Title: OPTIMISATION OF KEY PERFORMANCE INDICATORS ALONG A VALUE CHAIN

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Abstract

The purpose of this research is to determine a single measure of performance for a supply chain model. Furthermore, the supply chain was modelled using simulation techniques. The supply chain model chosen is the coal corridor in South Africa. Various frameworks were evaluated and the performance of the supply chain model was done using an adapted model originally suggested by Aronovich et. al 2010. The results from the adapted framework show that the Transnet supply chain model performed at 45% for the 2014 year. Improvement scenarios were then formulated based on the worst performing phases in the supply chain: rail transportation and shipping distribution. The rail element of the supply chain model was simulated using the Anylogic simulation package. Discrete event simulation methods were used. It was found that if Transnet Freight Rail upgraded the single track at Overvaal, utilised 100 wagon trains instead of 200 wagon trains and eliminated Ermelo as a hub they could increase their throughput by 20%. Furthermore, recommendations were made suggesting that the framework should be further adapted to include the need for multiple suppliers and the simulation model should incorporate the transport of coal via trucks.

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Nomenclature

ABM – Agent based modelling

BSC – Balanced scorecard

CSF – Critical success factor

CTC – Centralised traffic control

DES – Discrete event modelling

KPI – Key performance indicator

RBCT - Richards Bay coal Terminal

TFR - Transnet Freight Rail

TPA - Transnet Port Authority

TPT - Transnet Port Terminal

WIP – Work in progress

1 Introduction

This chapter introduces the purpose, background and motivation of the research. The research is done modelling the supply chain of Transnet, a large logistics company in South Africa. The research done into Transnet aims to formulate a method for obtaining a single measure of performance for the supply chain model. The necessity of KPI's are discussed in this section to further highlight the need for performance measures in supply chains.

1.1 Purpose

This study provides a method of simulation for optimising and validating performance indicators throughout the logistics element of the supply chain. Many industries now compete on supply chain level with logistics forming a significant expense for the customer (Tseng, Yue and Taylor, 2005; Abrahamsson and Rehme, 2010). The profitability and ability of the supply chain to provide growth and value to the customer plays a significant role in the strategy of retailers to gain a competitive advantage. Thus, for a logistics company to be able to be successful they must continually find new ways of reducing costs and increasing the value to the customer.

With this is mind the purpose of this research is to model the logistics element of the supply chain and provide a framework of key performance indicators (KPI's) which can be used to measure the overall performance of the logistics element of the supply chain, thus optimising the performance indicators of the supply chain.

1.2 Research Background

Transnet is a large logistics company in South Africa, which owns railways, and ports along the coastline. The company has three distinct divisions which make up the value chain. The Rail Division is responsible for transporting goods and commodities from inland areas to the port and vice versa. The second division in the value chain is the Port Terminal Division. This division is responsible for all processes and operations at all ports around the country of South Africa, i.e. the actual loading and offloading of cargo and the material handling from rail to vessel and vice versa. The final division is the Port Authority which is responsible for governing all processes and procedures at the port. These three divisions form the entire value chain for importing and exporting commodities. In the context of the supply chain, these divisions handle a large portion of the logistics element of the overall supply chain.

Therefore, for Transnet it is important that the company's performance is evaluated on the performance of the value chain as a whole. At the current state the company evaluates the performance of each division individually, which causes localised optimisation in the value chain. This causes a "silo" mentality in the value chain which limits the growth and competitiveness of the value chain. This study focuses on optimising the coal corridor, which is operated by Transnet.

1.3 Research Motivation

Performance indicators (PI’s) show the performance of a specific area of the company, for example the percentage increase in sales in a particular product. This PI may be useful in that specific area of operations, but may not have a direct influence on the strategy of the company. This is where the KPI differs significantly from the PI.

Key performance indicators (KPI’s) are a select number of PI’s (not more than 20 in most cases) which are direct measures of strategic decisions. There is no set of standard KPI’s for a given industry. The selection of KPI’s is dependent on the company’s strategic objective and vision. KPI’s identify which key areas of a company can be changed in order to maximise the affect on the company's performance. Good KPI's can immediately identify which areas need to be improved allowing for quick reaction when poor performance in detected (La Grouw, 2009).

KPI's are used for reporting on performance and efficiencies of a given company. Companies and shareholders rely on these indicators to help them make decisions regarding the management and strategy of the company and its employees. Therefore, the accuracy, relevance and integrity of these indicators are of significant importance to companies and their personnel. Optimising and validating performance indicators using scientific and mathematical methods are necessary in order to ensure the reliability of the performance indicators (Velimirovic, Velimirovic and Stankovic, 2011).

Transnet uses KPI’s extensively to evaluate the performance of the operating divisions, operating personnel and management personnel, see Transnet Integrated Report 2014. In order to have a true evaluation for the performance of the value chain and the company, the optimisation of the KPI’s along the value chain and their associated targets or goal values are necessary. This study is aimed at identifying and optimising key performance indicators along the value chain. The KPI’s are chosen based on their effect on the overall performance indicator of the company (revenue).

This study, furthermore, aims to create a framework for optimising KPI’s throughout the entire value chain and determine a single measure of performance for the value chain as a whole. That is, a single measure based on the capability of each company within the value chain to meet the demand of the end customer. Using the framework results, this study aims to find a more optimal level of performance for Transnet.

1.4 Problem Statement

Adapt the model introduced by Aronovich et al 2010 to the business environment of Transnet. The newly adapted framework provides a single KPI which measures the overall performance of the value chain. Furthermore, improvement scenarios are determined using the results from the adapted framework and a simulation model is built in order to test the validity of the scenarios (Aronovich *et al.*, 2010).

This chapter has shown the need for competing at a supply chain level, the background to the supply chain model chosen and the motivation for using KPI’s in this research. These ideas are investigated and critiqued further in the next chapter: Literature Review.

2 Literature Review

This chapter investigates KPI’s, the structure and operations of Transnet, simulation techniques and the global coal market. The Aronovich et al 2010 framework is chosen. This framework will be adapted to the value chain in which Transnet operates. Discrete event modelling using agents is the technique chosen for simulating the value chain.

2.1 Performance Indicators (PI’s) and KPI’s

KPI’s are financial or non-financial measures of how successful a company has been in accomplishing its goals for a set period of time. To ensure an effective and accurate measure of performance within an organisation processes must be defined, characterised and standardised. These three elements form the basis of the process approach to attaining performance measures. This approach ensures that not only outputs are measured, but all elements driving the performance of the overall process are measured. This forms a necessary base for KPI formulation (Velimirovic, Velimirovic and Stankovic, 2011).

KPI's not only form the basis for performance measurement, but also form the basis for continuous improvement. This allows companies to manage and improve system performance using the goals and targets set by KPI's. KPI's may be expressed in qualitative or quantitative forms.

PI’s not only provide a basis for decision making in a company, but they also provide goals and targets for incentivising employees (Velimirovic, Velimirovic and Stankovic, 2011).

- They provide a base for implementing the strategic direction of the company,
- They provide motivation for members in terms of goals and targets, which may be incentivised.

2.2 Characteristics of good KPI's

According Miller, 2012, to there are ten characteristics which make a good KPI. These are listed below (Miller, 2012):

- Reflect the strategic value drivers – KPI's must be set up such that they dictate or guide the company in the desired strategic direction.

- Defined by executives – the KPI's should be defined by management and should be defined with the short term and long term strategy in mind.
- Cascade throughout the organisation – each level of the organisation and the division must have KPI's which tie back to the level above, i.e. operation level KPI's and their associated targets must be related to management's KPI's.
- Based on corporate standards – Standardised measurements must be used by the company when making KPI's. This is to ensure that measurements across years and divisions are comparable.
- KPI's must be based on valid data – Data used for the formulation of the KPI must be able to be captured if it is not already being captured by the company. Data acquisition must not only be possible to catch, but must be accurate.
- KPI's must be easy to comprehend – this point presents two elements of difficulty for employees:
    - If the employee is given KPI’s to follow which are difficult to understand from a complexity and practicality point of view.
    - If the employee is given too many KPI’s to follow. In this case the employee may become overwhelmed with pursuing all KPI’s given to him/her. The median number of KPI's per employee is seven.
- KPI's must always be relevant – KPI's must be audited periodically and their use defined based on the strategic direction of the company. There is an associated lifecycle with KPI's. Initially they energise and impact performance greatly, but as time passes these effects are lost and they have to be revised.
- KPI's provide context – the metric data shows a number which reflects the performance. This performance is in comparison to the targets or expectations set out. These expectations can either be formulated by threshold values, benchmark or goal/ target values.
- KPI's must empower users (users being employees from operations to upper management level) – KPI's must reinforce incentive schemes within the organisation and vice versa. Each KPI must be checked and vetted before being linked to the incentive scheme.
- KPI's must lead to positive action – KPI's should generate an action of improved performance.

Aronovich, et al., 2010, share similar views on what good characteristics of KPI's are. Over and above the aforementioned characteristics the authors suggest that KPI's should:

- Encourage appropriate behaviour of employees – the performance measure encourages good performance and discourages poor performance.
- Measures only what is important – The performance measures focus on what is of real value in the managing process.
- Uses economies of effort – the collecting of data and analysis of the KPI is less costly than the benefit of using the KPI.
- Facilitate trust – The KPI encourages participation from all parties.

2.3 Selecting KPI's

There are many different perspectives when it comes to choosing the correct KPI's. Some frameworks focus on the ease of collecting data and the ability of the KPI's to be implemented practically. Other frameworks look at a more holistic approach of selecting KPI's and utilise perspectives from inside and outside the company. In this section different frameworks for defining KPI's is discussed.

2.3.1 Incorporating Revenue Management techniques

The article released by Alexander May et al, 2014, incorporated revenue management techniques into the optimisation of key performance measures in the air cargo industry. The article does an overview of the air cargo industry and looks specifically at the revenue management and operational model of Virgin Atlantic Cargo. The article focuses on developing a mathematical model to optimise KPI's for Virgin Atlantic cargo (May *et al.*, 2014).

The research methodology aims to eliminate the one Phaseal thinking of previous decision models which failed to incorporate the inter relations and correlations between performance measures. The model is dynamic as opposed to previously designed static models. In static models the parameters are set at the beginning of modelling and do not change, where as dynamic modelling allows KPI's to change based on their correlation and inter relations between measures(Alexander May et al, 2014).

The methodology started with specifying performance indicators based on advice from revenue management specialists. KPI's were then specified and the relevant operational processes mapped. Mapping put the processes in detail provided structure for performance measures and allowed inter relations between the measures to be established. Once the relationships between the measures were identified the KPI's were prioritised in relation to the company's goals. The basis for the prioritisation of KPI's is a model designed using Fuzzy multi criteria group decision making.

Alexander May et al, 2014 identify disadvantages of the method which include:

- It is hard to justify and explain hierarchies established in the model as it is not always possible to establish mathematical or logical relationships between KPI's and their underlying data fields. This means that drawing meaningful conclusions from this framework may be complex and often not possible.
- One suggestion for improvement made by the authors is that the KPI's should be developed from a literature base. This suggestion will be incorporated into the methodology of this study.

2.3.2 The Balanced Scorecard (BSC)

The balanced scorecard (BSC) measures the performance of a company from a financial, non-financial, organisational and non-organisational viewpoint. The BSC addresses shortcomings of previous methods of company performance measurement, which only measured performance from financial viewpoint. The balance scorecard aims to translate the vision and strategy of the company into objectives and measures in four business areas (Akkermans and Oorschot, 2002):

- Financial perspective – how the company wishes to be viewed by its shareholders.
- Customer – How the company wishes to be viewed by its customers.
- The business process perspective – which processes must the company excel to be viewed as successful in the eyes of its shareholders and customers.
- The organisational and growth perspective – which changes and improvements the company must make to be able to implement its vision.

An example of the standard BSC methodology is shown in Figure 2-1 (Murby and Gould, 2005). Figure 2-1 illustrates the derivation of KPI’s from the company’s strategic vision. The company is viewed in the four business areas. The objectives for each business area are determined. This may be done by interviews or identified through available business reports.

The PI's (or measures) necessary for each objective to be reached are then identified. These PI's are given targets in line with the company's strategy and objectives. Once the targets and the PI's are determined an action is designed in order to achieve the objective at hand (Kaplan, 2010).

The article by Durkacova et al, 2012, focuses on the advantages of using the balanced scorecard (BSC) in performance management. The advantages of the BSC is that it identifies key drivers for operational performance with respect to the strategic goals of the company, that is that the overall performance of a company can be measured using "just a few numbers" as opposed to a large number of performance measures (Akkermans and Oorschot, 2002). The BSC does lack a quantitative model to assist with decision making of specifying KPIs. The BSC also does not take into account the inter relationships between measures, however, it provides a necessary framework for the inclusion of qualitative data (Durkacova, Lavin and Karjust, 2012).

Limitations of the BSC include:

- There is not always a cause and effect relationship between areas of measurement in the BSC (Salem, Milad Abdelnabi , Dr. Norlena Hasnan, 2012). An example of this is the relationship between customer loyalty and financial performance.
- The BSC itself may become irrelevant over time and thus the BSC does not maintain a mechanism for validation (Salem, Milad Abdelnabi , Dr. Norlena Hasnan, 2012). In essence the BSC helps narrow down the number of performance measures, but does not necessarily select the right measures (Akkermans and Oorschot, 2002).
- It may be seen as impractical to integrate the BSC from a management level down to operations depending on the industry (Salem, Milad Abdelnabi , Dr. Norlena Hasnan, 2012). The BSC focuses heavily on a top down approach and does not have integration between top level strategies and operational measures (Akkermans and Oorschot, 2002).
- The BSC does not take into account the contributions and effects created by a supply chain, i.e. suppliers and customers (Akkermans and Oorschot, 2002).

