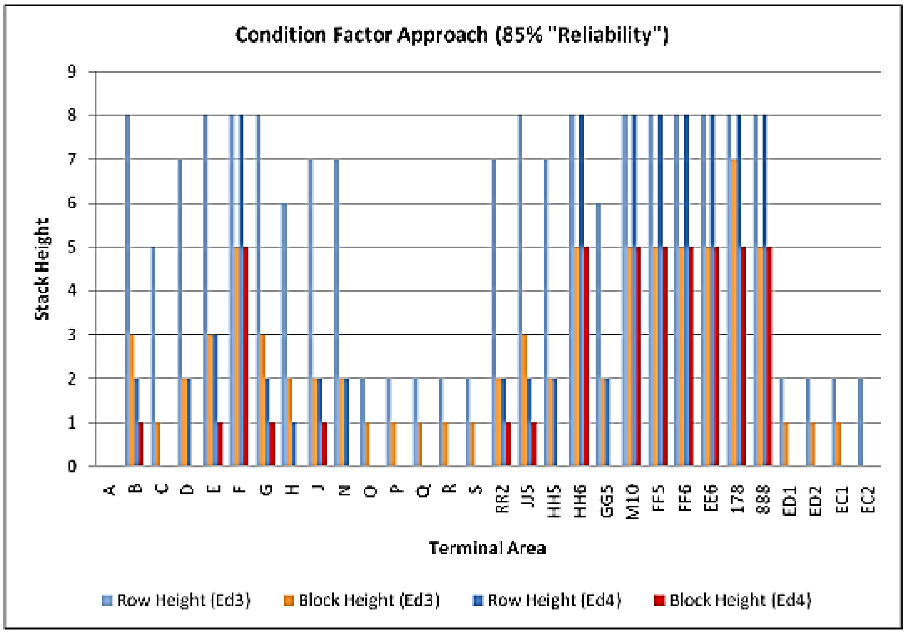


Figure 35: Stack capacity using condition factor

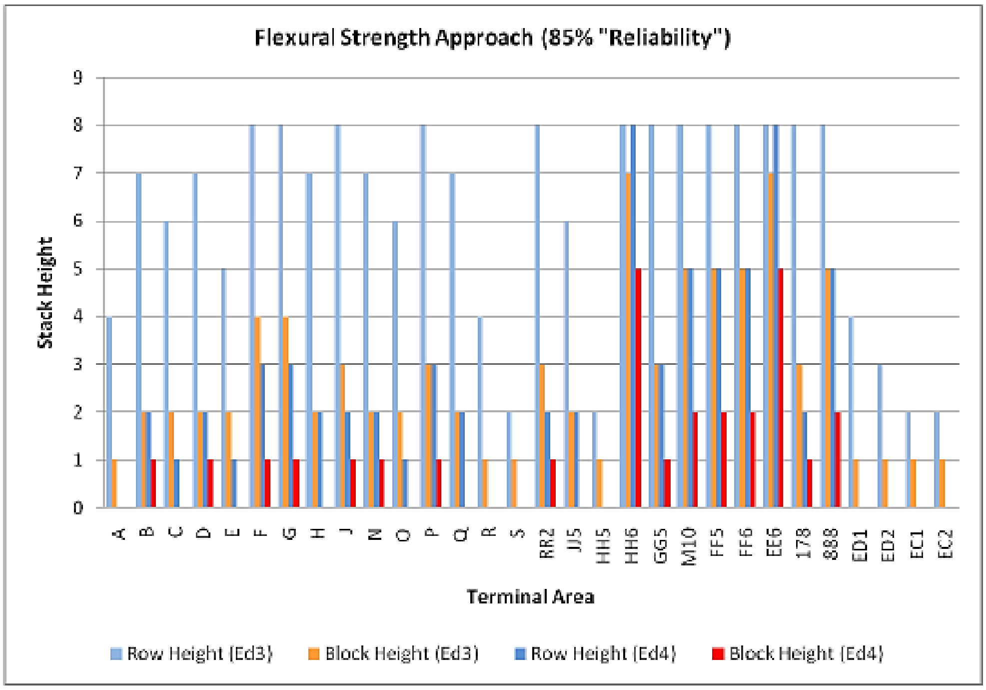


Figure 36: Stack capacity using flexural strength approach

Table 26: Pavement stacking capacity

Row Stack Capacity					
Area	Maximum Row Stack Height	Remaining Life (years) when subjected to:			
		2-High Row	3-High Row	4-High Row	
HH5,A,C,E ED1&2,EC1&2,O,P,Q,R,S	1 – (2) – 3	3 – (8) – 15	0.5 – (3) – 6	0.2 – (1) – 2	
RR2,JJ5,GG5,B,D,F,G,H,N,J	2 – (3) – 4	≥10	6 – (10) – 15	2 – (7) – 15	
FF5,FF6,HH6,M10,EE6, 178,888	3 – (4) – >4	≥15	10 – (15)-≥15	9 – (15)-≥15	
Block Stack Capacity					
Area	Maximum Block Stack Height	Remaining Life (years) when subjected to:			
		1-High Block	2-High Block	3-High Block	4-High Block
HH5,JJ5,A,C,E,H ED1&2,EC1&2,O,P,Q,R,S	≤ 1	2 – (5) – 15	<0.5	<0.5	<0.5
RR2,GG5,B,D,F,G,N,J, 178	0 – (1) – 2	≥10	0.5 – (2) – 5	≤ 1	<0.5
FF5,FF6,HH6,M10,EE6, 888	1 – (2) – 3	≥15	5 – (12)-≥15	1.5 – (5)–12	0.3 – (2) – 4
Legend: Colours used as interpretation category of existing capacity relative to target capacity: Blue – Good, Green – Fair, Yellow – Marginal (to Poor in case of Block Stacking), Orange – Poor, Red – Very Poor; Relative Row and Block stacking capacity shown in Figures 8 & 9 Note: Where appropriate, capacity given as range Low – (Expected) – High					

The results contained in Table 26 indicate that row stack capacity is marginal to good, while block stack capacity is generally poor. While the majority of the Berths 108 and 109 area will be able to accommodate 3 to 4 rows high stacking, the data reveal that the capacity is largely insufficient to accommodate block stacking. Areas related to row and block stack capacities in Table 26 are shown in Figures 37 and 38.

5.8 Pavement improvement considerations

The preceding sections had presented data on the existing structure and current condition of the DCT concrete pavement in the proximity of Berths 108 and 109. This data indicates:

- Thickness data indicates good correlation on average with design thicknesses where such information exists. The slab concrete compressive and flexural strengths are above the design values of 35 MPa and 3.8 MPa, respectively, based on laboratory test results. In situ determined flexural strengths exhibit high variability with approximately 10 percent of the values below 2 MPa.
- A granular to weakly cemented sub-base generally exists below the slab supported by a strong subgrade. In some areas, and especially evident in the area west of Berth 109, a stronger cement stabilised sub-base is present although deteriorated and highly variable.
- Approximately 15% of the area exhibits defective slabs of which approximately 10 percent require restoration while approximately 5% need to be replaced.
- Good corner and joint supporting conditions exist throughout the terminal with localised areas exhibiting poor joint transfer. In these areas corner breaks and/or minor faulting were observed during the visual inspection.
- Lack of routine maintenance in the form of joint seal replacement and cleaning of slot drains is evident.

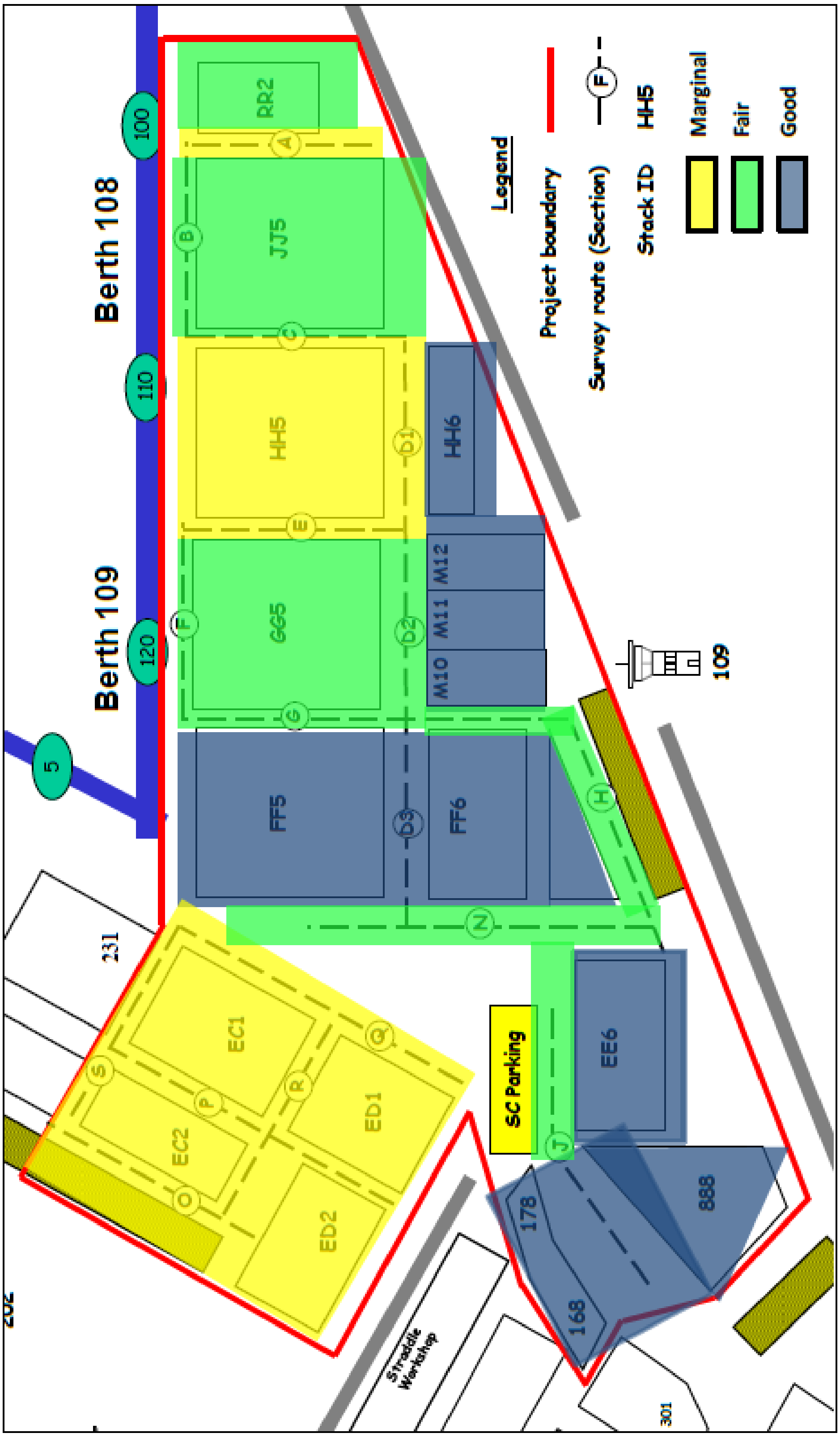


Figure 37: Row stack capacity

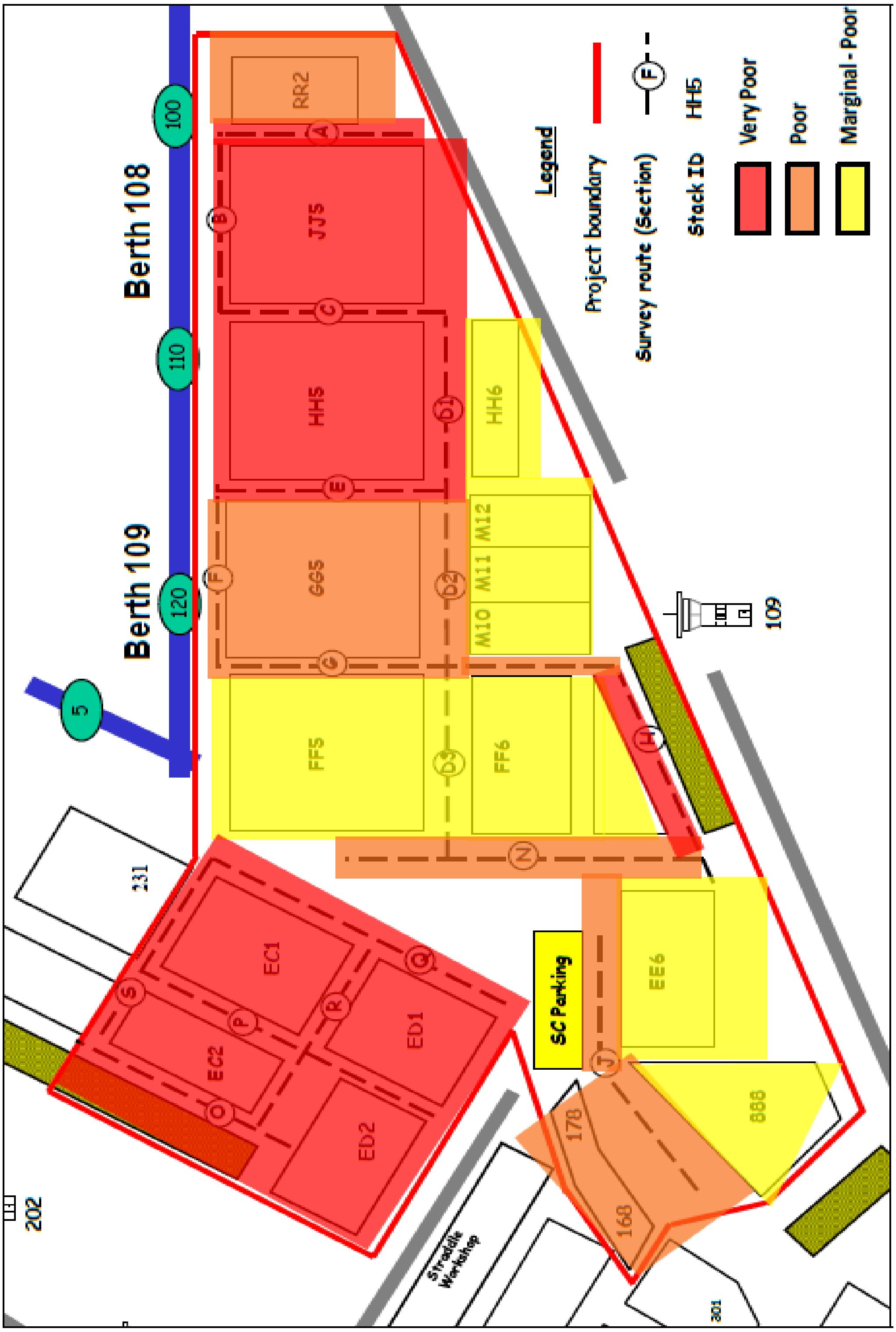


Figure 38: Block stack capacity

Figure 39 schematically illustrates the life-cycle of a concrete pavement facility including windows of opportunity to apply different strategies. As the pavement deteriorates, the most appropriate type of improvement or rehabilitation changes. Although a trade-off exists between rehabilitating now and allowing further deterioration, the first response to deterioration is usually restoration. Restoration provides the most economical strategy to extend the life of pavements with low to moderate deterioration. Deferring restoration within the boundaries of the window will result in more costly projects (John Knapton, 2007).