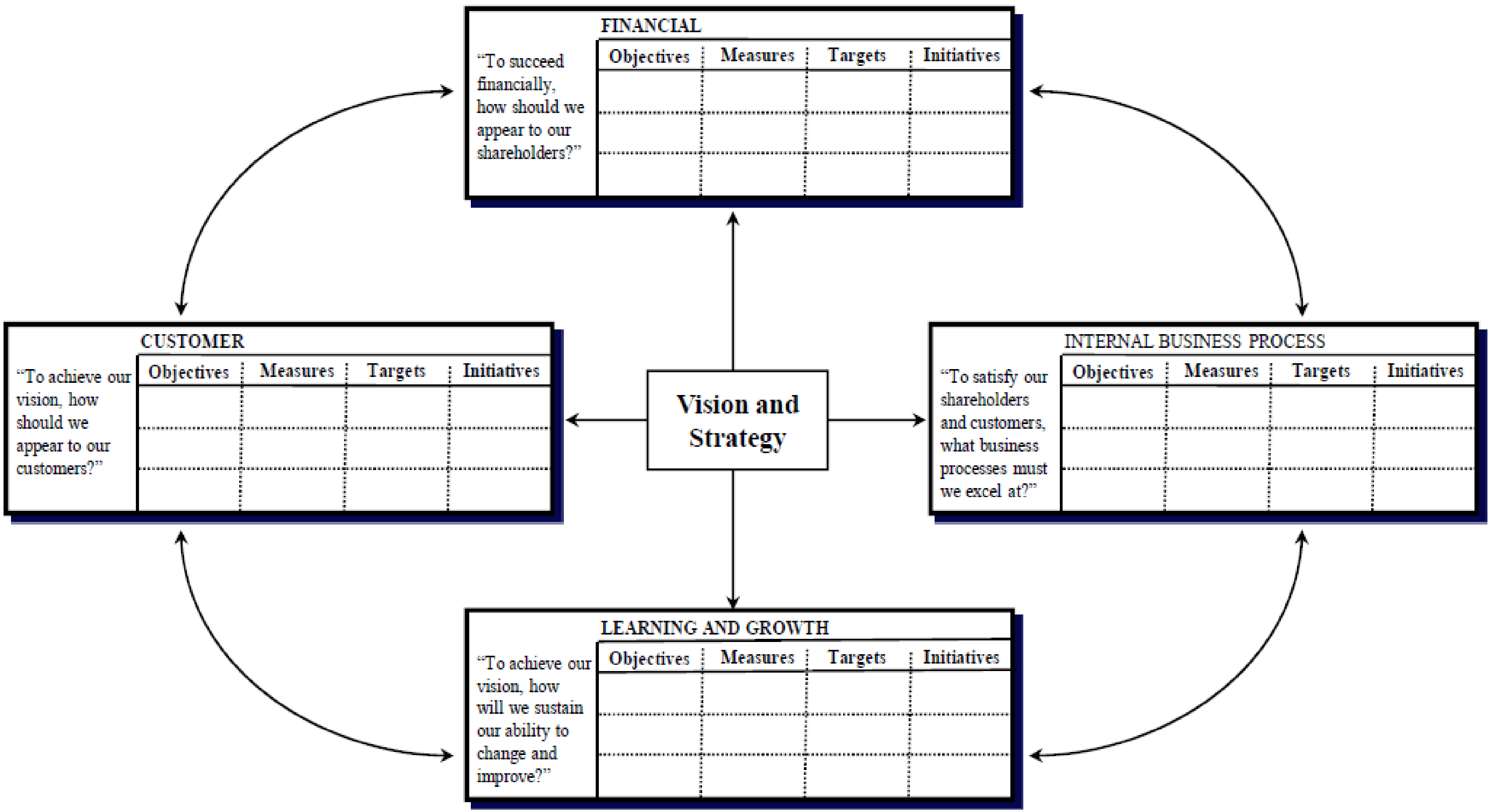


Figure 2-1: The Balanced Scorecard Methodology

In the article authored by Akkermans, et al., 2002, they attempt to overcome these limitations by including the simulation and modelling technique of Systems Dynamics into the BSC. Akkermans, et al., 2002, found that the systems dynamics approach does help improve the short comings of the BSC, however, does not eradicate them completely. They further conclude that the BSC methodology requires quantitative modelling and more input not only from an operations level, but also from other stakeholders, such as suppliers and customers

2.3.3 Supply Chain Performance Measurement Model

The approach by Aronovich et al (2010) into performance measurement is prepared for the monitoring of supply chain performance in the public health sector. According to Frazelle et al 2002, the behaviour of people is dependent on how their performance is measured. With this is mind the article by Aronovich et al (2010) focuses on choosing the correct metrics in order to effectively measure the performance of the supply chain, specifically, in the health care sector.

Aronovich, et al., 2010, states that before one can improve the performance of the supply chain, one must understand how well it is currently performing. Furthermore, it is stated that the key to choosing the correct performance indicators to focus on, is to start at the elements of the business that are underperforming.

The initial stage of the methodology presented by Aronovich, et al., 2010, is to compare the current set of performance indicators to the international best practices. The gap between best practices and the actual performance shows which areas need to be focused on in order to improve.

It is risky to focus on one element of business, such as finance, because improving one area may not necessarily increase the performance of the entire supply chain and may improve one area to the detriment of another (Aronovich, et al., 2010). Aronovich, et al., 2010, suggests that the four key business elements that should be simultaneously focussed on are quality, time, financial and productivity.

The method used by Aronovich, et al., 2010, analyses the entire supply chain as if it were integrated into a single company. The framework looked at five stages within the supply chain to define the necessary KPI's. The five stages in the supply chain are:

- Product Selection/ Forecasting,
- Supplier/ Sourcing,
- Warehousing/ Storage,
- Inventory Management,
- Distribution/ Transport

The framework developed by Aronovich, et al, 2010, is illustrated in Figure 2-2 and Figure 2-3. Although the framework developed by Aronovich, et al., 2010, is for the health care sector, there is value in utilising this framework in the coal industry. In both industries quick and dependable response time is needed and the quality of the service is expected to be highly efficient by customers.

For example, in the coal industry there are huge volumes passing through each stage of the supply chain. The cost of mistakes may be detrimental to the coal industry as the delays can cause substantial complications and damage to the reputation of Transnet and the mines (primary supplier).

The advantage of using the Aronovich framework is that there is a structure provided to measure the performance of a supply chain from different business viewpoints. That is, other approaches, such as the BSC tend to measure performance in a single business unit operating as a single entity. Thus framework incorporates the relationship between the stages in the supply chain to take effect on the overall supply chain performance.

2.4 Simulation Techniques

There are three different methods of building of modelling a simulation of the real world; systems dynamics, discrete event modelling and agent based modelling. The method chosen depends on the perspective of the modeller, the architecture of the problem and what the objective of building the model is. All three methods are discussed in this subsection and the discrete event simulation method is chosen for this research.

	Quality Indicators	Response Time Indicators	Cost/Financial Indicators	Productivity Indicators
Product Selection/ Forecasting/Procurement	Product Section Based on National Essential Medicines List	Lead Time for Contract/Purchase Order Issue	% Markup on Products in Cost Recovery System (Profit Margin)	Average number of Orders Processed Per Full-Time Equivalent (FTE) in Procurement
	Forecast Accuracy	Lead Time for Contract Award	% of Average International Reference Price Paid	% of Purchase Orders/Contracts Issued as Emergency Orders
	% of Procured Products Registered in Country		Ratio of Unit Prices Paid Through an Emergency Procurement vs. Competitive Bidding Process	
	% of Products that Undergo Quality Testing		Fixed Order Cost	
	% of Procured Products that Meet Stringent Regulatory Authority (SRA) or WHO Standards			
	Commitment to Established Procurement Plan			
	% of Contracts Issued as Framework Contracts			
Supplier/Sourcing (from purchaser's perspective)	Order Compliance	On-Time Delivery	Total Supply Cost	Supplier Fill Rate
	% of Orders with Products on Back Order	Supplier Lead-Time Variability		
	Shipping Accuracy			

Figure 2-2: Table of Procurement Performance Indicators (Aronovich, et al., 2010)

	Quality Indicators	Response Time Indicators	Cost/Financial Indicators	Productivity Indicators
Warehousing/Storage	Inventory Accuracy Rate	Warehouse Order Processing Time	Total Warehousing Cost	Storage Space Utilization
	Put-Away Accuracy	Customs Clearance Cycle	Value of Product Damaged in the Warehouse	Units Moved Per Person Hour
	Picking Accuracy Rate	Put-Away Time		% of Storage Space Dedicated for Handling
	Warehouse Accident Rate			
	Defined Security Measures			
Inventory Mgmt/LMIS Customer Response	Stockout Rate	Order Entry Time	Inventory Holding Cost	Inventory Turnover Rate
	Order Fill Rate	Order Turnaround Time	Value of Unusable Stock	Inventory Velocity
	Inventory Accuracy Rate	Order Lead Time	Value of Unaccounted Stock	% of Orders Placed Through Electronic Ordering System
	Stocked According to Plan		Average Response Cost	Facility Reporting Rates
	Adequate Shelf Life			
	Stock Wastage Due to Expiration or Damage			
	Plan in Place for Predictable Change in Demand			
	Order Entry Accuracy			
	Invoice Accuracy			
Distribution/Transport	On-Time Arrivals	Average Delivery Time	Total Transportation Cost	Vehicle Use Availability
	% of Shipments Where Quantity Dispatched Equals Quantity Received	Average Vehicle Loading/Unloading Time	Average Transportation Cost Per Kilometer/Volume/Weight	Container Capacity Utilization
	% of Shipments Arriving in Good Condition	Vehicle Turnaround Time	Ratio of Transportation Cost to Value of Product	Fleet Yield
	Kilometers Between Accidents			Average Number of Stops Per Route
	Time Between Accidents			

Figure 2-3: Table of Inventory Management and Distribution KPI's(Aronovich, et al., 2010)

The final adapted Aronovich framework is shown in Figure 2-4.

2.4.1 System Dynamics Modelling

In essence a systems dynamics model is a model that is modelled from a macroscopic perspective and is modelled like water flowing through a pipe. Systems dynamics focuses on flows around networks instead of the individual behaviour of entities. Systems dynamics is deterministic in nature and therefore returns the same output after each run of the model (Maidstone, 2010).

This method is most applicable to dynamic problems arising in complex systems. That is, any dynamic system characterised by interdependence, mutual interaction, information feedback and circular causality. The System Dynamics approach uses a perspective based on information feedback and delays to understand and analyse the dynamic behaviour of a complex system (Coyle, 1996).

The system dynamics approach involves (Guerrero, Schwarz and Slinger, 2016) (Jakeman *et al.*, 2013):

- Defining problems dynamically using graphs over time
- Aiming for an endogenous behavioural view. This means that the modeller focuses inward on the characteristics of the system as it is these characteristics which exacerbate the perceived problems.
- Perceiving that all concepts in the system are continuous quantities with circular causality.
- Finding stocks in the system, which accumulate in the system, and determine their inflow and outflow rates.
- Formulating a model which accurately reproduces the behaviour of the real system.
- Deriving conclusions and insight into policy decisions from the resulting from the model.
- Implementing changes from the results of the model.

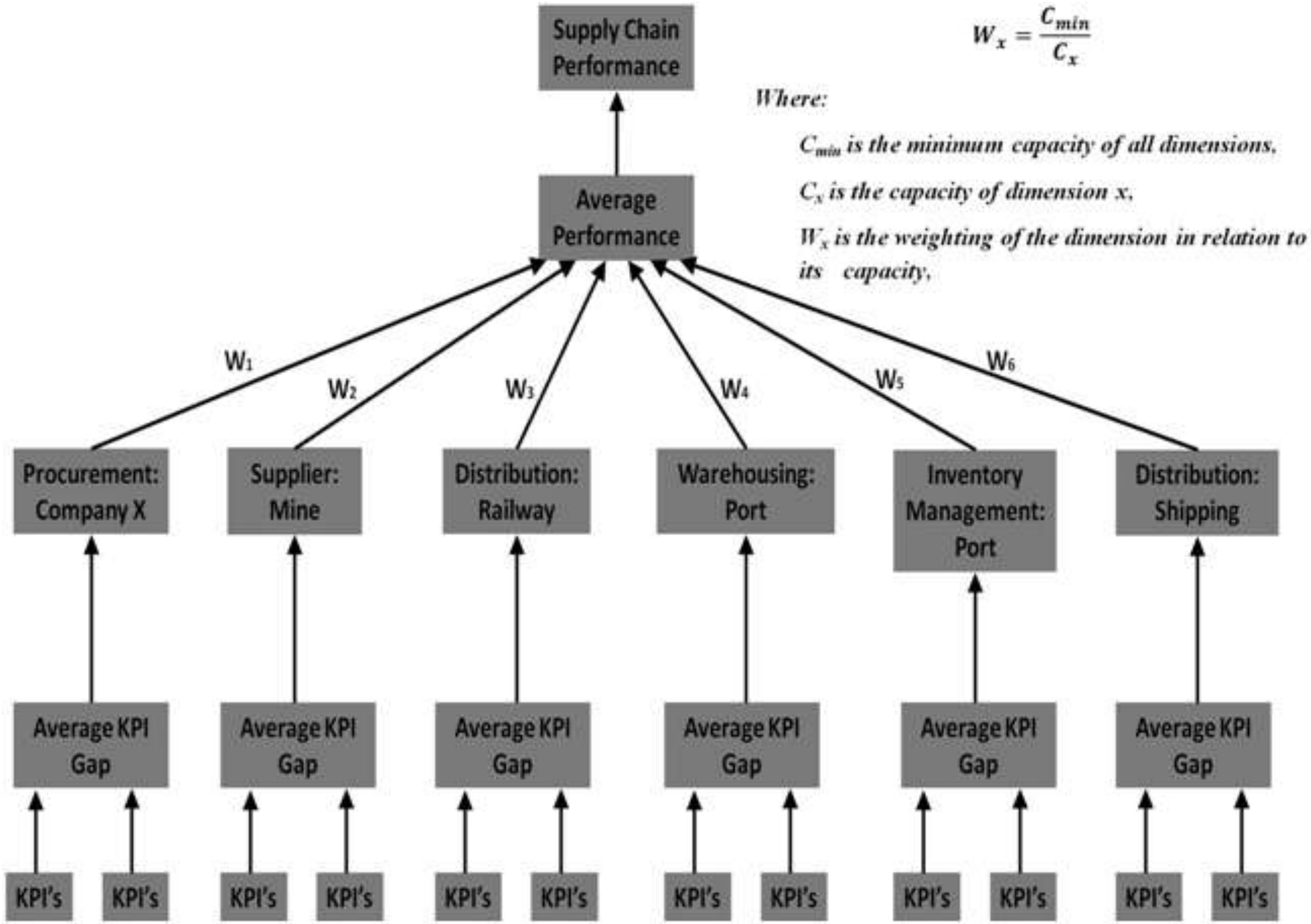


Figure 2-4: The Adapted Aronovich Framework

Advantages

- The first advantage of system dynamics modelling is that is forces the modeller to deepen their thinking and understanding of what elements drive the system or model.
- The second advantage is that it makes a clear distinction between true and perceived system conditions. Another advantage is that it provokes non-linear thinking (Letcher, 2012).

These advantages can be particularly useful when modelling a logistics network as it will enable the modeller to identify key elements driving the network before the model is complete. The modeller can then run the model and determine what drives the system versus what is perceived to drive the system and then use non-linear thinking to identify why the perceived drivers of the system are in actual fact not correct.

Disadvantages

- The disadvantages of using system dynamics modelling is that a complex model is vulnerable to losing its purpose as it increases in size. The model is also difficult to verify and validate when the model is complex and does not correspond to real world behaviour (Letcher, 2012).

In the problem presented in this study, the disadvantage mentioned above can be realised as the system we are modelling is highly complex and has a large amount of variables. This means that validating and verifying the model according to real world behaviour will be a complex and time consuming activity.

2.4.2 Discrete Event Modelling

Discrete Event Modelling (DES) is the method of simulating a real world system using the perspective that the dynamic nature of the system is created by the occurrence of discrete events (Matloff, 2006). Essentially discrete event modelling is the process of coding the behaviour of a complex real world system in an ordered and well defined sequence of events. Each event changes the state of the system, i.e. each event has cause and effect.

In DES the model is thought of as a network of queues and servers through which entities pass, entering and exiting different states. DES is stochastic in nature which means that there are elements of randomness in the model which make the results of each run of the model differ slightly (Maidstone, 2010, 2012).

The following must exist for the model to work (Maidstone, 2010, 2012) :

- Predetermined starting and end points, which can either, be events or instances in time.
- A method of tracking time between the start and end points of the process.
- A list of events that have happened since the start of the process.
- A list of events that is pending or expected to happen.
- A graphical, statistical or tabular record of the function describing the system being modelled.

Advantages

- DES places importance on the variability of the system which allows it to measure the dynamic behaviour of the system (Brailsford and Hilton, 2001).
- DES focuses on the individual elements of the simulation. This gives DES the ability to focus on the individual elements and their performance. This microscopic element means that DES can successfully and clinically compare scenarios and provide results useful in decision making (Caro and Möller, 2016).

Disadvantages

- In DES the modeller may only have an idea about how the system works. This means that in comparison with other models DES requires less insight into systems when modelling them. Essentially when DES is used the model and its intricate workings are considered to be a black or at minimum a dark grey box(Brailsford, et al., 2001).

2.4.3 Agent Based Modelling

Agent based modelling (ABM) is an approach to modelling systems that consist of autonomous, interacting agents. ABM provides an alternative method for the modelling of complex adaptive systems, i.e. systems which adapt to a change in environment (Macal and North, 2006). ABM is a method used for studying systems exhibiting two properties (Janssen, 2005):

- The system is made up of agents (entities or elements of the system) interacting with one another.
- The system exhibits properties emerging from the interactions of the agents in the system. In these instances the properties cannot be deduced by aggregating the properties of the agents.

An agent is considered to be a discrete or unique entity which can adapt or modify its behaviours. The assumptions made when using ABM are that some key aspects of the agents' behaviour can be described, the mechanisms which allow the agents to interact can be described, and the system can be built from the bottom up. Examples where ABM is used would be in systems with people, groups or organisations, social insects or swarms, robots or systems of collaborating robots.

The decisions made by agents can vary depending on the memory employed in the agents' cognitive load, the sophistication of rules, or internal models of the external world. ABS is based on a local interaction, which means that there is no figure of authority creating order (Macal and North, 2006). The modelling begins and ends with the agents' perspective, unlike other models.

Advantages

- ABM makes the model seem closer to reality because an ABM approach allows for the modeller to study aggregate properties of the model (Bazghandi, 2012). An example is given by Bazghandi where it is stated that ABM enables a more accurate description of how vehicles move because the modeller can code the way the vehicles move in a lane as opposed to simply defining an equation which dictates the density of cars in a lane. Similarly one can attribute personality traits to entries such as train drivers, machine operators, management and customers which will allow a more accurate real world application of the model.
- The flexibility of ABM provides a framework for tuning the complexity of the agents' behaviour, degree of rationality, ability to learn and rules of interactions. In cases where ABM is used it often occurs that agents tend to develop properties that are logically independent from the properties of the system. Castle uses the example of a traffic build up in the opposite direction to the lane in which the accident has occurred. In this case the traffic jam in the opposite or intuitively

"unblocked" direction can be explained by people looking at the accident on the opposite side of the road. This flexibility in ABM is useful in cases where the complexity of a system is not readily known at the start of a problem and some tinkering or insight is needed (Castle and Crooks, 2006; Bazghandi, 2012).

Disadvantages of ABM (Castle and Crooks, 2006; Bazghandi, 2012)

- One of the biggest limitations of ABM is the need for a large amount of computing power. This means that running large numbers of agents lengthens the computation of the simulation and thus ABM techniques are not designed for large and extensive simulations. The need for large amounts of computing power stems from the technique associated with ABM.
- ABM can be counterproductive to the purpose of the model. This is common to all modelling techniques, however, can be magnified in ABM as ABM is often used when the target is either difficult to access or not well understood making it easier to lose track of the specific purpose of the model.

The method of simulation chosen in this study is DES. This method is chosen because it can model the dynamic behaviour of the system and measure the performance of individual elements within the system. These advantages of DES are significant for running scenarios or experiments.

In conclusion to this chapter the Aronovich framework is chosen as the basis for KPI selection. The Aronovich framework is chosen over the BSC as it provides a more practical approach for supply chains and provides a platform to develop a single KPI to measure the performance of a supply chain.

3 Problem Description and Background

This chapter discusses the infrastructure of Transnet and all of its relevant divisions: Transnet Freight Rail (TFR), Transnet National Ports Authority (TNPA) and Transnet Port Terminals (TPT). The nature of the route and the characteristics of the coal trains, wagons and material handling equipment in the rail and port divisions are discussed. Cycle times of the relevant processes are also found in this chapter.

3.1 Richards Bay Port Coal Terminal

The port has a design capacity of 91Mtpa (million tons per annum) and resides on a 276ha area of land. The quay of the port is 2.2km long, hosting six berths. Four berths have a length of 350m, one berth with a length of 184m and then other with a length of 280m. All berths have a dredged depth of 19m and a max draft of 17.5m. The dredged depth is the actual depth of the channel the ship uses and the draft is the depth to which the ship may be loaded. The freight rail division ensures the delivery of coal to the port terminal from the mines and the port authority ensures the management and scheduling of all ships to and from the port terminal. The port terminal turns around over 900 ships per annum and can stockpile up to 8.2Mt of coal. An aerial view of the port terminal is shown in Figure 3-2 (Transnet National Ports Authority, 2010, 2016).

Trains are scheduled from 49 points throughout Mpumalanga and Kwazulu-Natal to the port terminal. Transnet Freight Rail and port terminal have a co-operative relationship which allows for the two business entities to provide the logistical network connecting the mines (suppliers) to outside world (customers) (Kuys, 2011; Transnet Freight Rail, 2014).

Once the 200 wagon long train arrives at the port terminal the train consist is split into two 100 wagon consists. Five wagon tipplers unload the wagons at a rate of 5 500 tons per hour. At this rate, 100 wagons are unloaded in just under 2 hours. 100 wagons are unloaded at a time because the infrastructure at RBCT does not allow for 200 wagon trains to be unloaded at once. Fourteen percent (14%) of this unloaded coal goes directly into the appropriate vessels via an automated belt conveyor. The remaining 86% of the unloaded coal is stored in one of the 92 stockpiles which store 36 grades of coal. The yard has a capacity of 8.2 million tons of coal (Transnet National Ports Authority, 2010; Richards Bay Coal Terminal, 2015).

The stacking and reclaiming process is complex and requires a control tower of highly trained staff to co-ordinate the stacking of coal onto the correct stockpile and the reclaiming of coal to be moved onto the appropriate vessel. The control tower picks the optimal route from the wagon to either the stockpile or to the ship from either the wagon or the stockpile. The coal is transported via conveyor belts that stretch over 50km in and around the yard. These conveyors move at 22km/h and are 2.2m wide. The yard machines are capable of stockpiling coal at 6000 tons per hour (Richards Bay Coal Terminal, 2015).

The ship-loaders have the following capacities: SL1 and SL2 each have a capacity of 8 500 tons per hour, SL3 10 000 tons per hour and SL4 12 000 tons per hour. Once the ship is loaded the ship and its cargo are the responsibility of the port authority (Richards Bay Coal Terminal, 2015) (*also see www.rbct.co.za/operations-6/infrastructure/*)

3.2 Freight Rail

The freight rail services are handled by an independent division within Transnet. This division transports the coal from the siding near the coal mine to the Ermelo station where a 200 wagon train consist is constructed. Each wagon is capable of taking up to 84 tons . For the remainder of this study a "train" will refer to a 200 wagon long train and a "100 wagon long train" will refer to a train of 100 wagons in length (Kuys, 2011).

Consists from the mines to Ermelo are constructed with four locomotives (locos) followed by 100 wagons followed by another four locomotives (100 wagon long train). Consists from Ermelo down to Richards bay are constructed with four locomotives followed by 100 wagons, four locomotives, 100 wagons and another four locomotives (train). This structure of train allows better braking as the braking forces are more evenly distributed throughout the train length. The symmetry of the train also allows for the train to be moved forwards or backwards with the same functionality (Kuys, 2011).

The gross payload per train consist is 22 000 tons, which is a train 2.2km in length. The trains are managed by Centralised Traffic Control (CTC) signalling (Kuys, 2011).

3.2.1 Route Profile

Figure 3-1 shows the route from the northern parts of the country through Ermelo to Richards Bay. The maximum acceptable loading capacity per axel for the given route throughout the country is 26 tons per axel. This is shown in red in Figure 3-1. The route itself has 137 bridges and 37 tunnels over a distance of 580km. The greatest limitation on throughput is the Overvaal tunnel which is 4km long and is single track and is located south of the Ermelo station before Piet Retief (Kuys, 2011).

There is undulating topography and the maximum speed throughout this route is limited to 60km/h. The route descends 1700m from Ermelo down to Richard's bay. The ruling gradient for loaded trains is 1:160 from Ermelo down to Richard's Bay and 1: 100 from the mines to Ermelo. The ruling gradient for empty trains from Richard's Bay back up to Ermelo is 1:66 (Kuys, 2011).

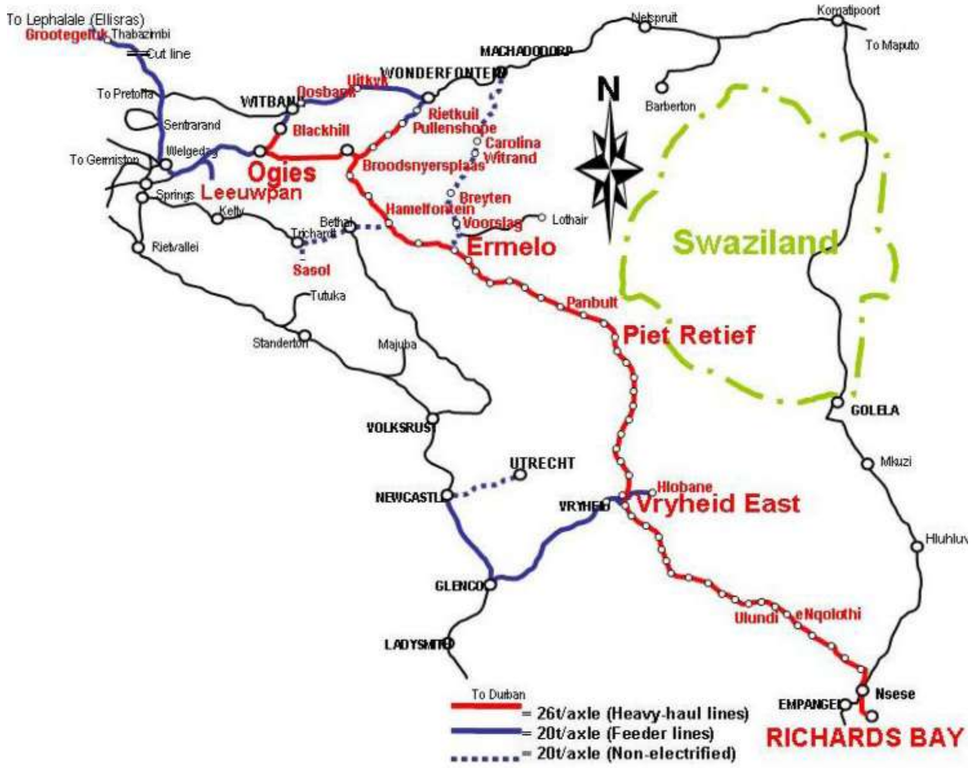


Figure 3-1: Coal Route (Kuys, 2011).

Figure 3-2: An Aerial View of the Richards Bay Coal Terminal

3.2.2 Cycle Times

Cycle times of the rail element of the supply chain is given below and taken from the technical paper authored by Govender et al (2015) and are shown in Table 3-1. The suggestion made in this article was to change the train structure to shorten the cycle times. The solution is formulated theoretically by Govender et al (2015) and shows a significant decrease in cycle time.

Table 3-1: Table of Railway Cycle Times (Govender, 2015)

		6L-200W		4L-100W-4L-100W	
	Route - Wagons	**Time / hrs**	**Wagons**	**Time / hrs**	**Wagons**
a	Richards Bay-Vryheid	6	800	5	667
	Vryheid-Ermelo Re-man	6	800	5	667
	Ermelo Re-man	4	533	1	133
b	EML-Mine-EML	14	1867	12	1600
	EML block yard 100's-to-200's	12	1600	1	133
c	EML-Vryheid	7	933	6	800
	Vryheid-Richards Bay	6	800	6	800
d	Off-loading process	7	933	12	1600
	Total	62	8300	48	6400

The following chapter identifies the research question and objectives based on the findings of the literature review.

4 Research Question and Objectives

The research question for this study is formulated as: Can a framework be developed that can be used to determine a single performance indicator representing the performance of the entire supply chain?

The following research objectives will be attempted:

- Develop a framework which can be used to determine the performance of the supply chain in question.
- Determine the current performance of the supply chain using the framework.
- Model the supply chain using simulation techniques.
- Use the framework to determine possible improvement scenarios and use the model and determine their affects on the overall performance of the supply chain.
- Compare the model performance output with the simulation outputs.

It should be emphasised that although the railway network is focused on significantly, the formation of an overall KPI aims to create a measure of performance for the entire value chain, i.e. the overall performance KPI takes into account the gaps in performance of each phase. Thus, the scenario where the railway delivers more coal than the port can handle will be guarded against. It should be noted that in the current state the port runs a ruling of carrying a minimum of 8 million tons of coal in its stockpile. The system is modelled as a pull system. The next chapter will discuss a detailed methodology of how these objectives will be reached.

5 Methodology

In this chapter the method of choosing KPI’s and targets was developed. This study aimed to produce a single measurement of performance for a given supply chain. In addition KPI’s were chosen and the Aronovich framework adapted to provide a current state of performance for Transnet. A single KPI was developed for the overall performance of the supply chain based on the capabilities of each element within the supply chain. Based on the results of the current performance of Transnet, improvement scenarios were formulated and a simulation was made to determine the effects the improvement scenarios would have on the system. The overall process flow of the methodology is shown in Figure 5-1: Overall Methodology Process Flow below:

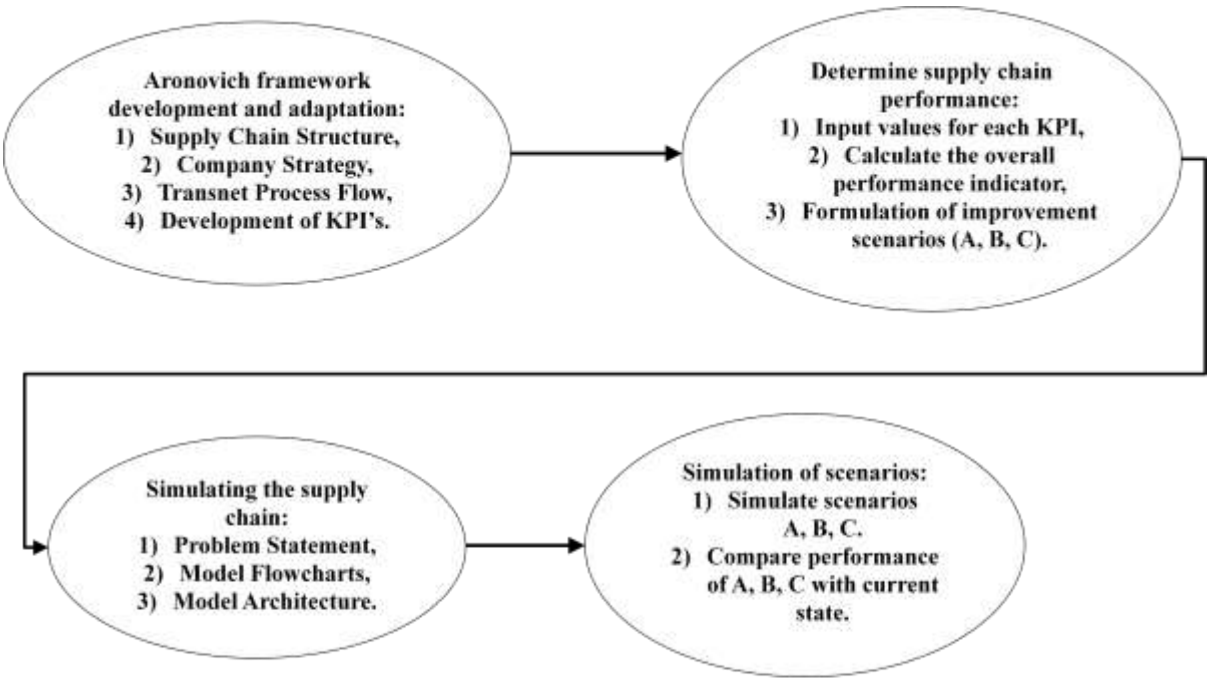


Figure 5-1: Overall Methodology Process Flow

The methodology used in this paper has four components (shown in Figure 5-2):

1) Adapt the Aronovich framework to be specific for Transnet's industry and supply chain,
2) Determine a single KPI for the performance of the supply chain,
3) Measure the current performance of the supply chain,
4) Run a simulation of Transnet's supply chain with improvement strategies to determine the effect on the overall performance of the supply chain.