Based on the estimated percentage of area with defective slabs, it is believed that the condition of the DCT facility is within the concrete restoration window. Furthermore, for 3-high row stacking (essentially the current operation), analysis suggests that the condition is entering a stage where bonded concrete overlays may be warranted to extend the life of the facility. Various preliminary analyses was obtained from (Transnet Limited, 2011) and may be viewed in Appendix D**.** This data indicates that for 3-high row stack scenarios, approximately 66% of the facility would require thin concrete overlays (75 mm 150 mm) and approximately 33% of the facility warrants thick concrete overlays (> 150 mm). For 5-high block stacking, approximately 33% of the facility would require thin concrete overlays and approximately 66% of the facility would require thick concrete overlays. Because only a relatively small portion of slabs need to be replaced, it is believed that a bonded overlay strategy would be reasonable. However, while the BPA manual advocates the use of concrete overlays, this type of strategy may not be feasible to implement at DCT. Concrete overlays are discussed further in Section 5.10.

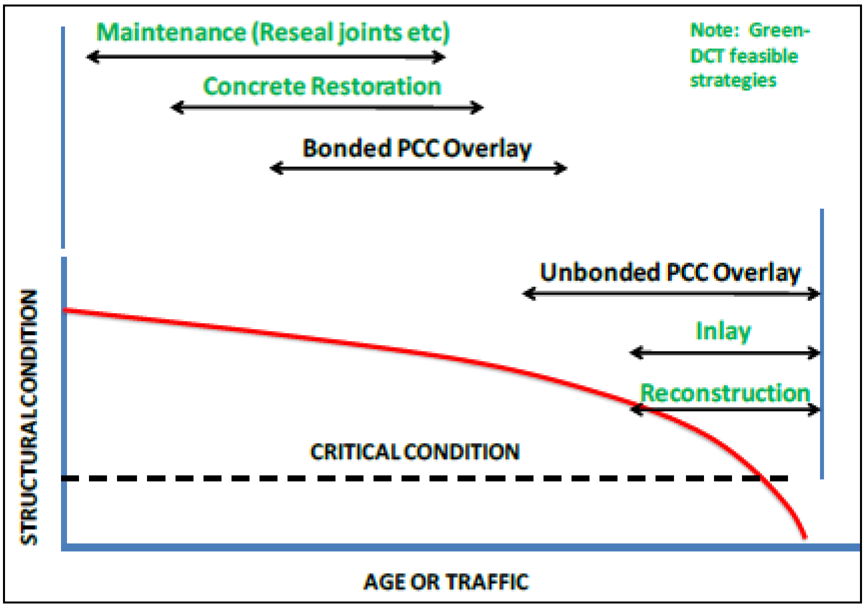


Figure 39: Life-cycle-diagram relationship – pavement condition and strategies
Source: (John Knapton, 2007)

5.9 Concrete pavement restoration and maintenance

Restoration refers to several techniques which bring the structural condition and rideability of the pavement to an acceptable level. In combination, the techniques not only repair distresses but also prevent or slow down recurrence of distresses. Restoration design should be addressed in the detailed design stage and include only those techniques that are necessary to address existing problems.

After approximately 15 years in service, this portion of the terminal exhibits in the order of 15% defective slabs of which approximately 10% require repairs and 5% need to be replaced. In this context, slab replacement (to the existing thickness) is included as a restoration technique while inlays and reconstruction involve larger areas and are associated with long term strategies or strategies considered at the end of the existing facility's life. In any event, a slab restoration program should be implemented as part of the maintenance programme at DCT. Slab restoration can extend pavement life by 8 to 15 years. This statement, however, should not be interpreted out of context, i.e. the restoration programme will not extend the life of the facility if it is operated under conditions that it was not designed for. The long term operational strategy therefore still dictates whether a slab restoration programme would be feasible or not.

As a general guideline, Table 27, lists typical restoration techniques and associated expected lives. The selection of an appropriate technique depends on the type and severity of distress. To achieve the desired performance, however, timely maintenance is important. During the current field investigation it was noted that joint seals and slot drains are poorly maintained. If not maintained, the probability of exposing the support/sub-base to unnecessary high moisture levels increases which may lead to higher levels of deterioration and eventually premature failures. An operational and maintenance plan, developed by pavement designers, can help define future maintenance needs.

Table 27: Typical concrete restoration techniques and expected life

Restoration Technique	Expected Life	Distress/ Problem
Full-depth repairs/ slab replacement	10 – 15 years	Slab cracking, faulting, pumping, deep spalling, structural deficiency
Partial-depth repairs	10 – 15 years	Shallow spalling
Joint resealing	5 – 15 years	Open joints, extruded and deteriorated seals
Crack sealing	10 years	Open cracks (as appose to hairline cracks)
Slab stabilization	No practical limit	Slab cracking, faulting, pumping, structural deficiency

Source: (John Knapton, 2007)

5.10 Reconstruction or inlays – concrete overlay versus reconstruction as a repair method to damaged concrete pavement at DCT

Concrete overlays for concrete pavement have not been used locally, but there is extensive experience of the method abroad, particularly in the United States of America where concrete as a paving material in port terminals, airports and highways remains popular. Asphalt overlays have been used more extensively locally, and recently in the Gauteng Freeway improvement programme, where both unreinforced, jointed and continuously reinforced, un-jointed pavements have been overlaid. For container terminals, asphalt overlays are not an option because of the high loading applied, particularly in the container stacks (John Knapton, 2007).

The need has never been greater for engineered strategies to preserve and maintain the nation's pavements. With shrinking budgets, ever-increasing traffic volumes and loads, and the critical emerging focus on infrastructure sustainability and pavement preservation, highway agencies are being asked to do more with less in managing their pavement networks (John Knapton, 2007). Concrete overlays can serve as sustainable and cost-effective solutions for improved management of pavement assets, including preservation, resurfacing, and rehabilitation. In addition, they contribute to more sustainable construction practices by preserving and extending pavement service for years beyond the original design life. Many concrete overlays have been in service for decades, effectively extending the life of the original pavement structures for 30 years or more (John Knapton, 2007).

For successful overlaying of an existing pavement, the pavement must be free of major structural defects. Where existing slabs have failed completely or exhibit active cracks, these must be rectified before overlaying. Passive cracks, which represent the majority of cracks in the DCT terminal, do not need to be repaired. Figure 40 shows a typical concrete pavement before and after repairs using concrete overlay.

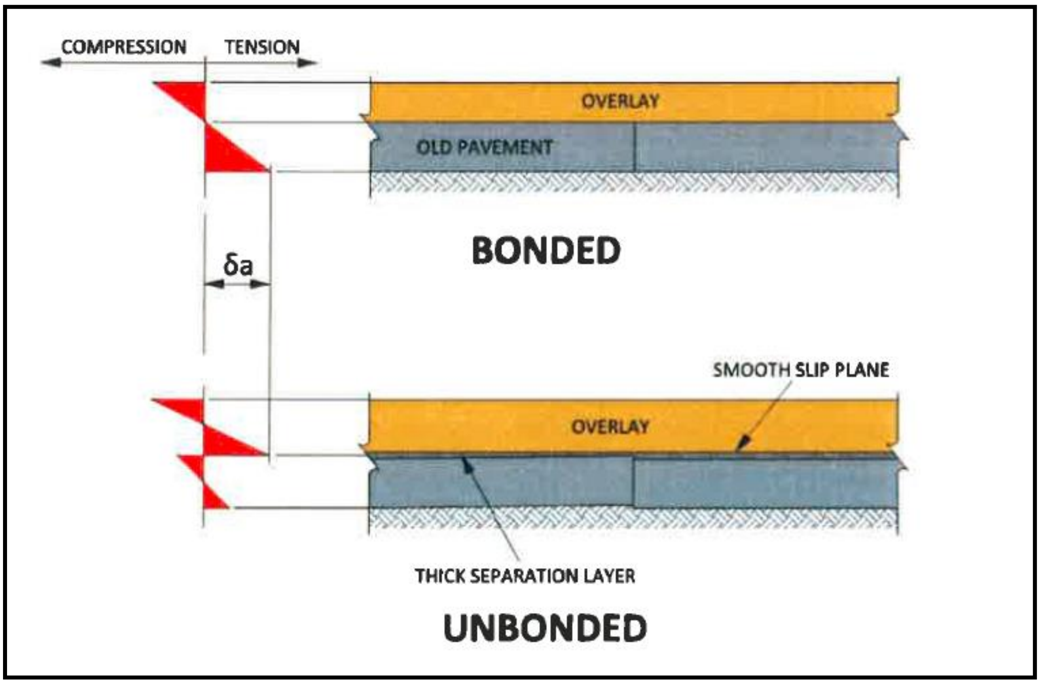
Figure 40: Typical concrete overlay [before (left) and after (right)]

5.10.1 Overlay alternatives

Concrete overlays may be of the bonded or un-bonded type. The structural differences are substantial and are graphically illustrated in Figure 41.

- Bonded overlays are constructed so as to be monolithic with the underlying slab, thereby strengthening the existing pavement. For successful application, full adhesion must be achieved and the existing concrete slabs must be essentially free from defects. The purpose of bonded concrete overlays is to add structural capacity and eliminate surface distresses on existing pavements that are in good to fair structural condition. Bonded overlays generally provide resurfacing solutions for routine or preventive pavement maintenance and for minor rehabilitation. The key to achieving desired performance is to ensure that the two structures, the existing pavement and the overlay, behave as one structure (John Knapton, 2007).
- An un-bonded overlay is separated from the existing pavement by a suitable separation layer. As there is no monolithic action with the existing slab, a thicker slab is required than in the case of a bonded overlay as illustrated in Figure 41. Un-bonded overlays are however more tolerant of defects in the existing slab and prevent reflective cracking. The purpose of an un-bonded overlay is to restore structural capacity to an existing pavement that was, moderately to significantly, deteriorated. Un-bonded overlays are minor or major rehabilitation strategies. The term “un-bonded” simply means that bonding between the overlay and the underlying pavement is not needed to achieve the desired performance (i.e., the thickness design procedure does not consider the existing pavement as a structural component of the surfacing layer). Thus, the overlay performs as a new pavement, and the existing pavement provides a stable base**.**

Figure 41: Structural differences between bonded and un-bonded overlays



Source: (John Knapton, 2007)

Table 28: Cost of reconstruction vs overlay cost estimate

Area /Phase	Remedial Measure	Unit cost	Discount factor	Period (Years)	NPV factor	Unit	Quantity		Overlay	Reconst
							Overlay	Reconst		
Berths 108-109	Reconstruct paving	1775			1.00	m²		442740	0	785 774 952
	Overlay Paving	954	1.08	0	1.00	m²	442740		422 152 590	0
	Repair existing paving for overlay (5%)	89	1.08	0	1.00	m²	442740		39 288 748	0
	Maintain new paving (@ 0.1% of reconstruct)	2	1.08	20	9.818	m²	442740	442740	4 144 694	7 714 738
	Replace slot drains with paving reconstruction	6799	1.08	0	1.00	m		14670	0	99 744 264
	Replace slot drains with paving overlay	7840	1.08	0	1.00	m	14670		115 012 800	0
	Maintain new slot drains (@5% of reconstruct)	34	1.08	20	9.818	m	14670	14670	4 896 446	4 896 446
	Sub Total								585 495 278	898 130 400
	P&G Costs (30%)					Sum			175 648 583	269 439 120
	Contingencies (20%)					Sum			117 098 056	179 626 080
	EPCM Costs (12%)					Sum			70 259 433	107 775 648
	Unit Cost (R/m²)								2142	3296
	Total								**948 502 350**	**1 454 971 249**

5.11 Cost of construction vs overlay

The cost of reconstructing the pavement is seen in Table 28 to be substantially higher than the cost of overlaying by approximately 50%. Construction time and operational disruption are also minimized. The use of a continuously reinforced, slip formed reinforced concrete overlay is appropriate for continued use of SC, particularly for the heavier 1/3 machines. Overlaying is usually used for RTG operation. A slightly thicker overlay is required for the 5 high stacking associated with RTG operation. The marginal cost of increasing the overlay thickness is however minimal.