5.1 Framework Development

After considering the methods researched in section 2.3 the supply chain performance measurement model was adapted and used to define key areas to be measured. As the system studied differed from the supply chain system in the original model used by Aronovich, the framework was adapted. Even though Transnet owns a large portion of the supply chain, each division is working as a separate business unit. This allowed the system to be modelled as a supply chain.

The adaption of the Aronovich framework was done as follows:

1) Determine the structure and material flow of the supply chain,
2) Determine Transnets strategy and vision,
3) Choose relevant KPI's,
4) Adapt framework to include single KPI for supply chain performance measurement.

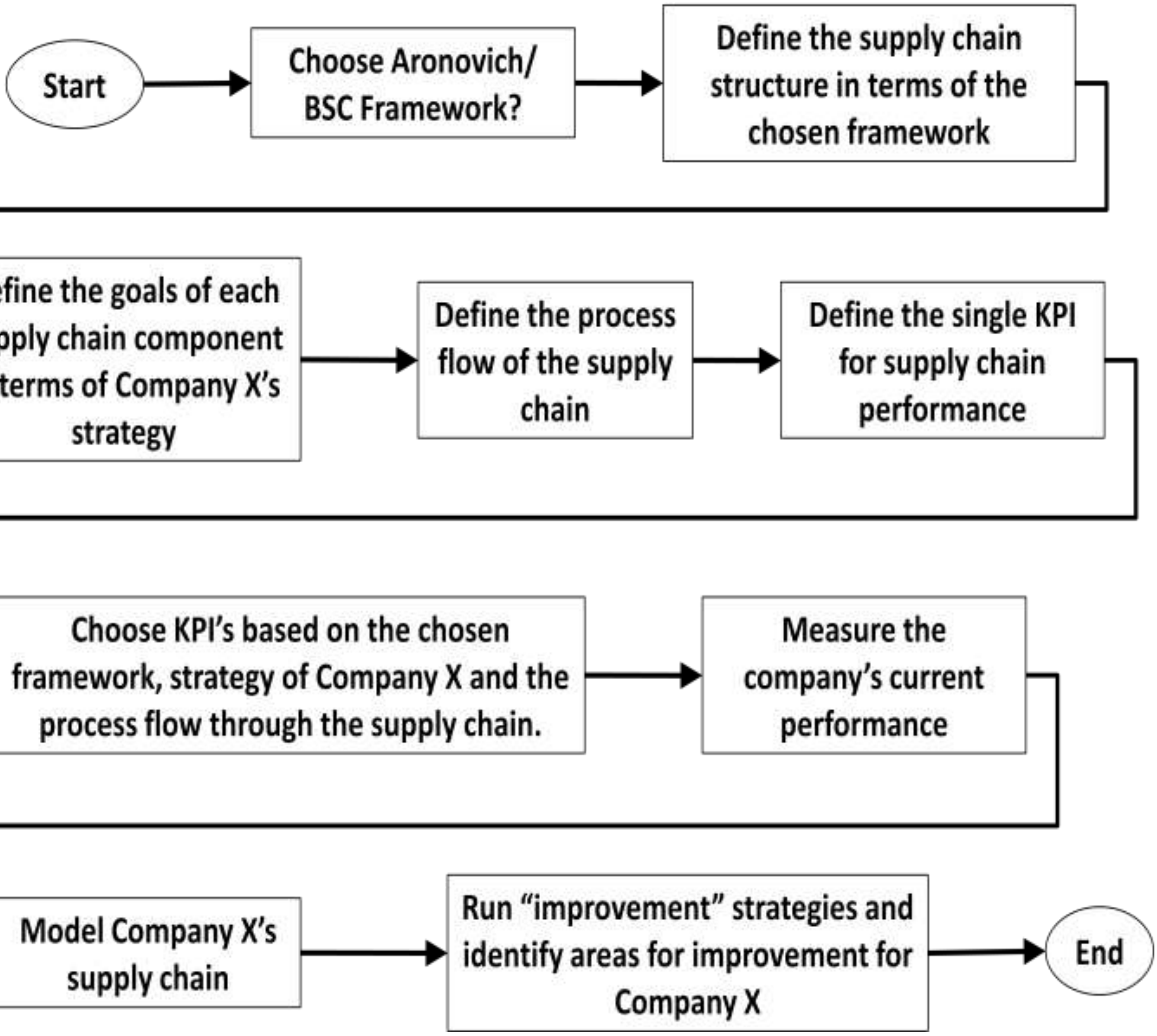


Figure 5-2: The Adapted Methodology Overview

5.1.1 Supply Chain Structure

The framework started at the procurement stage in Transnet and moved through until the exported coal was loaded onto the ship. Once loaded the supply chain has been deemed to have reached its end. The five phases of the supply chain relevant to Transnet from the start to the end are:

1) Procurement – Securing work for Transet locally and abroad.
2) Supplier (mine) – Produce coal for export.
3) Distribution/ logistics (Transnet Freight Rail – TFR) – Transport coal to port for export.

4) Warehousing/ Storage (Transnet Port Terminal – TPT) – Unloading of trains and storing of material.
5) Inventory Management (TPT) – Management of inventory and loading of ships.

Figure 5-3 shows the structure of Transnet's supply chain. In this framework the KPI's chosen regarding cycle times are averages, thus the assumption made is that all coal is picked up from one siding. The mines are seen as the suppliers in this situation as they are supplying the coal to Transnet to transport to the final distribution hub, where it is passed onto the ships. Transnet is a customer facing element of the supply chain which means that the performance of the company can harm not only Transnet, but its suppliers and partners within the supply chain.

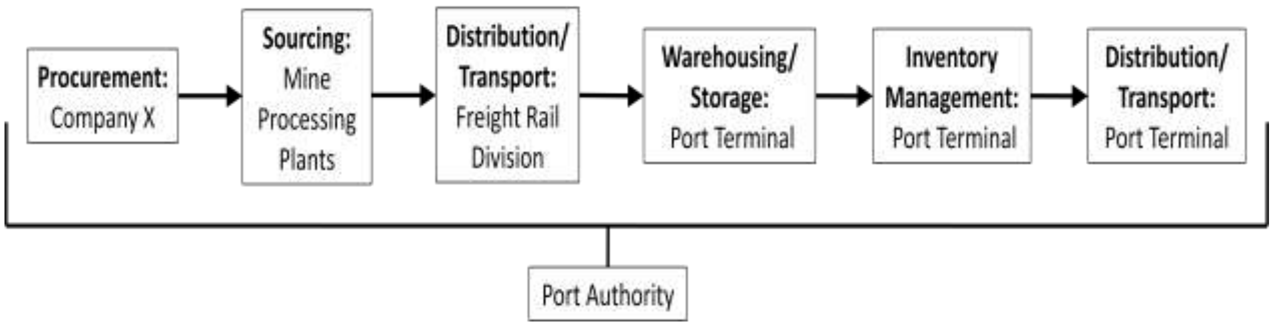


Figure 5-3: The Supply Chain Structure of Transnet

At this stage of the study, the following assumptions have been made:

Assumptions in Supply Chain Structure

- All coal is picked up from the same siding,
- The coal and its grading is never mixed or physically manipulated in any way throughout the supply chain described,
- Coal is transported from the siding to Ermelo and off to Richards Bay without any deviation in route,
- The supply chain ends with the coal being loaded onto the ship,
- The freight rail division is the first distribution element. That is the element of distribution which takes the product from the supplier to the "retailer", in this case, the port.
- The port terminal is the retailer or the final distribution aspect of the supply chain. The port terminal holds inventory and distributes the product to the end customer,

which lends itself to being modelled as the warehouse or retailer of the supply chain.

- The port terminal and the port authority are the final distribution element of the supply chain. Similar to a furniture store delivering its products to customers after purchase, the port terminal and the port authority deal with all the organisation and execution of distributing the product, bar piloting the ship to its final destination.

5.1.2 Company Strategy

The mandate set forward by Transnet is to assist in lowering the cost of doing business in South Africa by providing safe, cost effective and reliable port and rail transport and infrastructure (Transnet, 2014). The vision of Transnet is to meet the customer demand for reliable and safe freight transport by maximising the use of its assets, providing a sustainable operating environment and by increasing cost efficiency throughout the company.

From these points it can be deduced that Transnet aims to reduce costs, increase quality and reliability throughout the rail networks and ports in which it operates. From this information goals are developed for each supply chain element from which the performance indicators can be chosen. The goals for each supply chain element are shown in Figure 5-4. Transets goals and strategic vision is taken from the integrated report, 2014. Elements which were reported on and emphasised on in the reporting were used to shape the goals of each phase of the supply chain. It is seen that Transnet places high priority on safety, reliability and response time throughout its divisions.

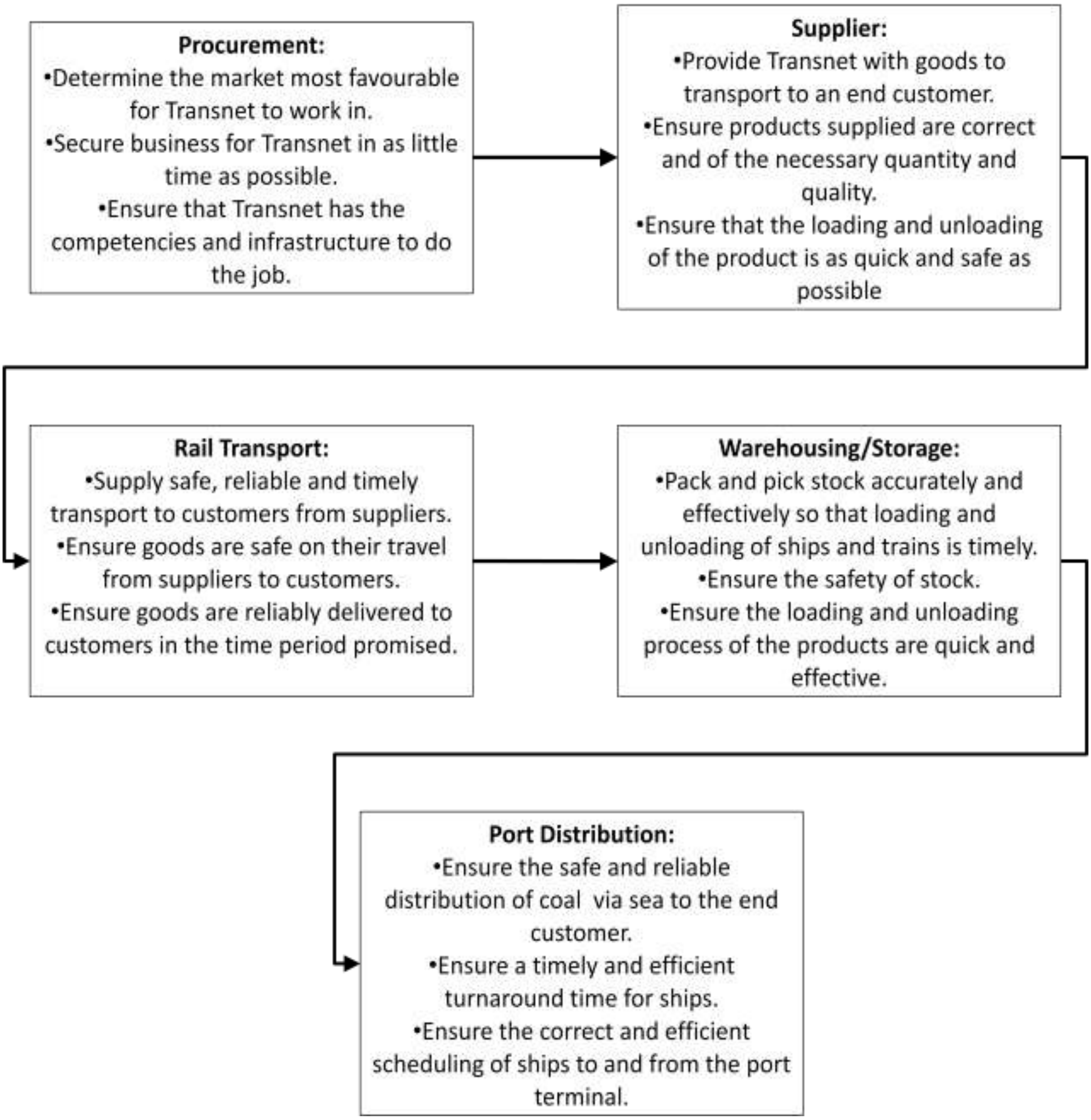


Figure 5-4: The Business Strategy Goals of Transnet

5.1.3 Basic Process Flow: Transnet

Figure 5-5 shows the basic flow of material and information through the supply chain. The supply chain begins with Transnets procurement and ends with the delivery onto a ship at the RBCT. The procurement phase is generic. In the procurement phase of the supply chain Transnet either gets approached or approaches a potential client. Once the initial contact (proposal) is complete Transnet enters into a contractual negotiation. The procurement proposal ends with Transnet and the potential client agreeing on a contract and entering into a working relationship or with a termination due to non agreement.

When the contract is agreed then the port authority is notified so that they can schedule the arrivals and departures of the customers' ships. Upon the agreement of a contract the coal is mined and processed for the export market by external suppliers. The rail division then despatches a train to the mine either based on a request from the mine or a scheduled delivery plan as agreed upon in the procurement phase. The mine will arrange the transport of coal via road if the siding is not on site. The train departs to the siding where it is loaded with coal, after which it returns to Ermelo where a new consist is made.

The transport to RBCT and the processes at RBCT and during transport via rail are as described in chapter three.

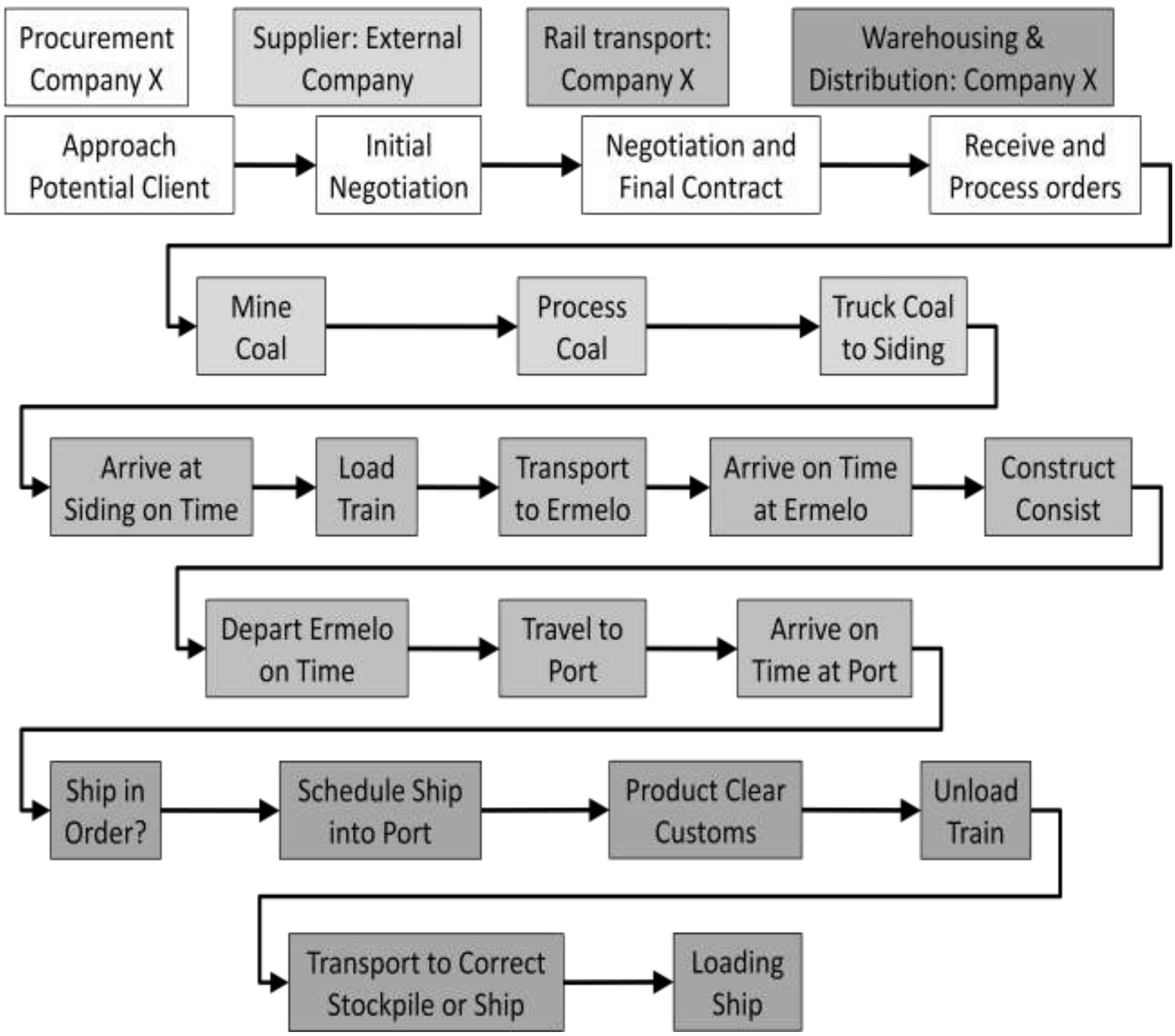


Figure 5-5: Basic Process Flow of Transnets Supply Chain

5.1.4 Development of KPI's

Aronovich, et al., 2010, developed a framework to measure and promote efficiency within the health care sector with regards to delivering medicine to the correct facilities in a timely and accurate manner. Similarly, the emphasis placed on efficiency and accuracy in the health care sector is needed equally as much in the supply chain in which Transnet operates. Both of these industries experience significant losses if inaccuracy and inefficiency were the norm, i.e. in the medical industry the greatest cost may be death, where in the case of Transnet, where big volumes are handled, the cost of inefficiency can become financially crippling or result in financial penalty depending on the written agreement with the supplier and customer.

The KPI's chosen in the framework from Aronovich, et al., 2010, are adapted to suit the strategic objectives of Transnet, as developed in chapter 6.1.3. A hybrid between the integrated report of 2014, the Aronovich framework and Transnets vision are used to determine which KPI’s are used in the adapted framework. The adapted framework, including the KPI's, is shown in Table 5-1, Table 5-2 and Table 5-3 . Each supply chain phase is shown separately for clarity.

Table 5-1, Table 5-2 and Table 5-3 summarises the framework that was identified based on Aronovich, et al., 2010. The framework includes additional KPI's identified from the company's business model and strategy. As the aim of the framework in this study is to determine the performance of the supply chain relating to logistics companies, KPI's are added or removed based on their applicability in the industry which Transnet operates in.

The framework used in this paper is referred to as "the adapted framework" for the remainder of this study.

Table 5-1: Table of Procurement and Supplier KPI's chosen for Transnet

Phase	Quality Indicators	Response Time Indicators	Cost/Financial Indicators	Productivity Indicators
Product Selection/ Forecasting/Procurement	Product selection based on best selling products	Lead time from initial approach to initial contract negotiation	% Mark-up on products sourced (Profit Margin)	Average number of orders processed per full-time equivalent staff in procurement
(Transnet)	Forecast Accuracy	Lead time for awarding contract	Local cost vs. international cost of product	% of emergency orders placed
	% of product sourced for export market		Ratio of unit prices paid through an emergency procurement vs. competitive bidding process	% Proposals turned into contracts
	% of products that undergo quality testing			
	% of procured products that meet regulations			
	Commitment to establish procurement plan			
	% of contracts issued as framework contracts			
Supplier/ Sourcing	Order compliance %	On Time delivery	Total Supply Cost	Supplier order fill rate
(Mine)	% Orders taken on back order	Supplier lead time		Supplier rate of production
	Shipping accuracy			

Table 5-2: Table of Rail Distribution and Warehousing KPI's Chosen.

Phase	Quality Indicators	Response Time Indicators	Cost/Financial Indicators	Productivity Indicators
Distribution	On time Arrivals	Average delivery time	Total transportation cost	Vehicle availability
(Rail Division)	% Shipments where quantity despatched equals quantity received	Average vehicle loading time	Average cost per km/weight	Vehicle capacity utilisation
	% Shipments arriving in good condition	Average vehicle unloading time	Transport cost to value of product	Fleet yield
	Kilometres between accidents	Vehicle turnaround time		Average number of stops per route
	Time between accidents	Time from request of vehicle to departure		Loading rate
	On Time departures	Vehicle drive time		Unloading Rate
	Time lost due to breakdown	Idle time		Wagon utilisation
				Driver utilisation
Phase	**Quality Indicators**	**Response Time Indicators**	**Cost/Financial Indicators**	**Productivity Indicators**
Warehousing/ Storage	Inventory accuracy rate	Warehouse order processing time	Total warehousing cost	Storage space utilization
(Port)	Put away accuracy	Customs clearance cycle	Value of damaged goods in warehouse	Units moved per hour
	Picking accuracy	Put away time		Storage space dedicated to product handling
	Warehouse accident rate			Stacking rate
	Security measures			Reclaiming rate

Table 5-3: Table of Inventory, Management and Shipping Distribution KPI's Chosen

Phase	Quality Indicators	Response Time Indicators	Cost/Financial Indicators	Productivity Indicators
Inventory Management	Order fill rate	Order turnaround time	Value of unusable stock	Inventory velocity
(Port)	Inventory accuracy rate	Order lead time	Value of missing stock	% Product ordered via electronic ordering system
	Stocked according to plan		Average cost to fill an order	Facility reporting rates
	Acceptable shelf life			
	Stock loss			
	Plan for predictable demand			
	Order entry accuracy			
	Invoice accuracy			
Distribution	On Time Arrivals	Average Loading Time	Total Loading Costs	Berth Utilisation
(Shipping)	% Ships not loadable	Ship Turnaround Time		Ships Berthed per Day
	% Ships with correct paperwork	Idle time		
	% Docking Incidents			
	On Time departures			

5.2 Supply Chain Performance Analysis

In this phase of the methodology the current performance of the supply chain was measured using the adapted framework described in section 5.1. Target values are determined against a combination of best practices, values found in the Transnets integrated report 2014 and ideal values. Ideal values are relevant to KPI's such as accidents for the year. It should be mentioned here that binary and continuous data sets are averaged together; however, a suggestion for future work is ensure that all data collected is continuous in nature to increase the accuracy of the framework. All achieved values were found in open source documentation on Transnet for the year 2014. The majority of the achieved values were attained from Transnet's integrated report for the year 2014. All information is taken over a one year period.

The methodology undertaken is as follows:

- The performance of the adapted framework was calculated using all known figures and values for Transnet's performance.
- Target values for the chosen KPI's were determined using market leaders, Transnet integrated report 2014 and ideal targets. An ideal target, for example, would be 100% for inventory accuracy.
- Each KPI was then measured against the target value.
- The differences in performance for the current state were calculated as a percentage for each KPI.
- The differences for each supply chain Phase (procurement, supplier, distribution, warehousing and inventory management) are the calculated by averaging the relative gaps of each KPI.
- Each supply chain Phase was weighted according to the phase of the supply chain with the smallest capacity.
- Each of the differences in the phases was then averaged out according to the weighting and the performance of the entire supply chain is calculated.

Figure 5-6 shows the methodology of the performance measurement of the supply chain.

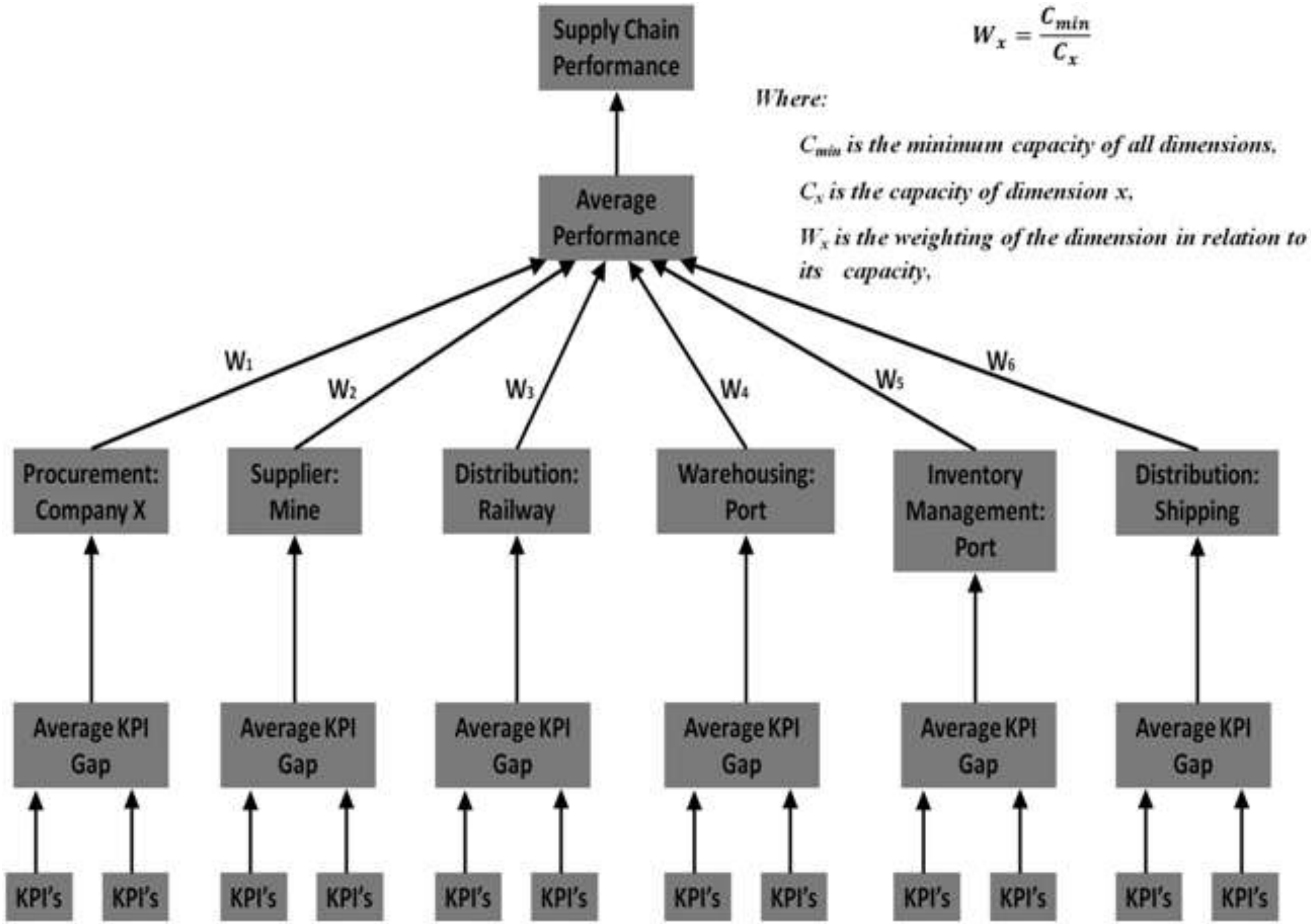


Figure 5-6: Supply Chain Performance Measurement Framework

5.3 Simulating Transnet's Value Chain

The simulation of Transnet's value chain shows how accurately the company's performance indicators measured the performance of Transnet and determined which areas needed to be monitored more closely. From the current performance analysis, scenarios were developed and run through the simulation to determine the effects on the system. These results will give Transnet a guideline on what areas to investigate further in order to increase throughput effectively. The rail network is focused on in the simulating of the value chain. It should be stated that the system aims to improve the efficiency of the value chain and not the capacity of any single phase of the value chain, i.e. improving the efficiency of the rail network would reduce the stockpiling of coal in line with creating a leaner pull orientated network.

The flow of materials, information and resources were mapped out in previous sections of Chapter Three and Chapter Six. The simulation is modelled using discrete event simulation.

5.3.1 Problem Statement

The problem statement was given in Chapter Three. Additional information and assumptions are described in this section. In addition to the problem statement in Chapter Three, the following points are relevant:

- The gross tonnage of each train is 22000 tons, with each wagon having a capacity of 84 tons.
- The braking of the trains is done in advance and laden trains will need a greater amount of railway to stop.
- The simulation will start with the creation of coal at the siding. The creation of 100 wagon trains occurs in a predetermined inter-arrival time at Ermelo, before departing for the mine.
- Once the 100 wagon train has returned to Ermelo and coupled with a second train it continues on to the RBCT where it is decoupled and unloaded before returning to Ermelo.
- The unloaded coal is loaded onto the ships. The ships arrive at a predetermined inter-arrival time. Once loaded then depart and the simulation is complete.
- There is maintenance for 21 days a year, thus all port and rail activities work 24 hours a day for 344 days a year.

The objective of the simulation is to determine the current performance of the supply chain and its performance indicators and test a variation of scenarios aimed at improving key areas in the line.

5.3.2 Flowcharts

Flowcharts for all phases of the supply chain can be seen in the Appendix A, Section A1.

5.3.3 Assumptions

- Drivers of the trains, machine operators and people within the system have constant and predictable behaviour.
- Machines and trains have predictable behaviour.
- Breakdowns occur as discrete events.
- With the given gradient of the route and the guidelines for the speed of heavy haulage trains the assumed speed for trains is 50-80km/h.
- Throughout the processes in the supply chain it is assumed that the port authority is fed information on new clients, coal production and the location of coal throughout the supply chain.
- The process flow of the supplier is kept as simple as possible as there are many suppliers of coal. It would be impractical to research their methods of dealing with the end customer when all that is needed for the value chain to work effectively is the pickup and delivery date for the order.
- All suppliers request 100 wagon trains at a time and all trains make one stop, at Ermelo, on their way from the mines to RBCT. This assumption is made because although there are many suppliers and in reality a train will have multiple orders from multiple suppliers on it, the siding from which the train is loaded in many cases in a common siding. Those mines big enough to have their own siding are assumed to produce enough coal to fill trains in their entirety.
- The simulation makes use of average values with regards to train sizes, speeds, turnaround times, travel times and breakdown occurrences.

5.4 Building the Model

5.4.1 Model Architecture

The overall model is shown in Figure 5-7. The model starts at the Ermelo rail yard which is represented by the green block labelled 1 and the small grey block before it. The gray block is the rail yard housing all the unused locomotives and wagons and the green block represents the working rail yard of Ermelo where the coupling and decoupling occurs and the switching of trains from AC to DC. The mine siding is represented by the brown and grey blocks labelled 2. The brown block represents the queue at the siding and the grey block is the siding where the loading of the coal takes place.