The separation layer, dictated by the condition of the existing slabs, is generally a 25 mm asphalt layer. Apart from performing the de-bonding function, this separation layer facilitates the accommodation of moderate faulting, surface spalling and joint spalling in the existing slab without having to repair these defects.

The thickness of the overlay, which is dictated by the condition of the existing pavement and the thickness of the monolithic pavement required for the design load on the existing support, is calculated at 300 mm for 5 high stacking. This is based on the assumption that major defects in the existing slab will be rectified before overlaying. Slab reinforcement is designed on the basis of crack control. As it is desirable to limit crack spacing and crack width for the purpose of minimizing moisture ingress and shear transfer in the slab, the reinforcing content is selected accordingly. Figure 42 shows a typical concrete overlay of a pavement.

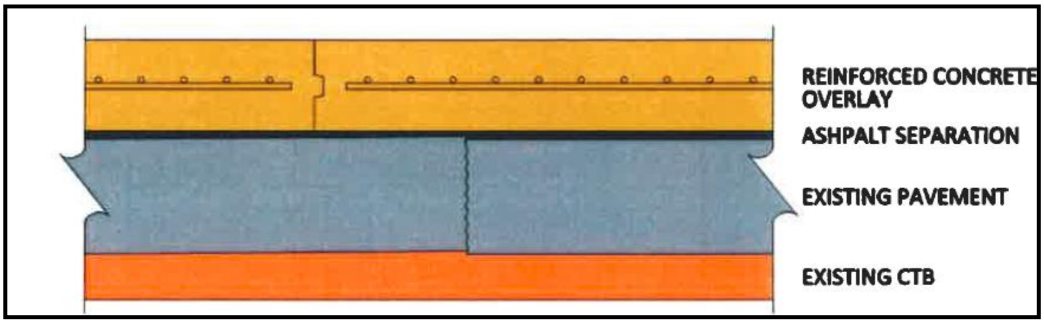


Figure 42: Concrete overlay of existing pavement
Source: Harrington and Fick (2014)

5.12 Drainage

The existing terminal is drained by way of slot drains running the length of the terminal at intervals of approximately 30 m. The average drain length is approximately 1000 m. As there are approximately 7 drains, the total length of the slot drains in the terminal is of the order of 7 km in the Berths 108 and 109 area. The drains comprise a precast top which incorporates the drainage slot, supported on a precast concrete base slab 2 m wide as shown in Figure 43. As the buttresses across the slots are inadequate to resist compressive forces arising from slab expansion, expansion joints are provided on either side of the drain as shown.

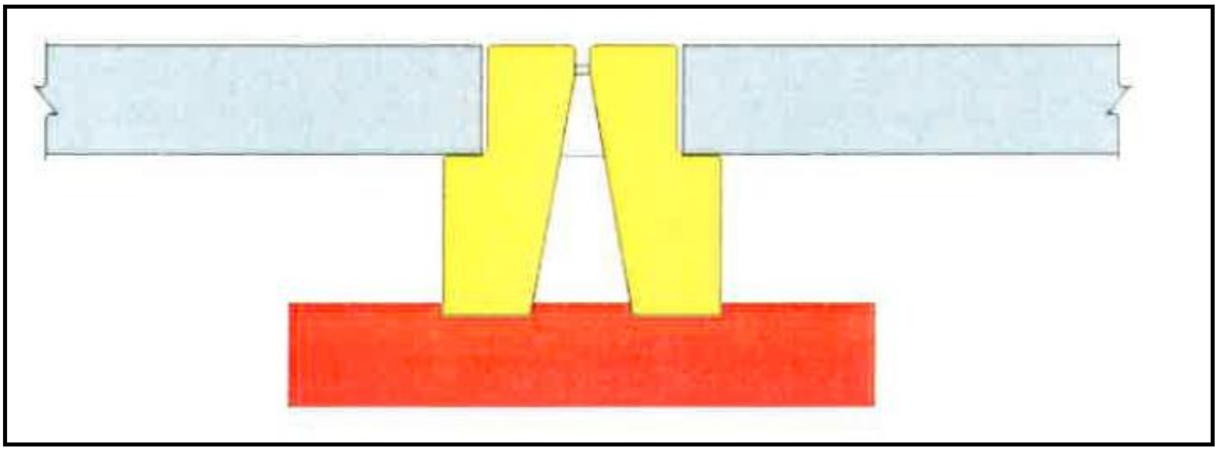


Figure 43: Profile of original slot drain
Source: Harrington and Fick (2014)

As a result of the flat soffit and the fact that there is no longitudinal gradient on the drains, flow rates in the drains are insufficient to carry sand to the catch-pits for removal. Consequently, many of the drains have become silted up and dysfunctional. Some of the pavement failure is attributed to saturation of the subgrade as a result of blocked drains. Another problem with these drains is their susceptibility to spalling. Although efforts to unblock the drain have been made, the difficulties reported have resulted in abandonment of cleaning efforts, and many of the drains remain blocked.

Since overlay strategies are not considered at DCT, reconstruction or inlay strategies are proposed for implementation at the end of the facility's serviceable life or alternatively as a phased construction approach to improve the capacity of the terminal over the long term. Reconstruction involves complete removal of the pavement structure and typically includes removal of the sub-base layer. Concrete pavement inlays allow engineering optimization of pavement reconstruction. Inlays can be used in selected areas without the need to change the elevation. Design slab thicknesses to accommodate different operational scenarios are based on the approach outlined in (Knapton, 2007) and summarised in Table 29.

Table 29: Concrete slab thickness requirement

Scenario	Life (years)	Slab Thickness (mm)			
		Plant: Travel Ways	Plant: Stacks	Container Stacking	Design
1: Straddles (3-high)	15	365	200	400	400
	20	395	200	400	400
	30	440	210	400	440
2: Straddle mix (3-high)	15	310	200	400	400
	20	350	200	400	400
	30	400	200	400	400
3: RTG (5-high)	15	N/A	340	455	455
	20		365	455	455
	30		420	455	455
4: RTG (3-high)	15	N/A	300	445	445
	20		315	445	445
	30		360	445	445
Note: Slab thickness based on 35 MPa concrete					

The thicknesses presented in Table 29 are based on high traffic scenarios and assume a channelization factor of 5. Stacking capacity generally dictates the design except for the SC scenarios over 30 years. The design concrete thickness for the different scenarios varies between 400 mm and 455 mm. Since stacking capacity dictates the design it is not necessary to consider traffic loading for the area west of Berth 109 separately. In addition, at this preliminary stage, no evidence exists that a separate design is required for dedicated truck lanes and a multi-functional facility is assumed. It is envisaged that the existing sub-base and subgrade will have to be reconstructed to a depth of at least 300 mm below the new slab consisting of 150 mm rip and re-compaction of the subgrade followed by construction of a high quality crushed stone sub-base or cement stabilised sub-base. Removal and reuse of the demolished concrete material includes:

- Coarse aggregate in new concrete reconstruction;
- Coarse aggregate for construction of cemented sub-base;

- Stock piling of material for base and sub-base material in road construction if applicable; and
- Disposal for non-pavement uses such as erosion control in ditches or shorelines.

5.13 Conclusions and recommendations

This chapter describes a comprehensive assessment of the condition of the Durban Port Terminal. The general findings from the assessment are:

- Visual assessment data indicate that approximately 15% of the covered area exhibits defective slabs of which approximately 10% require repairs while approximately 5% need replacement.
- Thickness data indicates good correlation on average with design thicknesses where such information exists.
- DCP data and visual inspection after coring suggest that a granular to weakly cemented sub-base exists below the slab supported by a strong subgrade. In some areas, and especially evident in the area west of Berth 109, a stronger cement stabilised sub-base is present although deteriorated and highly variable. The modulus of subgrade reaction back calculated from deflection tests represent this general situation well with values typically ranging between 50 MPa/m and 100 MPa/m.
- In general, good corner and joint supporting conditions throughout the terminal are seen with localised areas exhibiting poor joint transfer. In these areas corner breaks and/or minor faulting was observed during the visual inspection. The analysis assumes that joint and corner transfer will be restored as part of a concrete restoration programme.
- Based on all available data the evaluation area is not only divided geometrically between the Berths 108 and 109 area and the area west of Berth 109, but also in terms of structural performance.

The Berths 108 and 109 area generally performed better while the area west of Berth 109 showed poorer performance. The performance of the area west of Berth 109 may be ascribed to variability of the support. It is understood that this facility was constructed where a G-block facility previously existed. The originally stabilised crushed stone base was utilised for support of the concrete pavement after level corrections (mainly removal of the top portion) had been done. This anecdotal type of information confirms the existing observations and performance observed.

CHAPTER 6 - SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the conclusions and recommendations of the previous chapters regarding the determination of the most appropriate container handling infrastructure for the POD.

6.2 Conclusions and recommendations

From the literature review it is evident that the world's biggest and busiest port terminals have adopted the RTG system of operation.

During the detailed research conducted in the course of this study the outputs produced by SCs that are used in Pier 2 are compared to outputs produced by RTGs used in Pier 1. The production levels of RTGs far outweigh that of SCs in the POD. One of the reasons is with longer travelling distances TTUs are much quicker than SCs. A cost analysis indicated that the operating and purchase cost of a SC compared to a RTG is slightly lower, but the maintenance costs for SC are much higher. This differential is due to the fact that SCs break down more frequently than RTGs and the turnaround time to repair is much longer. SC accidents and collisions are quite common as well which results in downtime.

Many terminals internationally are turning to automation as it is a good opportunity to boost efficiency and reduce human handling which eliminates human error. The 2012/2013 Global Competitiveness Report by the World Economic Forum rated SA 140 out of 144 countries for low standards and lack of skills development. This has resulted in the creation of large uncompetitive labour force that will not be able to fit in this type of technological environment which will narrow down employment opportunities (Schwab, 2015).

The container terminal evaluation that was carried out on Berths 108 and 109 covered an area of approximately 300 000 m². There were different scenarios evaluated and RTG operation was proposed as a possible interim strategy. A visual assessment was carried out on Berths 108 and 109 and the data collected indicated that 30% percent of the slabs will require either localized repairs or routine maintenance therefore a Poor rating may be warranted. The reasons for panel failure were investigated. Table 30 shows the most common reasons found and related recommendations. Figures 44 to 50 illustrate various points made in Table 30.

Table 30: Recommendations for panel failures

Reason for panel failure	Recommendation
1. Improper placement of dowel bars	➢ Dowel and tie bars should be placed mid-depth of the slab. ➢ When installing dowel and tie bars loose concrete should be removed from the concrete face. ➢ A bond breaking compound should be applied to the face of the concrete and on one half of the dowel bar (the half that did not have epoxy applied to its surface) ➢ Dowel bars are generally placed transversely and tie bars longitudinally. ➢ When placing dowel and tie bars ensure that there is sufficient spacing between the bars to avoid clashing. ➢ To avoid poor joint performance and inadequate load transfer, dowel and tie bars should be placed at 90^o to the face of the concrete.
2. Fly ash used as infill material	➢ Firstly, trial pits were excavated (Figure 44) and samples were taken to the laboratory to test and confirm that the contaminated material was indeed fly ash. Thereafter all the fly ash material was cut and spoiled (Figure 45) and replaced with G5 and G2 up to the underside of the slab. The depth of the fly ash material went as far as 1 meter deep (Figure 46).
3. Damaged storm water pipes	➢ Due to the flooding of excavations because of high tides (Figure 47), a quick and effective solution had to be implemented when excavating down to the damaged stormwater pipe. The solution included bidim being wrapped around the vicinity of the collar and secured with binding wire (Figure 48).
4. Slot drains not being maintained	➢ After a slot drain is cleaned a team should return to that slot drain every 3 months, at least, due to the fact that oil and grease will always block the drain. ➢ Slot drain cleaning should be practiced on an ongoing basis and a full time drain cleaning team should be employed to carry out this task. ➢ The correct procedure to clean a slot drain is to firstly remove debris using a tool called a spoon (Figures 49 and 50) and thereafter perform hydro-jet cleaning of the drain.

5.	Unsuitable backfill material	➢ The unsuitable material should be removed and replaced with imported G10 and thereafter be completed with 150 mm of G5 and G2 up to the underside of the slab. After compaction of each of these layers, density tests should be carried out progressively. Density tests should be conducted at least every 300 mm on the G10 depending on the depth of the backfill.
6.	Joints not maintained	➢ Joints should be inspected on a regular basis and sealed when required. ➢ After sealing it is recommended that a pull out test be carried out.
7.	Failure along quay wall	➢ Fix bidim on the joint as a quick yet effective solution due to the flooding of excavations caused by high tides. Water pumps had to be used while repairing the quay wall to reduce the accumulation of water during high tides.

Figure 44: Trial pits

Figure 45: Contaminated material

Figure 46: Fly ash approximately 1m deep

Figure 47: Working against the tide

Figure 48: Wrapping bidim around the pipe

Figure 49: Spooning

Figure 50: Method of spooning

Remaining life estimates when subjecting the existing pavement to various plants associated with different operational strategies are summarised in Table 31. This analysis indicates that the facility would generally be able to accommodate traffic for at least 15 years while it is projected that some critical areas (approximately 25%) should be able to accommodate traffic for periods varying between 5 and 15 years.