The constriction of the Overvaal tunnel is represented by 3. The RBCT is represented by 4. This is where the trains are decoupled, the coal is unloaded and stored and the trains are coupled. The decoupling and coupling of the trains occurs before and after the grey blocks, respectively. The ocean and the source of the ships arriving are represented by the blue area.

The basic flow of the model is as follows:

1. The train is required to pick up 100 wagons of coal from the siding. The train's source is in the grey rail yard to the right of the working rail yard of Ermelo. The trains and wagons are created in 100 wagon consists and sent to the siding through the Ermelo rail yard.
    - **Assumptions:**
    - The trains move at a constant average speed as opposed to using different speed and acceleration values because it is assumed all trains are the same model and will have similar travel times. The average travel time is used for each train. Furthermore, information regarding the nature of the trains top speed, acceleration and deceleration capabilities were not readily available at the time this report was published. There are recommendations given in Section 8 which address the use of average values across the simulation as well as constant route profiles. The model is designed using a triangular distribution to model some real life variability.

- 100 wagon trains are modelled using 1 locomotive and 1 wagon, for simplicity.
- There is one mine siding from where all the coal is picked up. The siding has a capacity of 10 trains. The siding is modelled as such to provide simplicity to the network. The assumption represents the real world as the capacity of the siding is the same as that of the real world and the distances travelled in the cycle times used are average travel times from Ermelo to the mine and back to Ermelo.

2. Once at the mine the trains wait in the brown block at the mine siding which represents a queuing area. Once the siding has the capacity the train enters and the loading begins. A delay is used to represent the travel and loading times and the "seizing" or actual loading of the coal takes no time.
   - **Assumptions:**
   - The mines produce more than sufficient coal for export. As Transnet planned to export 77 million tonnes and only exported 69.6 million tonnes with no mention of any shortage occurring at the mine, it is reasonable to assume coal was not in shortage. The forecast of coal to be exported in the forthcoming years shows a steady increase, which validates this assumption furthermore.
   - Coal is represented by one large piece of coal. This is conceptually accurate, albeit, visually inaccurate.
3. From the mine the laden train now moves back to the Ermelo Yard where it waits to be coupled with an identical train of 100 loaded wagons. Once again the travel time is represented by a delay at the start of the rail yard at Ermelo.
   - **Assumptions:**
   - As the process of coupling in Anylogic requires the disposal of a train, which cannot be done if there is a resource attached to the agent (coal on the wagon) the coal is then unloaded before the train enters the yard (unloading or loading the coal, and the coupling and decoupling mechanism on Anylogic takes no time.). Therefore the reasonable assumption is made that the coal is offloading, the train is coupled and then the 200 wagon long consist is reloaded (seizes coal). The process described here has no affect on the time of the operations followed at the Ermelo yard.

4. Once the trains at the Ermelo Yard are coupled they leave the yard and immediately afterwards seize the coal that was dropped off. The train then continues on the way to the Overvaal tunnel where the train experiences a travel time delay, which is inclusive of the waiting time at the one way tunnel. This is true for both consists travelling to and from the RBCT.
   - **Assumptions:**
   - 200 wagon trains are simulated as single wagons seizing twice the capacity of coal as the simulated rail network has a maximum length. This means that if there is a bottleneck of trains that the network will be at full capacity and no more trains can be produced at the source. Thus, adjusting the capacity and utilising a single wagon avoids this potential complication, whilst not changing the real output. Recommendations to counter this assumption are given in Section 8.2.
   - The track is singular in the real world, however, the Overvaal tunnel is modelled as a double track as the travel times are average travel times which include the delays associated with the Overvaal Tunnel.
5. From the Overvaal tunnel the 200 wagon consist travels to the RBCT. Once it has arrived at the RBCT terminal it s decoupled before entering the terminal. The one 100 wagon consist enters the terminal to begin off loading and the second 100 wagon consist queues to enter the terminal. Once off loaded the trains are then coupled again and return to the Overvaal tunnel en route back to Ermelo where the train is "disposed", meaning that it is stored in the rail yard.

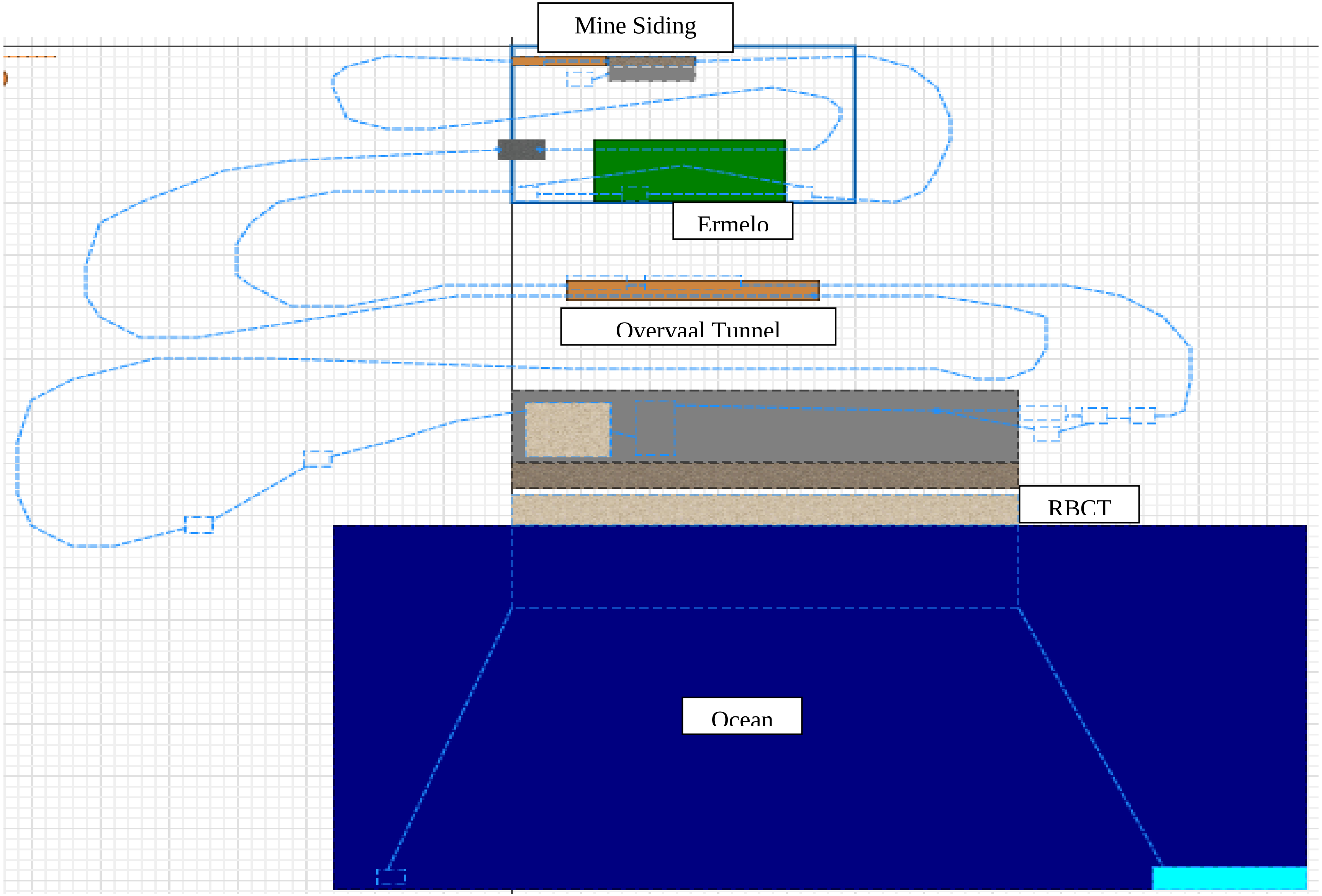


Figure 5-7: A Screenshot of the Overall Model Structure in Anylogic 7 (Anylogic Company, 2014)

5.5 Development and Running of Scenarios

The scenarios chosen for testing are based on the results of the adapted Aronovich framework outlined in this methodology and the results obtained from the simulation, which echo the findings from the framework. From the results it is evident that the rail network is a significant contributor to negative performance within the supply chain. The results suggest three scenarios to be tested within the supply chain and the rail network.

5.5.1 Scenario A: The improvement of the Ermelo hub and the running of 200 wagon trains

In this scenario Ermelo is used as a hub and uses 200 wagon long trains in a new format shortening the coupling and decoupling times significantly. The Overvaal single track still exists.

5.5.2 Scenario B: The introduction of running 100 length wagons only

In this scenario the 200 wagon long trains are eliminated and only smaller batches of 100 wagons are used. The route used is as normal and thus remains unchanged. Therefore, all trains must still make use of Ermelo as a hub and the Overvaal single track limitation still exists.

5.5.3 Scenario C: The removal of Ermelo as a hub, the use of 100 wagon trains and the upgrade of Overvaal.

In this scenario the Overvaal single track is upgraded to double track, the hub art Ermelo is removed and the trains are all operating in 100 wagon consists. The Overvaal tunnel is set to be upgraded to a two way tunnel. This new project will allow trains to go to RBCT and return from RBCT with no delay (EIMS, 2013).

6 Observations

This chapter shows the observations of the table of KPI's chosen to populate the adapted Arononvich model, the numerical calculations of those chosen KPI's and the simulation observations. Included in the table of chosen KPI's are explanations of all the targets values for the KPI's chosen.

6.1 Chosen KPI's

The chosen KPI's, their definitions and the performance questions that they answer with regards to the business operation of Transnet are shown Table 6-1 through to Table 6-6. It should be noted that Transnet has Live monitoring of their KPI's as needed for their annual integrated report which is available publicly.

In accordance with the methodology of Aronovich, et al., 2010, each KPI is explained mathematically. Once the KPI is mathematically defined a description of how the KPI affects the company in terms of the strategy and/ or the operations of the company is given. The KPI must then answer a question about the company's strategy and/ or operations. The answer to the question must explain how the KPI will affect the company on a strategic and/ or operational level.

An example is forecast accuracy taken from Table 6-1. The mathematical definition for the forecast accuracy is: (Forecast Volume – Actual Volume)/(Actual Volume) × 100. The description of the KPI is that a positive value would mean that there is an underestimation and a negative value shows an overestimation of the attribute being forecasted. Here the KPI answers the question: "How well is the forecasting process working?". A value of zero is the target value in this case, although it is and unlikely event it is a target worth pursuing. This is because forecasting accuracy will affect the entire supply chain. Target values are bolded text. Explanations of the target values will now be given in Table 6-1 through to Table 6-6.

6.1.1 Procurement KPI's and Targets

The following KPI's are taken from Table 6-1:

Percentage export quality coal of total volume produced – This KPI measures what percentage of coal is produced for export. The target for this KPI is set at 42%. This was calculated by the using the forecasted amount of coal to be exported, 77 Mtpa (Million tons per annum) divided by the total amount of coal produced at 260 Mtpa.

This KPI is important to Transnet as it allows them to gage the feasibility of the export market which may affect their decision on where to invest their time, i.e. local vs. international. The proportion instead of volume is taken as volumes mined may be inconsistent due to strikes and the instability within the mining sector. Furthermore, the local energy generator for Southern Africa (ESKOM) may purchase larger volumes of coal in a bid to stabilise the energy supply in this region. The proportion of Export vs Local coal volumes is used because trends may be found and used to forecast demand.

Forecast accuracy – This KPI measures the difference between what was forecasted and what the actual value achieved is. The ideal target for this KPI is 100%.

Percentage of procured products that meet regulations – This KPI measures how much of the product that is procured during the procurement process is suitable for the export market. The target for this KPI is set at 100% as an ideal target. The target is set as an ideal target because the procurement of the good should all be within regulation to avoid unnecessary losses.

Lead time to award contract – This KPI measures how long it takes for Transnet to formally agree contacts with its customers. This KPI customer facing, i.e. it is the contract Transnet is trying to acquire in order to add to its customer list. The target for this KPI is six weeks (G2 Incorporated, 2017). This target is based on the signing of a new telecom contract. The relationship between the customer and the company has a largely similar nature as explained by G2 Inc., 2017. The rules and regulations in the telecom industry are as complex as the coal industry. Thus, due to the nature of the coal industry and its regulations a six week target was deemed feasible in this study. Furthermore, investigation was carried out into PFMA (public finance management act) for this KPI and no guidelines were found.

Profit Margin for cost recovery system – This KPI measures what percentage mark up of the company is. The target for this value is five percent, as set out by Cerasis, 2014. The employment of logistics efficiency management has lead to the mark-up on logistics companies to be four to seven percent of the sales (Robinson, 2014).

Cost in comparison to international companies – This KPI measures the cost of transporting coal using Transnet versus internationally. The target for this value is R0,017 per km (US Energy Information Administration, 2014). The USA is the largest freight rail network in the world (Pierce, 2013). Transnet has the size and buying power of a large privatised freight rail network, such as those operating in the USA. Similarly to Transnet, the profile of the rail network in the USA services majority freight shipments as opposed to passengers. The coal export market in the USA is the fourth largest in the world and uses this rail infrastructure to export the commodity (Workman, 2018). Thus, with these similarities using the USA to form the basis for the costing is deemed feasible.

Orders processed per employee – This KPI measures the average number of orders processed per employee. The target for this KPI is 57. This target is based on the employee confirming one contract for every six weeks. The assumption is made that Transnet does not have a set procurement methodology, due to the fact that there is no mention of business activities linking the supplier to the end customer through any form of business admin on Transnets behalf (Transnet, 2014).

Table 6-1: Table of Procurement KPI's and Definitions

Phase: Procurement	**Key Performance Indicator**	**Formula**	**Description**	**Question & Target**
Quality	% Export Quality Coal of total volume procured	(Export Quality Coal)/(Total Coal Sold) × 100	Determines which market is in more demand, the local or the international market and where to shift the focus of the company.	Is the quality of the coal produced exportable? **42%**
	Forecast Accuracy	(Forecast Volume – Actual Volume)/(Actual Volume) × 100	Determines how accurately the forecasting techniques used are. Negative value means over estimation and positive value means underestimation	How well is the forecasting process working? **100%**
	% of procured products that meet regulations	(Total Number of Products Produced - Total Number of Products that do not that meet regulation)/(Total Number of Products Produced) × 100	Determines how many products are produced out or regulation. Ideally a low percentage is good.	Is the procurement process acquiring customers of the correct standard? **100%**
Response Time	Lead time to award contract	(Days from initial contact to issuing of contract)/(Total contracts awarded)	Determines how long between suppliers signing the contract and the initial negotiations start	How quickly is business secured? **6 weeks**
Financial	Profit Margin for cost recovery system	(Sales - Cost of Sales)/(Cost of Sales) × 100	Determines if a cost recovery system can work, i.e. can the company buy its own commodities and invest in future growth	How profitable the business is? **N/A**
	Cost in comparison to international companies	(Average cost per km)/(Average international cost per km) × 100	Shows the company's cost respective to the international norm. If the value is greater than % it means the cost for this service is a premium in comparison to the international norm.	How attractive is the business is to potential customers with regards to the rest of the world? **R0,017/Km**
Productivity	Orders processed per employee	(Total number of orders processed)/(Number of full time staff)	Determines staff productivity which can show a need for training or skills building or process inefficiencies.	How fast are orders sent to operations? **57**

6.1.2 Supplier KPI's and Targets

The KPI's discussed under this section are taken from Table 6-2:

Order Compliance – This KPI measures how many train loads of coal are delivered correctly from the supplier, i.e. is the coal the correct grade?, is the volume of coal correct? The target for this KPI is 100%. This is an ideal target which needs to be met in order to minimise unnecessary loses by both supplier and Transnet.