Table 31: Structural capacity to accommodate handling plant

Scenario	Area	Estimated Remaining Life	Remaining Life Critical Areas*
1A: Straddles (3-high)	Straddle Ways	≥ 15 years	7 – 10 years
2A: Straddle Mix (3-high)	Straddle Ways	≥ 15 years	10 – 15 years
1B: Straddles (3-high)	Stacks	≥ 15 years	N/A
2B: Straddle Mix (3-high)	Stacks	≥ 15 years	N/A
3: RTGs (5-high)	Stacks	≥ 15 years	5 – 10 Years
4: RTGs (3-high)	Stacks	≥ 15 years	7 – 15 years
Notes:*Critical areas include A, HH5, O, P, Q, R, S, ED1, ED2, EC1, EC2; The area represents approximately 25% or approximately 62,500 m^2			

Table 31 summarises the results of the stacking capacity analysis. The results indicate that row stack capacity is marginal to good, while block stack capacity is generally poor. While the majority of the Berths 108 and 109 area will be able to accommodate 3 to 4 rows high stacking, the data reveal that the capacity is largely insufficient to accommodate block stacking. Table 32 summarises the findings of the evaluation

Table 32: Pavement stacking capacity

Row Stack Capacity				
Area	Maximum Row Stack Height	Remaining Life (years) when subjected to:		
		2-High Row	3-High Row	4-High Row
HH5,A,C,E ED1&2,EC1&2,O,P,Q,R,S	1 – (2) – 3	3 – (8) – 15	0.5 – (3) – 6	0.2 – (1) – 2
RR2,JJ5,GG5,B,D,F,G,H,N,J	2 – (3) – 4	≥10	6 – (10) – 15	2 – (7) – 15
FF5,FF6,HH6,M10,EE6, 178,888	3 – (4) – >4	≥15	10 – (15)-≥15	9 – (15)-≥15
Legend: Colours used as interpretation category of existing capacity relative to target capacity: Blue – Good, Green – Fair, Yellow – Marginal (to Poor in case of Block Stacking), Orange – Poor, Red – Very Poor, Relative Row and Block stacking capacity shown in Figures 8 & 9 Note: Where appropriate, capacity given as range Low – (Expected) – High				

Block Stack Capacity					
Area	Maximum Block Stack Height	Remaining Life (years) when subjected to:			
		1-High Block	2-High Block	3-High Block	4-High Block
HH5,JJ5,A,C,E,H ED1&2,EC1&2,O,P,Q,R,S	≤ 1	2 – (5) – 15	<0.5	<0.5	<0.5
RR2,GG5,B,D,F,G,N,J, 178	0 – (1) – 2	≥10	0.5 – (2) – 5	≤ 1	<0.5
FF5,FF6,HH6,M10,EE6, 888	1 – (2) – 3	≥15	5 – (12)-≥15	1.5 – (5)–12	0.3 – (2) – 4
Legend: Colours used as interpretation category of existing capacity relative to target capacity: Blue – Good, Green – Fair, Yellow – Marginal (to Poor in case of Block Stacking), Orange – Poor, Red – Very Poor, Relative Row and Block stacking capacity shown in Figures 8 & 9 Note: Where appropriate, capacity given as range Low – (Expected) – High					

Table 33: Evaluation summary

Scenario	Existing Facility: Remaining Life and Representative Areas				Reconstruction
	Interpretation Category[1]	Years	% of Total Area[2]	% of Berth 108&109[2]	Required Slab Thickness[3] (mm)
1 & 2: Straddles (3-high)	Marginal	≤ 6	40%	15%	400 (440)[4]
	Fair	6 - 15	30%	40%	
	Good	≥ 10	30%	45%	
3: RTG (5-high)	Very Poor	< 1	100%	100%	455
4: RTG (3-high)	Poor to Very Poor	< 1	75%	65%	445
	Marginal	≤ 6	25%	35%	

The evaluation summary (Table 33) suggests that container stacking is the critical consideration, as opposed to plant traffic, and will dictate the selection of a long-term strategy. After approximately 15 years in service, this portion of the terminal exhibits in the order of 15% defective slabs of which approximately 10% require repair and 5% need to be replaced. In this context, slab replacement (to the existing thickness) is included as a restoration technique while inlays and reconstruction refer to large areas motivated by operational changes that impact on the long-term strategy. In any event, a slab restoration program should be implemented as part of the maintenance programme at DCT. Slab restoration can extend pavement life by 8 to 15 years. Typical restoration techniques and associated life expectancies are included in the report. To achieve the desired performance, however, timely maintenance is important. During the current field investigation it was noted that joint seals and slot drains are poorly maintained. If not maintained, the probability of exposing the support/sub-base to unnecessary high moisture levels increases which may lead to higher levels of deterioration and eventually premature failures. An operational and maintenance plan, developed by pavement designers, can help define future maintenance needs.

Concrete overlays can serve as sustainable and cost-effective solutions for improved management of pavement assets, including preservation, resurfacing, and rehabilitation. In addition, they contribute to more sustainable construction practices by preserving and extending pavement service for years beyond the original design life. Since overlay strategies to increase structural capacity are not considered as a practical alternative at DCT, reconstruction or inlay strategies are proposed for implementation at the end of the facility's serviceable life or alternatively as a phased construction approach to improve the capacity of the terminal over the long term.

In conclusion, various scenarios were examined; however, this study strongly recommends that the POD adopt RTG operation.

The technical investigation outlines that reconstruction or inlay strategies are proposed as a repair method with slab thickness varying between 400 mm and 455 mm for design periods of up to 30 years. The possible reasons for panel failure have been highlighted in the study and potential solutions have been stipulated. It is recommended these solutions be used as a guide to ensure that the design life of the pavement is achievable.

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APPENDICES

Appendix A: List of publications and conference presentations

Publications

Naicker R and Allopi D, Visual assessments of current pavement conditions in the stack areas of berth 203-205 at the Durban Container Terminal – Pier 2, International Journal of Engineering Science and Management, Volume 4, No. 2, April-June 2014, pp.40-46, ISSN 2277-5528

Naicker R and Allopi D, Evaluating straddle carriers and rubber tyred gantry to determine the most suitable container handling infrastructure between the quay and stack area, International Journal of Innovative Science, Engineering and Technology, Volume 2, No. 5, May 2015, pp 134-142, ISSN 2348-7968

Naicker R and Allopi D, Failure in the Durban Container Terminal, Journal of the Institution of Municipal Engineering of Southern Africa, Volume 40, No. 5, May 2015, ISSN 0257 1978

Naicker R and Allopi D, Analysis of electric-rubber tyred gantries for a more green Durban Container Terminal, International Organisation of Scientific Research Journal of Engineering, Volume 5, Issue 6, June 2015, pp 24-28, ISSN 2250-3021

Naicker R and Allopi D, Investigation into the reasons behind panel failure in the Durban Container Terminal – Pier 2, International Journal of Engineering Sciences & Research Technology, Volume 4, No. 8, August 2015, pp 910-917, ISSN 2277-9655

Naicker R and Allopi D, The need for expansion of the Durban Container Terminal, International Journal of Constructive Research in Civil Engineering, Volume 1, Issue 2, July-September 2015, pp 33-38, ISSN 2454-8693

Naicker R and Allopi D, Automation versus National Development Plan, International Journal of Engineering Sciences & Management Research, Volume 2, No. 9, September 2015, pp 58-62, ISSN 2349-6193

Naicker R and Allopi D, Improving performance at the Durban Container Terminal through automation, *Civil Engineering*, South African Institution of Civil Engineering, Volume 23, No. 9, October 2015, pp 74-76, ISSN 1021-2000

Naicker R and Allopi D, Reducing Straddle Carrier accidents at the Port, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 12, Issue 6, Nov-Dec 2015, pp 61-65, ISSN 2278-1684

Naicker R and Allopi D, Lighting up the future of ports with LED, South African Institution of Civil Engineering (SAICE), Volume 24, No. 2, March 2016, pp 65-66, ISSN 1021-2000

Naicker R and Allopi D, Concrete overlay versus reconstructing as a repair method to damaged concrete pavement at the Durban Container Terminal, International Journal of Research & Development Organisation, Volume 2, Issue 4 April 2016, pp 60-65, ISSN 2456-1479

Naicker R and Allopi D, Moving on the right track – from road to rail, Elixir International Journal, Elixir Civil Engg.94 (2016) 40597-40600, ISSN 2229-712X

Conference proceedings

Naicker R and Allopi D, Concrete overlay as a possible solution to damaged concrete pavement at the Durban Container Terminal, Proceedings of the Institute of Research Engineers and Scientists International Conference, Puket, Thailand, pp 1-3, ISBN 978-93-86291-82-0, January 2017

Appendix B: Wheel load repetitions

<u>Current Operation: General</u>

Total teu's/ annum	2900000	teu
108 & 109 (25%)	725000	teu
108 & 109 Containers	518000	containers
teu conversion factor:	1.40	
6 m containers	259000	(teu factor 1.5)
12 m containers	259000	(teu factor 1.5)

108 & 109 Stacking Areas	eff. Rows	Depth	Total
EE6	27	19	513
FF5	32	18	570
FF6	21	18	378
GG5	33	18	594
HH5	33	18	594
HH6	8	18	144
JJ5	26	18	468
RR2	19	8	152
Total etu positions:			3413
Max Capcity 3-High			10239 etu's

<u>Capacity:</u>

Current SC Row Stacks: 3-High

teu #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Side-by-Side (Transversally)	4.14	4.14	4.14	4.14	4.14	4.14	1.7											
Door-to-Door (Longitudinally)	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26
Height:	3																	
etu's/block	630																	
Effective Block Volume:	26977 m3																	

teu #	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Total
Side-by-Side (Transversally)																		26.54
Door-to-Door (Longitudinally)	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.06	218.9

Possible SC Row Stacks: 4-High

teu #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Side-by-Side (Transversally)	4.14	4.14	4.14	4.14	4.14	4.14	1.7											
Door-to-Door (Longitudinally)	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26
Height:	4																	
etu's/block	840																	
Effective Block Volume:	35970 m3																	
Capacity increase:	33.3 %																	

teu #	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Total
Side-by-Side (Transversally)																		26.54
Door-to-Door (Longitudinally)	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.06	218.9

RTG Block stacks: 5-High (Typically 6 wide x 32 to 34 teu's deep)

teu #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Width:	2.79	2.79	2.79	2.79	2.79	2.44	10.18											
Depth:	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40
Height:	5																	
etu's/block	1020																	
Effective Block Volume:	43678 m3																	
Capacity increase:	61.9 %	(figure excludes the utilization of available straddle way areas)																

teu #	19	20	21	22	23	24	24	26	27	28	29	30	31	32	33	34	Total
Width:																	26.57
Depth:	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.06	217.26

General:

Total teu's/ annum	2900000 teu
108 & 109 (25%)	725000 teu
108 & 109 Containers	518000 containers
6 m containers	259000 (teu factor 1.5)
12 m containers	259000 (teu factor 1.5)

Trips:

@ container generates 2 loaded trips
2 unloaded trips

Assumption:

1) Loaded and unloaded trips follow same path
2) Stacks: Two trips generated follow same path (from quay side to stack and from stack to transfer)
3) Travel Ways: Two trips genrated do not follow the same path

STACKS

Capacity based on current operation, stacking 3 high

					Loaded				Unloaded			
108 & 109 Stacks	Positions	% Total	Annually	Rows	Reps/Row	Reps/WP	Design Reps	Daily/Reps	Reps/Row	Reps/WP	Design Reps	Daily/Reps
EE6	518	15.1	78434	27	2905	5810	11620	32	2905	5810	11620	32
FF5	570	16.7	86308	32	2726	5451	10902	30	2726	5451	10902	30
FF6	379	11.1	57387	21	2733	5465	10931	30	2733	5465	10931	30
GG5	594	17.4	89942	33	2726	5451	10902	30	2726	5451	10902	30
HH5	594	17.4	89942	33	2726	5451	10902	30	2726	5451	10902	30
HH6	141	4.1	21350	8	2669	5337	10675	29	2669	5337	10675	29
JJ5	471	13.8	71318	26	2743	5486	10972	30	2743	5486	10972	30
RR2	154	4.5	23318	19	1227	2455	4909	13	1227	2455	4909	13
Total	3421	100	518000									

Capacity per position 151 annual container throughput

					Loaded				Unloaded			
West of 109	Positions	Annually	% Total	Rows	Reps/Row	Reps/WP	Design Reps	Daily/Reps	Reps/Row	Reps/WP	Design Reps	Daily/Reps
EC2	341	51633	25.6	30	1721	3442	6884	19	1721	3442	6884	19
ED2	254	38460	19.1	23	1666	3331	6662	18	1666	3331	6662	18
EC1	450	68138	33.8	30	2271	4543	9085	25	2271	4543	9085	25
ED1	285	43154	21.4	19	2271	4543	9085	25	2271	4543	9085	25
Total	1481	201386	100									

Excluded:

M10-12 (empties)	348 (low traffic)
EE1 (178 & 168 Reefers)	200 (used by larger terminal)

STRADDLE WAYS

Berths 108 & 109					
Low:					
108 & 109 Stacks	Positions	% Total	Annually	Reps	Daily
GG5	594	17.4	89942	44971	
HH5	594	17.4	89942	44971	
Total Loaded Reps				89942	246
Total Unloaded Reps				89942	246
Expected:					
108 & 109 Stacks	Positions	% Total	Annually	Reps	Daily
EE6	499	14.6	75557	0	
FF5	570	16.7	86308	43154	
FF6	379	11.1	57387	28694	
GG5	594	17.4	89942	89942	
HH5	594	17.4	89942	89942	
HH6	141	4.1	21350	21350	
JJ5	471	13.8	71318	71318	
RR2	154	4.5	23318	23318	
Total Loaded Reps				367718	1007
Total Unloaded Reps				367718	1007
High:					Daily
Total Loaded Reps				518000	1419
Total Unloaded Reps				518000	1419

West of 109					
Low:					
East of 109	Positions	% Total	Annually	Reps	Daily
EC1	450	33.8	68519	34259	
ED1	285	21.4	43395	21698	
Total Loaded Reps				55957	153
Total Unloaded Reps				55957	153
Expected:					
East of 109	Positions	% Total	Annually	Reps	Daily
EC2	341	25.6	51922	25961	
ED2	254	19.1	38675	19337	
EC1	450	33.8	68519	34259	
ED1	285	21.4	43395	21698	
Total Loaded Reps				101255	277
Total Unloaded Reps				101255	277
High:					
South Quay	Positions	% Total	Annually	Reps	Daily
EC2	341	10.9	51633	51633	
ED2	254	8.1	38460	38460	
EC1	450	14.3	68138	68138	
ED1	285	9.1	43154	43154	
231	285	9.1	43154	43154	
EB2(S)	341	10.9	51633	51633	
EB2(N)	285	9.1	43154	43154	
EB1	450	14.3	68138	68138	
EA1	450	14.3	68138	68138	
Total	3141	100.0	475603	475603	
Total Loaded Reps				475603	1303
Total Unloaded Reps				475603	1303

H-3

RTGs

General:

Current max etu Row st. capacity:	10239	etu's	
Current Annual Throughput:	725000	etu's	
Block stacks / 108 & 109 area:	21		
etu's per block:	1020		
Max etu Block stack capacity:	21420	etu's	
Projected RTG Annual Throughput:	**1516700.85**	**etu's**	
Increased Capacity*:	109	%	High, but more conservative
Assumed % of current productivity:	85	%	Same area used for double the throughput?
Eff. Projected RTG Throughput:	1289196	etu's	Only investigated, not used
Eff. Increased Capacity:	78	%	More realistic?
Containers handled (etu factor 1.4)	**1083657**	**Containers**	
Containers handled/block	**51603**		

Note: *As a check, if RTG stacks 3 high the capacity still increases with 26%.
This increase can be attributed to more efficient utilization of space (21 blocks).
It is assumed that this increase is largely due to elimination of SC travel ways.