Percentage Orders with products on back order – This measures the percentage of products that are on back order at any given time. This value has an ideal target of zero. This assumes that in an ideal situation there would be no orders on back order. The ordering process should be aligned with the operational capability of the value chain in order for this target to be reached.

Shipping accuracy – This KPI measures the ability of the supplier to deliver the correct order to the correct customer. The target for this KPI is an ideal target of 100%.

On time delivery – This measures the ability of the supplier to produce the correct amount of coal at the correct time, i.e. coal is produced at a rate such that the trains arrive, load and depart with no waiting time in between. The target value is an ideal target of 100%. This KPI is prioritised according to Transnets business strategy and thus the supplier needs to have the goods ready in time for departure (Transnet, 2014).

Supplier lead time variability – This KPI measures the ability of the supplier to consistently supply product for export. The target for this value is zero and is an ideal target. As the supplier is at the start of the supply chain, in terms of operations it is critical that variability is minimised. The increase in variability at the start of the supply chain can propagate in increasing magnitudes further down the chain.

Total supply cost – This KPI measures the total costs involved with supplying the value chain with the required product. The cost of this according to international standards is R128 per ton (Williams, 2005).

Supplier Fill Rate – This KPI measures the suppliers' ability to meet the demand of the value chain. The target for this is 100%, with a volume of 77 Mtpa. This target value of 77Mtpa is based on the expected coal export forecast. This is in line with both Transnets Expectation and the data released by the Chamber of Mines in 2014.

Table 6-2: Table of Supplier KPI's and Defnitions

Phase: Supplier (Mines)	**Key Performance Indicator**	**Formula**	**Description**	**Question & Target**
Quality	Order Compliance	(Numbers of trains loaded which meet defined criteria)/(Total number of orders filled)	Measures supplier performance and take action to improve supplier performance. Making sure suppliers deliver on time and deliver the number of orders meant to be delivered.	Is the supplier providing the right amount of goods? **100%**
	% Orders with products on back order	(Volume on back order)/(Total volume) × 100	This measures the efficiency of stock management. This measure may also be used to analyse supplier performance.	What % of the volume is on back order at any given time? **0**
	Shipping Accuracy	(Number of trains released without error)/(Total number of trains released)	Measures the efficiency of the supplier to deliver correct and accurate orders.	What % of trains processed have errors? **100%**
Response Time	On Time Delivery	(Trains arrive on time)/(Total number of trains released)	Measures the ability of suppliers to meet predetermined delivery times, as per contractual agreements.	Is the coal ready for departure upon the arrival of the train? **100%**
	Supplier lead time variability	Σ(Forecasted lead times-actual lead times)/[(Actual Lead times)(Total Orders)] × 100	This measures the consistency of the suppliers' ability to deliver goods.	How reliable and predictable are the suppliers? **0%**
Financial	Total Supply Cost	Total Cost = personnel costs + telecom cost + office costs + other related costs	Measure cost effectiveness of the supplier’s processes.	How much does it cost to run supplier company? **R128/ ton**
Productivity	Supplier Fill Rate	(Number of completed trains released)/(Total number of orders shipped) × 100	Ability of suppliers to meet order demand.	Are the suppliers meeting their order rate? **100%**

6.1.3 Rail Transport KPI's and Targets

The table summarising these KPI's, their formulas and their description are presented in Table 6-3:

On time departures – This KPI measures the percentage of trains that leave on time. The target for this KPI is an ideal target of 100%. This KPI may also be measured in minutes as it is done later in this study. The target value is then 15-30 minutes (Brown, 2016).

On time arrivals – This KPI measures the percentage of trains that arrive at their destination on time. The target for this KPI is an ideal target of 100%. As with the on time departures, this KPI may also be measured in minutes as it is done later in this study. The target value is then 15-30 minutes (Brown, 2016).

Trains where the quantity despatched is the quantity received – This KPI measure whether the tonnage that was collected by the trains is the same tonnage delivered by the train. The target percentage is an ideal target of 100%.

Trains arriving in good condition – This KPI measures what percentage of trains arrive with their goods in acceptable condition (volume and quality). The ideal target for this value is 100%.

Km (Kilometres) between accidents – This KPI measures how many Km occur between accidents. This can point towards maintenance issues. The target value for this is 100 000km (Transnet, 2014).

Average transport time – This KPI measures the time taken in transit. The target for this value is 20 hours. This is calculated using the ideal values for each step in the process. The time for each process can be found in the Transnet integrated report, 2014, RBCT, 2015 and Kuys, 2011. This target assumes no idle time.

Average loading and unloading time – This KPI measure how long it takes to load and unload a train. The target value is machine defined as 5500 tons per hour, which translates to 3.5 hours per train (Richards Bay Coal Terminal, 2015).

Vehicle turnaround time – This measures the time taken by the train from departure at Ermelo until arrival (with Empties). This target value is 48 hours (Govender, 2015).

Total Transportation Costs – This KPI measures the cost per km for transporting the goods to RBCT. The target value is given as R 946 per Km. This is calculated based on the average transportation cost per ton of R 66 per ton (US Energy Information Administration, 2014).

Average cost per weight – This KPI measures how much it costs to transport each ton of coal. The target value is R 66 (US Energy Information Administration, 2014).

Transportation costs versus product value – This identifies the cost of the route versus the cost of the actual product. This tells Transnet is it is cost effective enough for the end customer to use, i.e. does the product cost more that the transportation of the product. The target for this KPI according to the international market is 20% (US Energy Information Administration, 2014). It must be noted that this is note the margin of profit that Transnet is applying.

Train Availability – This KPI measures how often the vehicle is available for use over the year. The target for this KPI is an ideal target of 100% because Transnets business model implies that the availability of resources should a priority (Transnet, 2014).

Wagon capacity utilisation – This KPI measures how often the wagons are being used. The units for this KPI may be in Km, as km covered per loco per month or as a percentage. In this study it is reported as the former. The target value is 26618km. This is based on the forecasted amount of coal to be transported in the year (77 Mtpa). Here it is assumed that if the difference in performance is not 0, then the value must be negative. This is because if the wagons and locomotives are underutilised they are seen as liabilities as they still need regular servicing, but are not being used to their full potential (Transnet, 2014)

Fleet Yield – this measures the amount of product that is delivered by the fleet i.e. the rate of delivery. This target is based on the forecasted volume of export coal of 77 Mtpa (US Energy Information Administration, 2014).

Downtime maintenance – This measures the time taken for routine maintenance (traction). The target value for routine maintenance is 21 days (Transnet, 2014)

Downtime breakdowns – This measure the amount of time spend on unplanned maintenance. The target value for this is ideal and is set at zero.

Table 6-3: Table of Rail Transport KPI's and Definitions

Phase: Rail Transport	Key Performance Indicator	Formula	Description	Question & Target
Quality	On Time Departures	(Number of 100 wagon trains leaving on time)/(Number trains made for departure) × 100	Measures what percentage of trains departed on time	Is the train departing on time? **15-30 minutes**
	On Time Arrivals	(Number of 100 wagon trains arriving on time)/(Number trains made) × 100	Late deliveries can lead to stock outs and other traffic issues along the route.	Is the train arriving on time? **15-30 minutes**
	Trains where Quantity Despatched = Quantity Received	(Number of 100 wagon trains where received = despatched)/(Total 100 wagon trains made) × 100	Shows problems occurring in transit such as theft or infrastructure problems	Is the order received accurate? **100%**
	Trains arriving in good condition	(Consists arriving in good condition)/(Total number of 100 wagon trains) × 100	High values in this measure means that there is insufficient protection from the elements during transit or possible mishandling.	Is the product safe during transit? **100%**
	Km Between Accidents	(Total Kms travelled)/(Number of accidents for the year)	Poor route conditions, signalling issues, infrastructure problems.	Is the medium of transport and our infrastructure safe? **100 000 Km**
Response Time	Average Transport Time	(Total number of days from despatch to receipt)/(Total number of trains)	Measures the efficiency of processing orders.	How long is the route from the supplier to the port? **20 hours**
	Average Loading and Unloading Time	(Total time to load and unload train)/(Total number of train)	Measures the efficiency of the materials handling system.	How long does it take to load and unload the product? **3,5 Hours**
	Vehicle Turnaround Time	(Total amount of time that the vehicle is idle at the facility)/(Actual working time during that period)	Lower turnaround time means that more clients can be serviced.	How long does the vehicle remain idle at the port? **48 Hours**

Phase: Rail Transport (Continued...)	Key Performance Indicator	Formula	Description	Question & Target
Financial	Total Transportation Costs	Σ Total transport costs	Monitor for running expenses so that operational decisions can be well informed.	How much does it cost to transport the product? **R946/Km**
	Average Costs Per Weight	(Σ costs)/(Weight transported)	Monitor for running expenses so that operational decisions can be well informed.	How much does a certain weight cost to transport? **R66/ton**
	Transportation Costs vs. Product Value	(Σ costs)/(Total value of product transported)	Identify costly routes.	Which route is most costly to run? **20%**
Productivity	Train Availability	(Total days in use - Total days unavailable)/(Total days in year) × 100	Indication of fleet condition. 80-95% is acceptable range.	How often is the vehicle in use? **100%**
	Wagon Capacity Utilisation	(Total volume transported)/(Theoretical Maximum capacity for wagons) × 100	Measures the effective utilisation of resources.	How often are the wagons in use? **100%**
	Fleet Yield	(Σ quantity delivered)/(Working hours)	Efficiency of human resources and vehicles	How much can the fleet deliver? **77Mtpa**
	Downtime - Maintenance	(Routine Maintenance)/(Total Days in Year)	Measures how long routine maintenance.	What time do the trains have for maintenance? **21 Days**
	Downtime - Breakdowns	(Unplanned Maintenance)/(Total Days in Year)	Measures what percentage of work is lost due to unplanned events, such as breakdowns.	How much time is lost due to avoidable events? **0**

6.1.4 Warehousing KPI’s and Targets

The table summarising these KPI’s, their formulas and their description are presented in Table 6-4:

Inventory accuracy rate – This KPI measures the efficiency of the inventory control. The target value is an ideal value of 100%.

Put away rate – This KPI measures the ability of the warehouse to assign the correct product to the correct stockpile. The target value for this KPI is an ideal value of 100%.

Picking accuracy – This KPI measures the efficiency of the picking process. The target value for this KPI is 100% and is an ideal value.

Warehouse accident rate – This KPI measures the amount of accidents that occur during the warehousing processes. The ideal value for this KPI is zero.

Warehouse order processing measures the time taken by processes in the control of Transnet. Customs clearance cycle measures the time taken for customs to clear the goods. Both of these processes have little to no documentation on. The warehousing and custom cycles are looked at holistically as opposed to individually.

Put away time – This processes measures the time taken to unload the coal and store it correctly. This is a machine operated rate of production of 5500 tph (tons per hour) (Richards Bay Coal Terminal, 2015).

Total warehousing costs – This KPI measures the costs of warehousing coal, per ton. The target value is R1 per ton (Weber Logistics, 2014).

Value of damaged product in warehouse – This KPI measures the amount of product that is damaged during the warehousing process. The target value in this case is ideal and is zero percent.

Storage space utilisation – This KPI measures how much space is currently being occupied in the warehouse. The ideal value is 85% of capacity; however, if we are aiming to improve the physical storage space should be reduced in order to make the system leaner. This is in line with modelling the system as a pull system in the long term.

Units moved per hour – This KPI measures the amount of product that is moved in a given hour into the warehouse. The ideal value is machine defined as 5500 tph.

Percentage storage space dedicated to material handling – This KPI measures the amount of space in the warehouse that is dedicated to materials handling. This target value is 30-75% (Chheda, 2015; Frost and Sullivan, 2015).

Stockpile stacking rate – This KPI measures the rate at which coal is stacked into their respective stockpiles. The ideal value is 5500 tph which is machine defined(Richards Bay Coal Terminal, 2016).

Stockpile reclaiming rate – This KPI measures the rate at which coal is reclaimed fro the stockpile. This target is machine defined and is an ideal value of 5500 tph (Richards Bay Coal Terminal, 2015).

6.1.5 Inventory Management KPI's and Targets

The table summarising these KPI's, their formulas and their description are presented in Table 6-5:

Stock out rates – This KPI measures the percentage of time that there is no coal available in the warehouse. The target value for this KPI is an ideal value of 100%.

Order fill rate – This KPI measures the ability of Transnet to fill orders from the customer. The target for this KPI is 100% and is an ideal value.

Inventory accuracy – This KPI measures how well we are tracking the inventory coming in and out of the warehouse. The target is an ideal target of 100%. This KPI will inform Transnet of any wastage along he material handling path as well as any potential theft or destruction.

Stocked according to plan – This KPI measures the ratio between the days with stock and the days without stock. This indicates whether or not the suppliers are able to fulfil the demand set by the end user of the value chain. This target value is zero and is an ideal target to have.

Table 6-4: Table of Warehousing KPI's and Definitions

Phase: Warehousing	Key Performance Indicator	Formula	Description	Question & Target
Quality	Inventory Accuracy Rate	(Stockpile locations with no discrepancies)/(Total number of stockpiles) × 100	Assesses the efficiency of inventory control.	How many locations are working correctly without error? **100%**
	Put Away Accuracy	(Volume put in correct stockpile)/(Total Volume put away) × 100	Ability of the warehouse to assign the correct product into the correct stockpile.	Are the right grades of coal going to the right stockpiles?
	Picking Accuracy	(Volume picked correctly)/(Total volume picked) × 100	Measures the efficiency of how well the factory picks stock. Inefficiencies in picking may result in poor order quality and stock outs.	Are the grades of coal being picked correctly? **100%**
	Warehouse Accident Rate	Number of accidents per year	Shows how well trained staff are, how clear the safety guidelines and procedures are and how well the warehouse and its processes are managed. This measure may also help with identifying areas of improvement.	Is the working environment safe and managed correctly? **0%**
Response Time	Warehouse order processing time	Σ[Date and time of volume shipped - Date and time of volume received]/(Total volume) × 100	Identifies areas of improvement within the processing of shipments from the warehouse	How long does coal sit for before being released? **N/A**
	Customs clearance cycle	Warehouse arrival time - Port arrival time	Identifies delays in the customs processes.	How long do customs take to release the goods? **N/A**
	Put Away Time	Time unloaded - Time Stored in location	Monitors the efficiency of the put away processes.	How long does it take the coal to be unloaded and stored correctly? **5500 tph**

Table 6-4: Table of warehousing KPIs (Continued...)