Operational Assumptions:

1) Gantry will stack in one position/bay as long as possible
2) Assume that at least 5 to 6 containers will be stacked in one bay at a time, maximum 30
3) Depending on the stacking efficiency, each bay generates:
   2 dynamic unloaded movements: to stack and unstack with 50% chance of repetition, i.e effectivley 1 movement
   2 dynamic unloaded leave movements with 50% chance of a repetition, i.e. effectively 1 movement
   2 Static loaded movements during stack and unstack
   Therfore: 2 dynamic loaded and 2 static loaded
4) Therefore, depending on stacking efficiency:

Repetitions/ bay	4
Min containers handled at bay:	6
Max Repetitions/ container	0.67
Max containers handled at bay:	30
Min Repetitions/ container	0.13
Average repetitions/ container	0.4

Annual Wheel Load Repetitions (empty + loaded)		Loaded	Unoaded
Min Annual RTG Repetitions	6880	3440	3440
Min Daily RTG Repetitions	19	9	9
Avg Annual RTG Repetitions	20641	10321	10321
Avg Daily RTG Repetitions	57	28	28
Max Annual RTG Repetitions	34402	17201	17201
Max Daily RTG Repetitions	94	47	47

Appendix C: Stacking capacity and wheel load structural capacity

CF Approach (85th%)

Section	H (mm)	Stacking Capacity - Ed3			Stack Capacity - Ed4			Repetition Curves (Million Repetitions)							
	Eq. C10	S	R	B	S	R	B	2R	3R	4R	1B	2B	3B	4B	5B
A	131	1	0	0	0	0	0	0	0	0	0	0	0	0	0
B	517	8	8	3	7	2	1	9	5	2.4	7.5	0.4100	0.0460	0.0120	0.0062
C	417	8	5	1	2	0	0	5	1.3	0.25	3.4	0.0942	0.0087	0.0018	0.0008
D	497	8	7	2	6	2	0	8	4	1.5	7	0.2250	0.0455	0.0120	0.0061
E	488	8	7	2	6	2	0	7.5	3.7	1.2	6	0.1500	0.0432	0.0113	0.0058
F	655	8	8	5	8	8	5	20	11	8.5	15.3	4.5	1.2	0.41	0.20
G	524	8	8	3	7	2	1	9	5	2.4	7.5	0.4100	0.0460	0.0120	0.0062
H	467	8	6	2	5	1	0	7	2.8	1	5.5	0.1870	0.0208	0.0048	0.0023
J	501	8	7	2	6	2	1	8	4	1.5	7	0.2250	0.0455	0.0120	0.0061
N	488	8	7	2	6	2	0	7.5	3.7	1.2	6	0.1500	0.0432	0.0113	0.0058
O	323	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
P	323	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
Q	336	7	2	1	0	0	0	2	0.245	0.120	1.2	0.017	0.00091	0.00013	0.00005
R	323	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
S	319	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
RR2	505	8	7	2	6	2	1	8	4	1.5	7	0.2250	0.0455	0.0120	0.0061
JJ5	524	8	8	3	7	2	1	9	5	2.4	7.5	0.4100	0.0460	0.0120	0.0062
HH5	305	6	2	1	0	0	0	1	0.1424	0.0506	0.25	0.0064	0.0003	0.0000	0.0000
HH6	647	8	8	5	8	8	5	20	11	8.5	15.3	4.5	1.2	0.41	0.20
GG5	484	8	6	2	6	2	0	7.5	3.7	1.2	6	0.1500	0.0432	0.0113	0.0058
M10	655	8	8	5	8	8	5	20	11	8.5	15.3	4.5	1.2	0.41	0.20
FF5	647	8	8	5	8	8	5	20	11	8.5	15.3	4.5	1.2	0.41	0.20
FF6	647	8	8	5	8	8	5	20	11	8.5	15.3	4.5	1.2	0.41	0.20
EE6	647	8	8	5	8	8	5	20	11	8.5	15.3	4.5	1.2	0.41	0.20
178	624	8	8	7	8	8	5	15.3	9.5	7.5	12	3	0.72	0.2	0.15
888	645	8	8	5	8	8	5	20	11	8.5	15.3	4.5	1.2	0.41	0.20
ED1	323	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
ED2	319	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
EC1	332	7	2	1	0	0	0	2	0.245	0.120	1.2	0.017	0.00091	0.00013	0.00005
EC2	281	6	2	0	0	0	0	0.4	0.127	0.045	0.358	0.0057	0.0003	0.0000	0.0000
Weighted Avg	484	7.5	5.6	2.8	4.7	3.3	1.8	9.5	5.0	3.3	7.3	1.5	0.4	0.1	0.1

FS Approach (85th%)

Section	H (mm)	Stacking Capacity - Ed3			Stack Capacity - Ed4			Edition 4 Repetition Curves							
	Eq. C10	S	R	B	S	R	B	2R	3R	4R	1B	2B	3B	4B	5B
A	380	8	4	1	1	0	0	3.4	0.56	0.18	1.8	0.0282	0.0018	0.0003	0.0001
B	500	8	7	2	6	2	1	8	4	1.5	7	0.225	0.0455	0.01195	0.00608
C	450	8	6	2	4	1	0	6	2.1	0.72	4.5	0.1755	0.0195	0.0045	0.0022
D	514	8	7	2	7	2	1	9	5	2.4	7.5	0.41	0.046	0.012042	0.006156
E	470	8	5	2	5	1	0	7	2.8	1	5.5	0.1870	0.0208	0.0048	0.0023
F	543	8	8	4	8	3	1	10	6	3.4	8	0.72	0.096	0.028	0.015
G	543	8	8	4	8	3	1	10	6	3.4	8	0.72	0.096	0.028	0.015
H	486	8	7	2	6	2	0	7.5	3.7	1.2	6	0.15	0.043198	0.0113	0.0058
J	519	8	8	3	7	2	1	9	5	2.4	7.5	0.41	0.046	0.012042	0.006156
N	506	8	7	2	6	2	1	8	4	1.5	7	0.225	0.0455	0.01195	0.00608
O	469	8	6	2	5	1	0	7	2.8	1	5.5	0.1870	0.0208	0.0048	0.0023
P	536	8	8	3	7	3	1	10	6	3.4	8	0.72	0.096	0.028	0.015
Q	488	8	7	2	6	2	0	7.5	3.7	1.2	6	0.15	0.043198	0.0113	0.0058
R	375	8	4	1	1	0	0	3.4	0.56	0.18	1.8	0.0282	0.0018	0.0003	0.0001
S	308	6	2	1	0	0	0	1	0.1424	0.0506	0.25	0.0064	0.0003	0.0000	0.0000
RR2	523	8	8	3	7	2	1	9	5	2.4	7.5	0.41	0.046	0.012042	0.006156
JJ5	475	8	6	2	6	2	0	7	2.8	1	5.5	0.1870	0.0208	0.0048	0.0023
HH5	315	6	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
HH6	625	8	8	7	8	8	5	15.3	9.5	7.5	12	3	0.72	0.2	0.15
GG5	536	8	8	3	7	3	1	10	6	3.4	8	0.72	0.096	0.028	0.015
M10	585	8	8	5	8	5	2	11.5	7.5	5	10	1.5	0.2125	0.0709	0.0410
FF5	577	8	8	5	8	5	2	11.5	7.5	5	10	1.5	0.2125	0.0709	0.0410
FF6	577	8	8	5	8	5	2	11.5	7.5	5	10	1.5	0.2125	0.0709	0.0410
EE6	625	8	8	7	8	8	5	15.3	9.5	7.5	12	3	0.72	0.2	0.15
178	517	8	8	3	7	2	1	9	5	2.4	7.5	0.41	0.046	0.012042	0.006156
888	575	8	8	5	8	5	2	11.5	7.5	5	10	1.5	0.2125	0.0709	0.0410
ED1	375	8	4	1	1	0	0	3.4	0.56	0.18	1.8	0.0282	0.0018	0.0003	0.0001
ED2	370	8	3	1	1	0	0	3.4	0.56	0.18	1.8	0.0282	0.0018	0.0003	0.0001
EC1	321	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
EC2	326	7	2	1	0	0	0	1.5	0.238	0.090	0.9	0.0128	0.0007	0.0001	0.0000
Weighted Avg	484	7.7	6.2	2.9	5.3	2.5	1.0	7.8	4.3	2.5	6.3	0.7	0.1	0.0	0.0

CF Approach (85th%)

Section	Remaining Life - Low Estimate (Years)								Remaining Life - Middle Estimate (Years)								Remaining Life - High Estimate (Years)							
	2R	3R	4R	1B	2B	3B	4B	5B	2R	3R	4R	1B	2B	3B	4B	5B	2R	3R	4R	1B	2B	3B	4B	5B
A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B	> 15	8.62	4.14	12.93	0.71	0.08	0.02	0.01	> 15	> 15	14.1	> 15	2.41	0.27	0.07	0.04	> 15	> 15	> 15	> 15	5.86	0.66	0.17	0.09
C	8.62	2.24	0.43	5.86	0.16	0.02	0.00	0.00	> 15	7.65	1.5	> 15	0.55	0.05	0.01	0.00	> 15	> 15	3.57	> 15	1.35	0.12	0.03	0.01
D	13.79	6.90	2.59	12.07	0.39	0.08	0.02	0.01	> 15	> 15	8.8	> 15	1.32	0.27	0.07	0.04	> 15	> 15	> 15	> 15	3.21	0.65	0.17	0.09
E	12.93	6.38	2.07	10.34	0.26	0.07	0.02	0.01	> 15	> 15	7.1	> 15	0.88	0.25	0.07	0.03	> 15	> 15	> 15	> 15	2.14	0.62	0.16	0.08
F	> 15	> 15	14.66	> 15	7.76	2.07	0.71	0.34	> 15	> 15	> 15	> 15	> 15	7.06	2.41	1.18	> 15	> 15	> 15	> 15	> 15	> 15	5.86	2.86
G	> 15	8.62	4.14	12.93	0.71	0.08	0.02	0.01	> 15	> 15	14.1	> 15	2.41	0.27	0.07	0.04	> 15	> 15	> 15	> 15	5.86	0.66	0.17	0.09
H	12.07	4.83	1.72	9.48	0.32	0.04	0.01	0.00	> 15	> 15	5.9	> 15	1.10	0.12	0.03	0.01	> 15	> 15	14.29	> 15	2.67	0.30	0.07	0.03
J	13.79	6.90	2.59	12.07	0.39	0.08	0.02	0.01	> 15	> 15	8.8	> 15	1.32	0.27	0.07	0.04	> 15	> 15	> 15	> 15	3.21	0.65	0.17	0.09
N	12.93	6.38	2.07	10.34	0.26	0.07	0.02	0.01	> 15	> 15	7.1	> 15	0.88	0.25	0.07	0.03	> 15	> 15	> 15	> 15	2.14	0.62	0.16	0.08
O	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
P	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
Q	3.45	0.42	0.21	2.07	0.03	0.00	0.00	0.00	11.76	1.44	0.7	7.06	0.10	0.01	0.00	0.00	> 15	3.50	1.71	> 15	0.24	0.01	0.00	0.00
R	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
S	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
RR2	13.79	6.90	2.59	12.07	0.39	0.08	0.02	0.01	> 15	> 15	8.8	> 15	1.32	0.27	0.07	0.04	> 15	> 15	> 15	> 15	3.21	0.65	0.17	0.09
JJ5	> 15	8.62	4.14	12.93	0.71	0.08	0.02	0.01	> 15	> 15	14.1	> 15	2.41	0.27	0.07	0.04	> 15	> 15	> 15	> 15	5.86	0.66	0.17	0.09
HH5	1.72	0.25	0.09	0.43	0.01	0.00	0.00	0.00	5.88	0.84	0.3	1.47	0.04	0.00	0.00	0.00	14.29	2.03	0.72	3.57	0.09	0.00	0.00	0.00
HH6	> 15	> 15	14.66	> 15	7.76	2.07	0.71	0.34	> 15	> 15	> 15	> 15	> 15	7.06	2.41	1.18	> 15	> 15	> 15	> 15	> 15	> 15	5.86	2.86
GG5	12.93	6.38	2.07	10.34	0.26	0.07	0.02	0.01	> 15	> 15	7.1	> 15	0.88	0.25	0.07	0.03	> 15	> 15	> 15	> 15	2.14	0.62	0.16	0.08
M10	> 15	> 15	14.66	> 15	7.76	2.07	0.71	0.34	> 15	> 15	> 15	> 15	> 15	7.06	2.41	1.18	> 15	> 15	> 15	> 15	> 15	> 15	5.86	2.86
FF5	> 15	> 15	14.66	> 15	7.76	2.07	0.71	0.34	> 15	> 15	> 15	> 15	> 15	7.06	2.41	1.18	> 15	> 15	> 15	> 15	> 15	> 15	5.86	2.86
FF6	> 15	> 15	14.66	> 15	7.76	2.07	0.71	0.34	> 15	> 15	> 15	> 15	> 15	7.06	2.41	1.18	> 15	> 15	> 15	> 15	> 15	> 15	5.86	2.86
EE6	> 15	> 15	14.66	> 15	7.76	2.07	0.71	0.34	> 15	> 15	> 15	> 15	> 15	7.06	2.41	1.18	> 15	> 15	> 15	> 15	> 15	> 15	5.86	2.86
178	> 15	> 15	12.93	> 15	5.17	1.24	0.34	0.26	> 15	> 15	> 15	> 15	> 15	4.24	1.18	0.88	> 15	> 15	> 15	> 15	> 15	10.29	2.86	2.14
888	> 15	> 15	14.66	> 15	7.76	2.07	0.71	0.34	> 15	> 15	> 15	> 15	> 15	7.06	2.41	1.18	> 15	> 15	> 15	> 15	> 15	> 15	5.86	2.86
ED1	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
ED2	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
EC1	3.45	0.42	0.21	2.07	0.03	0.00	0.00	0.00	11.76	1.44	0.7	7.06	0.10	0.01	0.00	0.00	> 15	3.50	1.71	> 15	0.24	0.01	0.00	0.00
EC2	0.69	0.22	0.08	0.62	0.01	0.00	0.00	0.00	2.35	0.75	0.3	2.10	0.03	0.00	0.00	0.00	5.71	1.82	0.65	5.11	0.08	0.00	0.00	0.00

FS Approach (85th%)

Section	Remaining Life - Low Estimate (Years)								Remaining Life - Middle Estimate (Years)								Remaining Life - High Estimate (Years)							
	2R	3R	4R	1B	2B	3B	4B	5B	2R	3R	4R	1B	2B	3B	4B	5B	2R	3R	4R	1B	2B	3B	4B	5B
A	5.86	0.97	0.30	3.10	0.05	0.00	0.00	0.00	> 15	3.29	1.0	10.59	0.17	0.01	0.00	0.00	> 15	8.00	2.51	> 15	0.40	0.03	0.00	0.00
B	13.79	6.90	2.59	12.07	0.39	0.08	0.02	0.01	> 15	> 15	8.8	> 15	1.32	0.27	0.07	0.04	> 15	> 15	> 15	> 15	3.21	0.65	0.17	0.09
C	10.34	3.62	1.24	7.76	0.30	0.03	0.01	0.00	> 15	12.35	4.2	> 15	1.03	0.11	0.03	0.01	> 15	> 15	10.29	> 15	2.51	0.28	0.06	0.03
D	> 15	8.62	4.14	12.93	0.71	0.08	0.02	0.01	> 15	> 15	14.1	> 15	2.41	0.27	0.07	0.04	> 15	> 15	> 15	> 15	5.86	0.66	0.17	0.09
E	12.07	4.83	1.72	9.48	0.32	0.04	0.01	0.00	> 15	> 15	5.9	> 15	1.10	0.12	0.03	0.01	> 15	> 15	14.29	> 15	2.67	0.30	0.07	0.03
F	> 15	10.34	5.86	13.79	1.24	0.17	0.05	0.03	> 15	> 15	> 15	> 15	4.24	0.57	0.17	0.09	> 15	> 15	> 15	> 15	10.29	1.38	0.41	0.22
G	> 15	10.34	5.86	13.79	1.24	0.17	0.05	0.03	> 15	> 15	> 15	> 15	4.24	0.57	0.17	0.09	> 15	> 15	> 15	> 15	10.29	1.38	0.41	0.22
H	12.93	6.38	2.07	10.34	0.26	0.07	0.02	0.01	> 15	> 15	7.1	> 15	0.88	0.25	0.07	0.03	> 15	> 15	> 15	> 15	2.14	0.62	0.16	0.08
J	> 15	8.62	4.14	12.93	0.71	0.08	0.02	0.01	> 15	> 15	14.1	> 15	2.41	0.27	0.07	0.04	> 15	> 15	> 15	> 15	5.86	0.66	0.17	0.09
N	13.79	6.90	2.59	12.07	0.39	0.08	0.02	0.01	> 15	> 15	8.8	> 15	1.32	0.27	0.07	0.04	> 15	> 15	> 15	> 15	3.21	0.65	0.17	0.09
O	12.07	4.83	1.72	9.48	0.32	0.04	0.01	0.00	> 15	> 15	5.9	> 15	1.10	0.12	0.03	0.01	> 15	> 15	14.29	> 15	2.67	0.30	0.07	0.03
P	> 15	10.34	5.86	13.79	1.24	0.17	0.05	0.03	> 15	> 15	> 15	> 15	4.24	0.57	0.17	0.09	> 15	> 15	> 15	> 15	10.29	1.38	0.41	0.22
Q	12.93	6.38	2.07	10.34	0.26	0.07	0.02	0.01	> 15	> 15	7.1	> 15	0.88	0.25	0.07	0.03	> 15	> 15	> 15	> 15	2.14	0.62	0.16	0.08
R	5.86	0.97	0.30	3.10	0.05	0.00	0.00	0.00	> 15	3.29	1.0	10.59	0.17	0.01	0.00	0.00	> 15	8.00	2.51	> 15	0.40	0.03	0.00	0.00
S	1.72	0.25	0.09	0.43	0.01	0.00	0.00	0.00	5.88	0.84	0.3	1.47	0.04	0.00	0.00	0.00	14.29	2.03	0.72	3.57	0.09	0.00	0.00	0.00
RR2	> 15	8.62	4.14	12.93	0.71	0.08	0.02	0.01	> 15	> 15	14.1	> 15	2.41	0.27	0.07	0.04	> 15	> 15	> 15	> 15	5.86	0.66	0.17	0.09
JJ5	12.07	4.83	1.72	9.48	0.32	0.04	0.01	0.00	> 15	> 15	5.9	> 15	1.10	0.12	0.03	0.01	> 15	> 15	14.29	> 15	2.67	0.30	0.07	0.03
HH5	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
HH6	> 15	> 15	12.93	> 15	5.17	1.24	0.34	0.26	> 15	> 15	> 15	> 15	> 15	4.24	1.18	0.88	> 15	> 15	> 15	> 15	> 15	10.29	2.86	2.14
GG5	> 15	10.34	5.86	13.79	1.24	0.17	0.05	0.03	> 15	> 15	> 15	> 15	4.24	0.57	0.17	0.09	> 15	> 15	> 15	> 15	10.29	1.38	0.41	0.22
M10	> 15	12.93	8.62	> 15	2.59	0.37	0.12	0.07	> 15	> 15	> 15	> 15	8.82	1.25	0.42	0.24	> 15	> 15	> 15	> 15	> 15	3.04	1.01	0.59
FF5	> 15	12.93	8.62	> 15	2.59	0.37	0.12	0.07	> 15	> 15	> 15	> 15	8.82	1.25	0.42	0.24	> 15	> 15	> 15	> 15	> 15	3.04	1.01	0.59
FF6	> 15	12.93	8.62	> 15	2.59	0.37	0.12	0.07	> 15	> 15	> 15	> 15	8.82	1.25	0.42	0.24	> 15	> 15	> 15	> 15	> 15	3.04	1.01	0.59
EE6	> 15	> 15	12.93	> 15	5.17	1.24	0.34	0.26	> 15	> 15	> 15	> 15	> 15	4.24	1.18	0.88	> 15	> 15	> 15	> 15	> 15	10.29	2.86	2.14
178	> 15	8.62	4.14	12.93	0.71	0.08	0.02	0.01	> 15	> 15	14.1	> 15	2.41	0.27	0.07	0.04	> 15	> 15	> 15	> 15	5.86	0.66	0.17	0.09
888	> 15	12.93	8.62	> 15	2.59	0.37	0.12	0.07	> 15	> 15	> 15	> 15	8.82	1.25	0.42	0.24	> 15	> 15	> 15	> 15	> 15	3.04	1.01	0.59
ED1	5.86	0.97	0.30	3.10	0.05	0.00	0.00	0.00	> 15	3.29	1.0	10.59	0.17	0.01	0.00	0.00	> 15	8.00	2.51	> 15	0.40	0.03	0.00	0.00
ED2	5.86	0.97	0.30	3.10	0.05	0.00	0.00	0.00	> 15	3.29	1.0	10.59	0.17	0.01	0.00	0.00	> 15	8.00	2.51	> 15	0.40	0.03	0.00	0.00
EC1	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00
EC2	2.59	0.41	0.16	1.55	0.02	0.00	0.00	0.00	8.82	1.40	0.5	5.29	0.08	0.00	0.00	0.00	> 15	3.40	1.28	12.86	0.18	0.01	0.00	0.00

Condition Factor Approach (95% Reliability)

		1A: Straddle Ways			2A: Straddle Mix			1B: Strad in Stacks			2B: Straddle Mix			RTG (5-High)			4: RTG (3-High)		
Area	%Risk	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
A	5	1	0	0	1	0	0	4	3	2	2	1	1	1	0	0	1	0	0
B	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
C	5	> 15	> 15	11	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	13	> 15	> 15	> 15
D	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
E	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
F	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
G	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
H	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
J	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
N	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
O	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
P	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
Q	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
R	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
S	5	> 15	10	7	> 15	12	9	> 15	> 15	> 15	> 15	> 15	> 15	15	5	3	> 15	8	5
RR2	5	> 15	> 15	13	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
JJ5	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
HH5	5	> 15	10	7	> 15	11	8	> 15	> 15	> 15	> 15	> 15	> 15	15	5	3	> 15	8	5
HH6	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
GG5	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
M10	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF5	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF6	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
EE6	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
178	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
888	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
ED1	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
ED2	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
EC1	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
EC2	5	> 15	7	5	> 15	8	5	> 15	> 15	> 15	> 15	> 15	> 15	4	1	1	6	2	1
Daily Traffic																			
108&109		513	2095	2952	186	761	1071	160	250	330	60	95	120	185	555	930	120	335	550
109 West		319	577	2710	116	209	984												
General Traffic SF		1																	
Channelised SF		5																	

Condition Factor Approach (85% Reliability)

		1A: Straddle Ways			2A: Straddle Mix			1B: Strad in Stacks			2B: Straddle Mix			RTG (5-High)			4: RTG (3-High)		
Area	%Risk	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
A	15	1	0	0	< 1	< 1	< 1	4	3	2	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
B	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
C	15	> 15	> 15	11	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	13	> 15	> 15	> 15
D	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
E	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
F	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
G	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
H	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
J	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
N	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
O	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
P	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
Q	15	> 15	10	7	> 15	14	10	> 15	> 15	> 15	> 15	> 15	> 15	> 15	7	4	> 15	12	7
R	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
S	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
RR2	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
JJ5	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
HH5	15	> 15	10	7	> 15	11	8	> 15	> 15	> 15	> 15	> 15	> 15	15	5	3	> 15	8	5
HH6	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
GG5	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
M10	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF5	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF6	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
EE6	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
178	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
888	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
ED1	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
ED2	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
EC1	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
EC2	15	> 15	7	5	> 15	8	5	> 15	> 15	> 15	> 15	> 15	> 15	4	1	1	6	2	1
Daily Traffic																			
108&109		513	2095	2952	186	761	1071	160	250	330	60	95	120	185	555	930	120	335	550
109 West		319	577	2710	116	209	984												
General Traffic SF		1																	
Channelised SF		5																	

Flexural Strength Approach (95% Reliability)

		1A: Straddle Ways			2A: Straddle Mix			1B: Strad in Stacks			2B: Straddle Mix			RTG (5-High)			4: RTG (3-High)		
Area	%Risk	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
A	5	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	10	> 15	> 15	> 15
B	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
C	5	> 15	> 15	11	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	13.3	> 15	> 15	> 15
D	5	> 15	12	8	> 15	> 15	11.51	> 15	> 15	> 15	> 15	> 15	> 15	> 15	8	5	> 15	13	7.97
E	5	> 15	> 15	11	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	14.7	> 15	> 15	> 15
F	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
G	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
H	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
J	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
N	5	> 15	> 15	11	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	14.7	> 15	> 15	> 15
O	5	> 15	13	9	> 15	> 15	13	> 15	> 15	> 15	> 15	> 15	> 15	> 15	12	7	> 15	> 15	12
P	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
Q	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
R	5	> 15	5	4	8	2	1	> 15	> 15	> 15	> 15	> 15	12.8	2	1	0	3	1	1
S	5	> 15	5	3	7	2	1	> 15	> 15	> 15	> 15	14	11	2	1	0	3	1	1
RR2	5	> 15	14	10	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	10.9	> 15	> 15	> 15
JJ5	5	> 15	13	9	> 15	> 15	14	> 15	> 15	> 15	> 15	> 15	> 15	> 15	14	8	> 15	> 15	13.7
HH5	5	> 15	5	4	8	2	1	> 15	> 15	> 15	> 15	> 15	12.8	2	1	0	3	1	1
HH6	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
GG5	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
M10	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF5	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF6	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
EE6	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
178	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
888	5	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
ED1	5	> 15	13	9	> 15	> 15	13	> 15	> 15	> 15	> 15	> 15	> 15	> 15	14	8	> 15	> 15	13.9
ED2	5	> 15	10	7	> 15	11	8	> 15	> 15	> 15	> 15	> 15	> 15	14.8	5	3	> 15	8	5
EC1	5	> 15	5	4	8	2	1	> 15	> 15	> 15	> 15	> 15	12.8	1.85	1	0	2.85	1	1
EC2	5	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
Daily Traffic																			
108&109		513	2095	2952	186	761	1071	160	250	330	60	95	120	185	555	930	120	335	550
109 West		319	577	2710	116	209	984												
General Traffic SF		1																	
Channelised SF		5																	

Flexural Strength Approach (85% Reliability)

		1A: Straddle Ways			2A: Straddle Mix			1B: Strad in Stacks			2B: Straddle Mix			RTG (5-High)			4: RTG (3-High)		
Area	%Risk	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
A	15	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	10	> 15	> 15	> 15
B	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
C	15	> 15	> 15	14	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
D	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
E	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
F	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
G	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
H	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
J	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
N	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
O	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
P	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
Q	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
R	15	> 15	13	9	> 15	> 15	14	> 15	> 15	> 15	> 15	> 15	> 15	> 15	14	8	> 15	> 15	13.7
S	15	> 15	10	7	> 15	11	8	> 15	> 15	> 15	> 15	> 15	> 15	14.8	5	3	> 15	8	5
RR2	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
JJ5	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
HH5	15	> 15	10	7	> 15	12	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	10	6
HH6	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
GG5	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
M10	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF5	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
FF6	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
EE6	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
178	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
888	15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
ED1	15	> 15	13	9	> 15	> 15	14	> 15	> 15	> 15	> 15	> 15	> 15	> 15	14	8	> 15	> 15	13.7
ED2	15	> 15	13	9	> 15	> 15	13	> 15	> 15	> 15	> 15	> 15	> 15	> 15	12	7	> 15	> 15	12
EC1	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
EC2	15	> 15	10	7	> 15	13	9	> 15	> 15	> 15	> 15	> 15	> 15	> 15	6	4	> 15	11	6
Daily Traffic																			
108&109		513	2095	2952	186	761	1071	160	250	330	60	95	120	185	555	930	120	335	550
109 West		319	577	2710	116	209	984												
General Traffic SF		1																	
Channelised SF		5																	

Appendix D: Structural improvement analysis

EDITIION 4 (Standard - Account for CBP)

Overlay Requirements (Approximate 95% Reliability)

Row Stacking: 3 High C10 Thickness = 530 mm

Block Stacking: 5 High C10 Thickness = 620 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	5	380	150	240	131	399	489	274	250	238	231	223	364	308	294	285	275
B	5	500	30	120	517	13	103	21	85	81	79	76	111	144	137	133	128
C	5	417	113	203	417	113	203	113	145	138	134	130	203	204	194	188	182
D	5	350	180	270	483	47	137	114	145	139	134	130	204	204	194	188	182
E	5	430	100	190	480	50	140	75	120	115	111	107	165	179	171	165	160
F	5	543	0	77	655	0	0	0	72	68	66	64	39	97	92	89	86
G	5	493	37	127	474	56	146	47	102	97	94	91	137	160	153	148	143
H	5	486	44	134	467	63	153	54	106	101	98	95	144	165	157	152	147
J	5	506	24	114	488	42	132	33	93	89	86	83	123	151	144	140	135
N	5	430	100	190	474	56	146	78	122	116	113	109	168	181	172	167	161
O	5	370	160	250	319	211	301	186	192	183	177	171	276	251	239	231	224
P	5	469	61	151	323	207	297	134	159	151	146	142	224	217	207	200	194
Q	5	478	53	143	329	201	291	127	154	147	142	137	217	212	202	196	189
R	5	234	296	386	323	207	297	251	235	224	217	209	341	293	280	271	262
S	5	225	305	395	310	220	310	262	242	231	223	216	352	301	287	277	268
RR2	5	395	135	225	441	89	179	112	144	138	133	129	202	203	193	187	181
JJ5	5	373	157	247	514	16	106	86	128	122	118	114	176	186	177	172	166
HH5	5	233	297	387	301	229	319	263	242	231	224	216	353	301	287	278	269
HH6	5	575	0	45	597	0	23	0	72	68	66	64	34	94	89	87	84
GG5	5	491	39	129	508	22	112	31	92	87	85	82	121	150	143	139	134
M10	5	543	0	77	655	0	0	0	72	68	66	64	39	97	92	89	86
FF5	5	527	3	93	597	0	23	2	73	69	67	65	58	109	104	101	98
FF6	5	469	61	151	647	0	0	31	91	87	84	82	76	121	115	111	108
EE6	5	622	0	0	643	0	0	0	72	68	66	64	0	72	68	66	64
178	5	506	24	114	610	0	10	12	79	76	73	71	62	112	107	103	100
888	5	496	34	124	641	0	0	17	83	79	76	74	62	112	107	103	100
ED1	5	369	161	251	318	212	302	186	193	184	178	172	276	251	240	232	224
ED2	5	307	223	313	317	213	303	218	213	203	197	190	308	272	259	251	242
EC1	5	232	298	388	320	210	300	254	237	226	218	211	344	295	282	272	263
EC2	5	322	208	298	278	252	342	230	221	211	204	197	320	280	267	258	250

EDITIION 4 (Standard - Account for CBP)

Overlay Requirements (Approximate 85% Reliability)

Row Stacking: 3 High C10 Thickness = 530 mm

Block Stacking: 5 High C10 Thickness = 620 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	15	380	150	240	131	399	489	274	250	238	231	223	364	308	294	285	275
B	15	500	30	120	517	13	103	21	85	81	79	76	111	144	137	133	128
C	15	450	80	170	417	113	203	97	134	128	124	120	187	193	184	178	172
D	15	514	16	106	497	33	123	25	87	83	81	78	115	146	139	135	130
E	15	470	60	150	488	42	132	51	105	100	97	93	141	163	156	151	146
F	15	543	0	77	655	0	0	0	72	68	66	64	39	97	92	89	86
G	15	543	0	77	524	6	96	3	73	70	68	66	87	128	122	118	114
H	15	486	44	134	467	63	153	54	106	101	98	95	144	165	157	152	147
J	15	519	11	101	501	29	119	20	85	81	78	76	110	143	137	132	128
N	15	506	24	114	488	42	132	33	93	89	86	83	123	151	144	140	135
O	15	469	61	151	323	207	297	134	159	151	146	142	224	217	207	200	194
P	15	536	0	84	323	207	297	103	139	132	128	124	191	195	186	180	174
Q	15	488	43	133	336	194	284	118	148	141	137	132	208	207	197	191	185
R	15	375	155	245	323	207	297	181	189	180	175	169	271	248	236	229	221
S	15	308	222	312	319	211	301	216	212	202	196	189	306	271	258	250	241
RR2	15	523	7	97	505	25	115	16	82	78	76	73	106	141	134	130	125
JJ5	15	475	55	145	524	6	96	30	91	87	84	81	120	150	143	138	134
HH5	15	315	215	305	305	225	315	220	215	205	198	191	310	273	260	252	244
HH6	15	625	0	0	647	0	0	0	72	68	66	64	0	72	68	66	64
GG5	15	536	0	84	484	46	136	23	86	83	80	77	110	143	137	132	128
M10	15	585	0	35	655	0	0	0	72	68	66	64	18	83	79	77	74
FF5	15	577	0	43	647	0	0	0	72	68	66	64	22	86	82	79	76
FF6	15	577	0	43	647	0	0	0	72	68	66	64	22	86	82	79	76
EE6	15	625	0	0	647	0	0	0	72	68	66	64	0	72	68	66	64
178	15	517	13	103	624	0	0	6	76	72	70	68	51	105	100	97	94
888	15	575	0	45	645	0	0	0	72	68	66	64	22	86	82	79	77
ED1	15	375	155	245	323	207	297	181	189	180	175	169	271	248	236	229	221
ED2	15	370	160	250	319	211	301	186	192	183	177	171	276	251	239	231	224
EC1	15	321	209	299	332	198	288	204	204	194	188	182	294	262	250	242	234
EC2	15	326	204	294	281	249	339	226	219	209	202	195	316	277	264	256	247

EDITION 3 (Non-standard - Account for CBP)

Overlay Requirements (Approximate 95% Reliability)

Row Stacking: 3 High C10 Thickness = 340 mm

Block Stacking: 5 High C10 Thickness = 575 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	5	380	0	195	131	209	444	104	139	133	129	124	319	279	266	258	249
B	5	500	0	75	517	0	58	0	72	68	66	64	66	115	109	106	102
C	5	417	0	158	417	0	158	0	72	68	66	64	158	174	166	161	156
D	5	350	0	225	483	0	92	0	72	68	66	64	159	175	167	161	156
E	5	430	0	145	480	0	95	0	72	68	66	64	120	150	143	138	134
F	5	543	0	32	655	0	0	0	72	68	66	64	16	82	78	76	73
G	5	493	0	82	474	0	101	0	72	68	66	64	92	131	125	121	117
H	5	486	0	89	467	0	108	0	72	68	66	64	99	136	129	125	121
J	5	506	0	69	488	0	87	0	72	68	66	64	78	122	117	113	109
N	5	430	0	145	474	0	101	0	72	68	66	64	123	151	144	140	135
O	5	370	0	205	319	21	256	11	78	75	72	70	231	221	211	204	198
P	5	469	0	106	323	17	252	8	77	73	71	69	179	188	179	173	168
Q	5	478	0	98	329	11	246	5	75	72	69	67	172	183	175	169	163
R	5	234	106	341	323	17	252	61	111	106	103	99	296	264	252	244	236
S	5	225	115	350	310	30	265	72	119	113	109	106	307	271	259	250	242
RR2	5	395	0	180	441	0	134	0	72	68	66	64	157	174	166	160	155
JJ5	5	373	0	202	514	0	61	0	72	68	66	64	131	157	150	145	140
HH5	5	233	107	342	301	39	274	73	119	113	110	106	308	272	259	251	242
HH6	5	575	0	0	597	0	0	0	72	68	66	64	0	72	68	66	64
GG5	5	491	0	84	508	0	67	0	72	68	66	64	76	121	115	112	108
M10	5	543	0	32	655	0	0	0	72	68	66	64	16	82	78	76	73
FF5	5	527	0	48	597	0	0	0	72	68	66	64	24	87	83	80	78
FF6	5	469	0	106	647	0	0	0	72	68	66	64	53	106	101	98	95
EE6	5	622	0	0	643	0	0	0	72	68	66	64	0	72	68	66	64
178	5	506	0	69	610	0	0	0	72	68	66	64	35	94	90	87	84
888	5	496	0	79	641	0	0	0	72	68	66	64	40	97	93	90	87
ED1	5	369	0	206	318	22	257	11	79	75	73	70	231	222	212	205	198
ED2	5	307	33	268	317	23	258	28	90	86	83	80	263	242	231	224	216
EC1	5	232	108	343	320	20	255	64	113	108	104	101	299	266	254	245	237
EC2	5	322	18	253	278	62	297	40	98	93	90	87	275	250	239	231	223

EDITION 3 (Non-standard - Account for CBP)

Overlay Requirements (Approximate 85% Reliability)

Row Stacking: 3 High C10 Thickness = 340 mm

Block Stacking: 5 High C10 Thickness = 575 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	15	380	0	195	131	209	444	104	139	133	129	124	319	279	266	258	249
B	15	500	0	75	517	0	58	0	72	68	66	64	66	115	109	106	102
C	15	450	0	125	417	0	158	0	72	68	66	64	142	164	156	151	146
D	15	514	0	61	497	0	78	0	72	68	66	64	70	117	111	108	104
E	15	470	0	105	488	0	87	0	72	68	66	64	96	134	128	124	120
F	15	543	0	32	655	0	0	0	72	68	66	64	16	82	78	76	73
G	15	543	0	32	524	0	51	0	72	68	66	64	42	98	94	91	88
H	15	486	0	89	467	0	108	0	72	68	66	64	99	136	129	125	121
J	15	519	0	56	501	0	74	0	72	68	66	64	65	114	109	105	102
N	15	506	0	69	488	0	87	0	72	68	66	64	78	122	117	113	109
O	15	469	0	106	323	17	252	8	77	73	71	69	179	188	179	173	168
P	15	536	0	39	323	17	252	8	77	73	71	69	146	166	158	153	148
Q	15	488	0	88	336	4	239	2	73	69	67	65	163	178	169	164	158
R	15	375	0	200	323	17	252	8	77	73	71	69	226	218	208	202	195
S	15	308	32	267	319	21	256	26	89	85	82	79	261	241	230	223	215
RR2	15	523	0	52	505	0	70	0	72	68	66	64	61	111	106	103	99
JJ5	15	475	0	100	524	0	51	0	72	68	66	64	75	121	115	111	108
HH5	15	315	25	260	305	35	270	30	91	87	84	81	265	244	233	225	218
HH6	15	625	0	0	647	0	0	0	72	68	66	64	0	72	68	66	64
GG5	15	536	0	39	484	0	91	0	72	68	66	64	65	114	109	105	102
M10	15	585	0	0	655	0	0	0	72	68	66	64	0	72	68	66	64
FF5	15	577	0	0	647	0	0	0	72	68	66	64	0	72	68	66	64
FF6	15	577	0	0	647	0	0	0	72	68	66	64	0	72	68	66	64
EE6	15	625	0	0	647	0	0	0	72	68	66	64	0	72	68	66	64
178	15	517	0	58	624	0	0	0	72	68	66	64	29	90	86	83	81
888	15	575	0	0	645	0	0	0	72	68	66	64	0	72	68	66	64
ED1	15	375	0	200	323	17	252	8	77	73	71	69	226	218	208	202	195
ED2	15	370	0	205	319	21	256	11	78	75	72	70	231	221	211	204	198
EC1	15	321	19	254	332	8	243	14	80	77	74	72	249	233	222	215	208
EC2	15	326	14	249	281	59	294	36	95	91	88	85	271	248	237	229	221

EDITION 4 (Non-standard - Disregard CBP)

Overlay Requirements (Approximate 95% Reliability)

Row Stacking: 3 High C10 Thickness = 530 mm

Block Stacking: 5 High C10 Thickness = 620 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	5	380	150	240	131	399	489	274	178	170	165	159	364	237	226	219	211
B	5	500	30	120	517	13	103	21	14	13	13	12	111	72	69	67	65
C	5	417	113	203	417	113	203	113	74	70	68	66	203	132	126	122	118
D	5	350	180	270	483	47	137	114	74	70	68	66	204	132	126	122	118
E	5	430	100	190	480	50	140	75	49	47	45	44	165	107	102	99	96
F	5	543	0	77	655	0	0	0	0	0	0	0	39	25	24	23	22
G	5	493	37	127	474	56	146	47	30	29	28	27	137	89	85	82	79
H	5	486	44	134	467	63	153	54	35	33	32	31	144	93	89	86	83
J	5	506	24	114	488	42	132	33	21	20	20	19	123	80	76	74	71
N	5	430	100	190	474	56	146	78	51	48	47	45	168	109	104	101	97
O	5	370	160	250	319	211	301	186	121	115	111	108	276	179	171	165	160
P	5	469	61	151	323	207	297	134	87	83	80	78	224	146	139	134	130
Q	5	478	53	143	329	201	291	127	82	78	76	73	217	141	134	130	126
R	5	234	296	386	323	207	297	251	163	156	151	146	341	222	212	205	198
S	5	225	305	395	310	220	310	262	171	163	157	152	352	229	218	211	204
RR2	5	395	135	225	441	89	179	112	73	69	67	65	202	131	125	121	117
JJ5	5	373	157	247	514	16	106	86	56	53	52	50	176	115	109	106	102
HH5	5	233	297	387	301	229	319	263	171	163	158	153	353	229	219	212	205
HH6	5	575	0	45	597	0	23	0	0	0	0	0	34	22	21	21	20
GG5	5	491	39	129	508	22	112	31	20	19	19	18	121	79	75	73	70
M10	5	543	0	77	655	0	0	0	0	0	0	0	39	25	24	23	22
FF5	5	527	3	93	597	0	23	2	1	1	1	1	58	38	36	35	34
FF6	5	469	61	151	647	0	0	31	20	19	18	18	76	49	47	45	44
EE6	5	622	0	0	643	0	0	0	0	0	0	0	0	0	0	0	0
178	5	506	24	114	610	0	10	12	8	8	7	7	62	40	38	37	36
888	5	496	34	124	641	0	0	17	11	11	10	10	62	40	38	37	36
ED1	5	369	161	251	318	212	302	186	121	116	112	108	276	180	171	166	160
ED2	5	307	223	313	317	213	303	218	142	135	131	126	308	200	191	185	179
EC1	5	232	298	388	320	210	300	254	165	158	152	147	344	224	213	206	200
EC2	5	322	208	298	278	252	342	230	150	143	138	134	320	208	199	192	186

EDITION 4 (Non-standard - Disregard CBP)

Overlay Requirements (Approximate 85% Reliability)

Row Stacking: 3 High C10 Thickness = 530 mm

Block Stacking: 5 High C10 Thickness = 620 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	15	380	150	240	131	399	489	274	178	170	165	159	364	237	226	219	211
B	15	500	30	120	517	13	103	21	14	13	13	12	111	72	69	67	65
C	15	450	80	170	417	113	203	97	63	60	58	56	187	121	116	112	108
D	15	514	16	106	497	33	123	25	16	15	15	14	115	74	71	69	66
E	15	470	60	150	488	42	132	51	33	32	31	30	141	92	87	85	82
F	15	543	0	77	655	0	0	0	0	0	0	0	39	25	24	23	22
G	15	543	0	77	524	6	96	3	2	2	2	2	87	56	54	52	50
H	15	486	44	134	467	63	153	54	35	33	32	31	144	93	89	86	83
J	15	519	11	101	501	29	119	20	13	13	12	12	110	72	68	66	64
N	15	506	24	114	488	42	132	33	21	20	20	19	123	80	76	74	71
O	15	469	61	151	323	207	297	134	87	83	80	78	224	146	139	134	130
P	15	536	0	84	323	207	297	103	67	64	62	60	191	124	118	114	110
Q	15	488	43	133	336	194	284	118	77	73	71	69	208	135	129	125	121
R	15	375	155	245	323	207	297	181	118	112	109	105	271	176	168	163	157
S	15	308	222	312	319	211	301	216	141	134	130	125	306	199	190	184	178
RR2	15	523	7	97	505	25	115	16	11	10	10	9	106	69	66	64	62
JJ5	15	475	55	145	524	6	96	30	20	19	18	18	120	78	75	72	70
HH5	15	315	215	305	305	225	315	220	143	136	132	128	310	202	192	186	180
HH6	15	625	0	0	647	0	0	0	0	0	0	0	0	0	0	0	0
GG5	15	536	0	84	484	46	136	23	15	14	14	13	110	72	68	66	64
M10	15	585	0	35	655	0	0	0	0	0	0	0	18	12	11	11	10
FF5	15	577	0	43	647	0	0	0	0	0	0	0	22	14	13	13	12
FF6	15	577	0	43	647	0	0	0	0	0	0	0	22	14	13	13	12
EE6	15	625	0	0	647	0	0	0	0	0	0	0	0	0	0	0	0
178	15	517	13	103	624	0	0	6	4	4	4	4	51	33	32	31	30
888	15	575	0	45	645	0	0	0	0	0	0	0	22	15	14	13	13
ED1	15	375	155	245	323	207	297	181	118	112	109	105	271	176	168	163	157
ED2	15	370	160	250	319	211	301	186	121	115	111	108	276	179	171	165	160
EC1	15	321	209	299	332	198	288	204	132	126	122	118	294	191	182	176	170
EC2	15	326	204	294	281	249	339	226	147	140	136	131	316	206	196	190	184

EDITION 3 (Standard - Disregard CBP)

Overlay Requirements (Approximate 95% Reliability)

Row Stacking: 3 High C10 Thickness = 340 mm

Block Stacking: 5 High C10 Thickness = 575 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	5	380	0	195	131	209	444	104	68	65	63	61	319	208	198	192	185
B	5	500	0	75	517	0	58	0	0	0	0	0	66	43	41	40	39
C	5	417	0	158	417	0	158	0	0	0	0	0	158	103	98	95	92
D	5	350	0	225	483	0	92	0	0	0	0	0	159	103	98	95	92
E	5	430	0	145	480	0	95	0	0	0	0	0	120	78	75	72	70
F	5	543	0	32	655	0	0	0	0	0	0	0	16	10	10	10	9
G	5	493	0	82	474	0	101	0	0	0	0	0	92	59	57	55	53
H	5	486	0	89	467	0	108	0	0	0	0	0	99	64	61	59	57
J	5	506	0	69	488	0	87	0	0	0	0	0	78	51	48	47	45
N	5	430	0	145	474	0	101	0	0	0	0	0	123	80	76	74	71
O	5	370	0	205	319	21	256	11	7	7	6	6	231	150	143	138	134
P	5	469	0	106	323	17	252	8	5	5	5	5	179	116	111	107	104
Q	5	478	0	98	329	11	246	5	3	3	3	3	172	112	106	103	100
R	5	234	106	341	323	17	252	61	40	38	37	35	296	193	184	178	172
S	5	225	115	350	310	30	265	72	47	45	43	42	307	200	191	184	178
RR2	5	395	0	180	441	0	134	0	0	0	0	0	157	102	97	94	91
JJ5	5	373	0	202	514	0	61	0	0	0	0	0	131	85	81	79	76
HH5	5	233	107	342	301	39	274	73	47	45	44	42	308	200	191	185	179
HH6	5	575	0	0	597	0	0	0	0	0	0	0	0	0	0	0	0
GG5	5	491	0	84	508	0	67	0	0	0	0	0	76	49	47	46	44
M10	5	543	0	32	655	0	0	0	0	0	0	0	16	10	10	10	9
FF5	5	527	0	48	597	0	0	0	0	0	0	0	24	16	15	14	14
FF6	5	469	0	106	647	0	0	0	0	0	0	0	53	35	33	32	31
EE6	5	622	0	0	643	0	0	0	0	0	0	0	0	0	0	0	0
178	5	506	0	69	610	0	0	0	0	0	0	0	35	23	21	21	20
888	5	496	0	79	641	0	0	0	0	0	0	0	40	26	24	24	23
ED1	5	369	0	206	318	22	257	11	7	7	7	6	231	150	143	139	134
ED2	5	307	33	268	317	23	258	28	18	17	17	16	263	171	163	158	153
EC1	5	232	108	343	320	20	255	64	42	40	38	37	299	194	185	179	174
EC2	5	322	18	253	278	62	297	40	26	25	24	23	275	179	171	165	160

EDITION 3 (Standard - Disregard CBP)

Overlay Requirements (Approximate 85% Reliability)

Row Stacking: 3 High   C10 Thickness =   340 mm

Block Stacking: 5 High   C10 Thickness =   575 mm

Area	%Risk	FSA			CFA			3-High Row Stacking					5-High Block Stacking				
		Existing Eq H	Row OL	Block OL	Existing Eq H	Row OL	Block OL	Avg ROL	C30	C35	C40	C45	Avg BOL	C30	C35	C40	C45
A	15	380	0	195	131	209	444	104	68	65	63	61	319	208	198	192	185
B	15	500	0	75	517	0	58	0	0	0	0	0	66	43	41	40	39
C	15	450	0	125	417	0	158	0	0	0	0	0	142	92	88	85	82
D	15	514	0	61	497	0	78	0	0	0	0	0	70	45	43	42	40
E	15	470	0	105	488	0	87	0	0	0	0	0	96	62	60	58	56
F	15	543	0	32	655	0	0	0	0	0	0	0	16	10	10	10	9
G	15	543	0	32	524	0	51	0	0	0	0	0	42	27	26	25	24
H	15	486	0	89	467	0	108	0	0	0	0	0	99	64	61	59	57
J	15	519	0	56	501	0	74	0	0	0	0	0	65	42	41	39	38
N	15	506	0	69	488	0	87	0	0	0	0	0	78	51	48	47	45
O	15	469	0	106	323	17	252	8	5	5	5	5	179	116	111	107	104
P	15	536	0	39	323	17	252	8	5	5	5	5	146	95	90	87	84
Q	15	488	0	88	336	4	239	2	1	1	1	1	163	106	101	98	95
R	15	375	0	200	323	17	252	8	5	5	5	5	226	147	140	136	131
S	15	308	32	267	319	21	256	26	17	16	16	15	261	170	162	157	152
RR2	15	523	0	52	505	0	70	0	0	0	0	0	61	40	38	37	35
JJ5	15	475	0	100	524	0	51	0	0	0	0	0	75	49	47	45	44
HH5	15	315	25	260	305	35	270	30	20	19	18	17	265	172	164	159	154
HH6	15	625	0	0	647	0	0	0	0	0	0	0	0	0	0	0	0
GG5	15	536	0	39	484	0	91	0	0	0	0	0	65	42	40	39	38
M10	15	585	0	0	655	0	0	0	0	0	0	0	0	0	0	0	0
FF5	15	577	0	0	647	0	0	0	0	0	0	0	0	0	0	0	0
FF6	15	577	0	0	647	0	0	0	0	0	0	0	0	0	0	0	0
EE6	15	625	0	0	647	0	0	0	0	0	0	0	0	0	0	0	0
178	15	517	0	58	624	0	0	0	0	0	0	0	29	19	18	17	17
888	15	575	0	0	645	0	0	0	0	0	0	0	0	0	0	0	0
ED1	15	375	0	200	323	17	252	8	5	5	5	5	226	147	140	136	131
ED2	15	370	0	205	319	21	256	11	7	7	6	6	231	150	143	138	134
EC1	15	321	19	254	332	8	243	14	9	8	8	8	249	162	154	149	144
EC2	15	326	14	249	281	59	294	36	24	23	22	21	271	176	168	163	157

Appendix E: Editing certificate

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EDITING CERTIFICATE

Re: **Rowen Naicker**
Master's dissertation: **SELECTING THE MOST APPROPRIATE CONTAINER HANDLING INFRASTRUCTURE FOR DURBAN CONTAINER TERMINAL**

I confirm that I have edited this dissertation and the references for clarity, language and layout. I am a freelance editor specialising in proofreading and editing academic documents. I returned the document to the student with track changes so correct implementation of the changes in the text and references is the responsibility of the student. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homeopathy at Technikon Natal in 1999 (now the Durban University of Technology). During my 13 years as a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology I supervised numerous Master's degree dissertations.

Dr Richard Steele
17 November 2017
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