Phase: Warehousing	**Key Performance Indicator**	**Formula**	**Description**	**Question & Target**
Financial	Total warehousing cost	Total warehouse cost = (labour + space + utilities + material + equipment + other)/(Quantity of stocked product)	Monitors the costs of different components in the warehouse.	How much does it cost to keep the warehouse operational? **R1/ton**
	Value of damaged product in warehouse	(Damaged product)/(Shipped product) × 100	Monitors the care of handling products in and around the port.	How much volume gets damaged? **0%**
Productivity	Storage space utilisation	(Total storage space in use)/(Total storage space available) × 100	Monitors the availability of storage in the warehouse. Having too little can mean overstocking and too small a value can mean under stocking or oversized warehousing facilities.	Are we over or under stocked? **85%**
	Units moved per hour	(Volume of product moved)/(Number of hours worked)	Measures the effectiveness of materials handling in the warehouse facility.	How much can we move in a given period of time? **5500tph**
	% of storage space dedicated to product handling	(Storage area for product handling)/(Total storage area) × 100	If this measure is too small it can lead to inefficiencies and accidents resulting in the loss or damage of goods or labour.	Does our warehouse have enough space to operate effectively? **30-75%**
	Stockpile Stacking Rate	Machine defined value	This measures defines how quickly stockpiling of the product can be.	At what rate can be store product? **5500tph**
	Stockpile Reclaiming Rate	Machine defined value	This measures how quickly picking product from a stockpile can be.	At what rate can we pick product from the stockpile? **5500tph**

Table 6-5: Table of Inventory Management KPI's and Definitions

Phase: Inventory Management	Key Performance Indicator	Formula	Description	Question & Target
Quality	Stock out rates	(Number of days without coal)/(Number of days in operation) × 100	Measures product availability and the ability of the company to meet demands of the customer.	Is there an occurrence of under stocking? **0%**
	Order fill rate	(Volume and grade of coal ordered - Volume and grade of coal received)/(Total volume received) × 100	Measures the performance of the issuing facility and how efficient the inventory is managed,	How efficient is the ordering and receiving of stock processes? **100%**
	Inventory accuracy	(Grades where volume record count = physical volume count)/(Total number of grades) × 100	Relates to the whole inventory management process from putting away to picking and everything in between. This measure is essential for forecasting.	Are we recording the incoming and outgoing volumes correctly? **100%**
	Stocked according to plan	(Number of days with stock out of range)/(Total number of days in operation) × 100	Measures stock management. If this ratio is too high then it means that there is too much variability in the stock management and the processes need to be evaluated.	Are our supply and demand values matching? **100%**
Response Time	Order Turnaround Time	(Number of days to process all orders received)/(Total number of orders processed)	Measures the efficiency of processing orders.	How quickly can we process orders? **15hrs**
	Order Lead Time	(Time order received - Time order placed)/(Total number of orders placed)	Measures the efficiency of distributing the goods.	How long does it take for the order to be received? **64hrs**

Table 6-5: Table of Inventory Management KPI’s (Continued...)

Phase: Inventory Management	Key Performance Indicator	Formula	Description	Question & Target
Financial	Inventory Holding Cost	Holding Cost = (sum of all capital and non-capital costs)	This measure helps the inventory supervisor to maintain the correct supplies such that excess costs are not being incurred	How much does it cost us to keep stock? **R1 per Ton**
Productivity	Inventory Turnover Rate	(Total volume of items distributed or sold)/(average value of inventory)	This value should be from 6-12. If it is too high it means that there is insufficient stock and of it is too low it means that there is too much stock.	How many times is our inventory being replaced? **10**

(Section 6.1.5 Inventory Management KPI's and Targets continued...)

Order turnaround time – This KPI measures how quickly stock is turned over. This KPI provides insight into the length of time stock is held and how quickly the processes are working. The ideal target is 15 hours. This value is purely material handling and value adding time (Govender, 2015).

Order lead time – This KPI measures the total time taken for the order to be processed, i.e. from the start of the value chain until it is picked from the warehouse and placed on the ship. The target value for this process is 64 hours (Govender, 2015).

Inventory holding cost – This KPI measures the cost incurred by holding stock. The target value for holding stock is R1 per ton (Weber Logistics, 2014).

Inventory turnover rate – This KPI measures how many times stock is sold over a given year. This KPI shows which grades of coal are most common. The target for this value is 10 and is calculated by using the forecasted amount of coal for export in 2014, 77 Mt.

6.1.6 Shipping KPI's and Targets

The table summarising these KPI's, their formulas and their description are presented in Table 6-6:

On time arrivals – This KPI measures whether the ship arrives at the correct time without delays. The ideal target for this value is 100% or in hours it is zero.

Percentage ships not loadable – This KPI measures what percentage of the ships that arrive are unable to be loaded for whatever reason. The target value for this KPI is zero and is an ideal value.

Percentage of ships with correct paperwork – This KPI measures the percentage of ships that arrive have all of their documentation in order. The target value for this KPI is 100% and is an ideal value.

Percentage of docking incidents – This KPI measures how safe and efficient the docking processes and facilities are. The target value for this KPI is zero and is an ideal value.

On time Departures – This KPI measures the percentage of ships that leave on time. The ideal target value is 100%.

Average loading time – This KPI measures the average time taken to load a ship. This is a machine defined process if the non value adding and idle time is removed. Therefore, the target value for this KPI is 15 hours (Transnet, 2014).

Ship turnaround time – This KPI measures the time it takes for the ship to depart the port after it has arrived in South African waters. This KPI shows how efficient the port and the port authority are working. The target for this KPI is 15 hours (Transnet, 2014).

Idle time – This KPI measures the time the ship waits in South African waters before entering the port to be loaded. This KPI shows how efficient the port processes are and if the just in time methodology is being implemented. The target value is zero and is an ideal value.

Total loading costs – This KPI measures what the cost for loading a ship is. The ideal target value is R1 per ton (Weber Logistics, 2014).

Berth utilisation – This KPI measures how often the berths are occupied. The target value for this KPI is 40%. The calculation is adapted to fit six berths with four ship loaders (De Weille and Ray, 1974; Park, Yoon and Park, 2014)

Ships berthed per day – This KPI measures the number of ships berthed per day. The target value of this KPI is six because the ship loaders can handle at least 6 ships per day, even if there are only four ship loaders. This target is dependent on a machine defined capability found in Transnets Integrated Report, 2014.

Table 6-6: Table of Shipping Distribution KPI's and Definitions

Phase: Shipping	Key Performance Indicator	Formula	Description	Question & Target
Quality	On Time Arrivals	(Number of ships arriving on time)/(Total number of ships) × 100	Late arrivals can cause unnecessary delays and scheduling complications.	Is the ship arriving on time? **100%**
	% Ships not loadable	(Total number of ships not loadable)/(Total number of ships arriving) × 100	Ships not loaded immediately will result in excessive delays and back orders.	Is the Port Authority communicating with the customer efficiently? **0%**
	% Ships with correct paperwork	(Ships with the correct customs paperwork)/(Total number of ships) × 100	Ships with the incorrect paperwork cannot dock at the scheduled time which causes delays in the loading and process.	Is the port authority scheduling the customers in to port efficiently? **100%**
	% Docking Incidents	(Number of incidents occurring whilst ship is docking)/(Total ships docked)	If there are too many incidents operational efficiency will be affected and employees' lives endangered.	Is the docking process safe and efficient? **0%**
	On Time departures	(Number of ships departing on time)/(Total number of ships) × 100	If the ships depart late they will arrive at their final destination late impacting customer's perception of the product negatively.	Is the port authority operating in line with the port terminals capability? **100%**
Response Time	Average Loading Time	(Time product is loaded - time product is picked)	If the loading time is too long it will delays will occur and the ship will not be able to leave on time.	How efficient is the loading process? **15hrs**
	Ship Turnaround Time	(Time ship departs - Time ship arrives)	If the ship turnaround time is too long the ship cannot depart on time.	Is the in port process efficient? **15hrs**
	Idle time	(Time ship enters port - Time ship arrives at port)	If the ship waits too long before being docking the scheduling process may be inefficient.	How efficiently is the port authority scheduling customers to port? **0%**

Element: Shipping	Key Performance Indicator	Formula	Description	Question & Target
Financial	Total Loading Costs	(Cost of loading machinery + cost of labour + cost of utilities + other associated costs)	If this value is too high then reducing the loading process needs to be investigated.	How much does it cost the Transnet to load a ship? **R1 per ton**
Productivity	Berth Utilisation	(Amount of time the berth is occupied)/(Total amount of time the berth is in operation)	If the berth utilisation is high the need to expand may be necessary, if the berth utilisation is to low it means that there is unutilised capacity in the port.	How often is the berth being used? **40%**
	Ships Berthed per Day	(Number of ships berthed per day)	If the number of ships berthed is too long then the port capacity is being under utilised	Is there excess capacity at the port? **6**

6.2 Framework

This section contains the observations of the adapted Aronovich framework. The results shown in this section are compared to the target values identified in chapter seven. A short description of each table is given in this chapter leading up to the final results found in chapter eight. All data used is found publicly and is for the 2014 Transnet business year.

The headings in the tables 6-7 through 6-12 are explained as follows:

- Top left designates the phase of the supply chain (procurement etc.).
- The unit is the unit of measure for that specific KPI.
- The target is the target determined as per the explanations in chapter 7.
- The achieved is the value that the company achieved.
- The difference is the value of the difference between the achieved value and the target value for that KPI. A positive/ negative value for the difference can be either good or bad depending on the nature of the KPI. The meaning of a positive or negative difference is dependent on the nature of the KPI, however, in general the negative value signifies underperformance.
- The Average Indicator Difference is the average difference for that grouping of indicators, i.e. quality, response time, financial and productivity.
- The phase difference is the average difference of all the Average Indicator Differences. This shows the overall performance of the phase. All differences are utilised as absolute values in calculations as the difference between the target and the achieved value should tend to zero to avoid variations in the value chain.

Table 6-7 summarises the results from the procurement phase of the framework. Each table is structured similarly with the unit of the KPI followed by the target, the achieved value and then the difference between the achieved and target value. The Average Indicator Difference is the average of all Average Indicator Differences and the phase difference is the average difference of all the Average Indicator Differences. These averages are calculated by summing their totals and dividing by the number of elements summed. For example in the procurement phase the difference in the forecast accuracy is -9%. The only other difference in performance is the percentage product sourced for the export market, -10%. The average of all 4 KPI's in the quality indicator is then 5%, now named the Average Indicator Difference. Similarly the average all the

Average Indicator Differences makes up the phase difference which represents the amount by with the phase over or underperforms. The phase indicator and phase difference are both absolute values.

Table 6-7: Table of Procurement Framework Figures

Procurement (Transnet)	**Unit**	**Target**	**Achieved**	**Difference**	**Average Indicator Difference**	**Phase Difference**
Quality Indicator					-5%	-32%
Forecast Accuracy	%	100	91	-9%	-	-
% of product sourced for export market	%	42	38	-10%	-	-
Quality testing		Yes	Yes	0%	-	-
% of procured products that meet regulations	%	100	100	0%	-	-
Financial					-59%	-32%
% Mark-up on products sourced (Profit Margin)	%	5%	9%	-70%	-	-
Local cost vs. international cost of product per km	R/Km	0,017	0,035	-106%	-	-
Ratio of unit prices paid through an emergency procurement vs. competitive bidding process	None	0	0	0%	-	-

In the procurement phase all the differences are negative and signify an underperformance. Depending on the type of KPI a lower number may be positive and a higher number may be negative. For example: the local cost vs. the international cost per km. In this case the lower the value, the better, so the difference will be positive. Thus the positive or negative sign answers the question "is it better for this KPI to be greater or less than the target value?" The answer from this question shows the user whether a positive or negative sign must be used.

The framework aims to eliminate as much variance as possible and thus high importance is placed on achieving the target values. The target values must be accurate if the framework is to work effectively.

Table 6-8: Table of Supplier Framework Calculations

Supplier (Mines)	Units	Target	Actual	Difference	Average Indicator Difference	Phase Difference
Response Time					-117%	-42%
On Time delivery	Hours	100	100	0%	-	-
Supplier lead time	Hours per train load	0,6	2	-233%	-	-
Financial					0%	-42%
Total Supply Cost	R	128	128	0%	-	-
Productivity					-10%	-42%
Supplier order fill rate	none	100	90	-10%	-	-
Supplier rate of production	tph	210959	190684	-10%	-	-

Table 6-8 summarises the results from the suppliers KPI's. The differences are once again all negative implying there is underperformance in relation to the target values.

Table 6-9: Table of Railway Distribution Framework Calculations

Distribution (Railway)	Unit	Target	Actual	Difference	Average Indicator Difference	Phase Difference
Quality Indicators					-307%	-114%
On Time departures Ermelo to mine	minutes	15	43	-186%	-	-
On time Arrivals (mine)	minutes	15	43	-186%	-	-
% Shipments where quantity despatched equals quantity received	%	100	100	0%	-	-
% Shipments arriving in good condition	%	100	100	0%	-	-
Kilometres between accidents	km	100000	57000	-43%	-	-
On time arrivals (Port)	Minutes	15	134	-791%	-	-
Time lost due to breakdown (Traction)	Minutes per train	1	10	-940%	-	-
Response Time Indicators					-118%	-114%
Average delivery time	Minutes	20	37	-85%	-	-
Average vehicle loading time (Mine)	Hours	4	4	0%	-	-
Average vehicle unloading time (Port)	Hours	4	12	-243%	-	-
Cycle Time	Hours	48	70	-46%	-	-
Vehicle drive time	Hours	16	16	0%	-	-
Idle time	Hours	5	22	-337%	-	-
Cost/Financial Indicators					-26%	-114%
Total transportation cost per km	R/km	946	1081	-14%	-	-
Average cost per weight	R/ton	66	76	-14%	-	-
Transport cost to value of product	%	13	20	-49%	-	-
Productivity Indicators					-4%	-114%
Vehicle availability	%	100	100	0%	-	-
Vehicle capacity utilisation	000km/loco/month	26618	25925	-3%	-	-
Fleet yield	Tons per hour	9326	8261	-11%	-	-
Loading rate	Tons per hour	5500	5500	0%	-	-
Unloading Rate	Tons per hour	5500	5500	0%	-	-
Train utilisation	Unit	1,6	1,8	-13%	-	-

Table 6-10: Table of Warehousing Framework Calculations

Warehousing (port)	Units	Target	Actual	Difference	Average Indicator Difference	Phase Difference
Quality indicators					-20%	-21%
Inventory accuracy rate	%	100	100	0%	-	-
Put away accuracy	tph	100	100	0%	-	-
Picking accuracy	tph	100	100	0%	-	-
Warehouse accident rate	None	0	60	-100%	-	-
Security measures	None	100	100	0%	-	-
Response Time Indicators					0%	-21%
Put away rate	tph	5500	5500	0%	-	-
Cost/Financial Indicators					-42%	-21%
Total warehousing cost per ton	R/ton	1	1,84	-84%	-	-
Value of damaged goods in warehouse	R	0	0	0%	-	-
Productivity Indicators					-22%	-21%
Units moved per hour	tph	5500	1867	-66%	-	-
Stacking rate	tph	5500	5500	0%	-	-
Reclaiming rate	tph	5500	5500	0%	-	-

Table 6-11: Table of Inventory Management Framework Calculations

Inventory Management (port)	Units	Target	Actual	Difference	Average Indicator Difference	Phase Difference
Quality Indicators					-1%	-58%
Stock out rates	%	0	0	0%	-	-
Order fill rate	tph	9250	8615	-7%	-	-
Inventory accuracy rate	%	100	100	0%	-	-
Stocked according to plan	%	100	100	0%	-	-
Plan for unpredictable demand	None	Yes	Yes	0%	-	-
Order entry accuracy	%	100	100	0%	-	-
Invoice accuracy	%	100	100	0%	-	-
Response Time Indicators					-173%	-58%
Order turnaround time	Hours	15	45	-200%	-	-
Order lead time	Hours	64	158	-147%	-	-
Cost/Financial Indicators					-42%	-58%
Inventory holding cost	R/ton	1	1,84	-84%	-	-
Value of unusable stock	R	0	0	0%	-	-
Value of missing stock	R	0	0	0%	-	-
Average cost to fill an order	R	45000	82800	-84%	-	-
Productivity Indicators					-16%	-58%
Inventory turnover rate	None	10,0	8,4	-16%	-	-

Table 6-12: Table of Shipping Distribution Framework Calculations

Distribution (Shipping)	Units	Target	Actual	Difference	Average Indicator Difference	Phase Difference
Quality Indicators					-67%	-144%
On time Arrivals (Ship)	Hours	0	57	-100%	-	-
% Ships not loadable	Unit	0	0	0%	-	-
On Time departures (Ship)	Hours	0	57	-100%	-	-
Response Time Indicators					-286%	-144%
Average Loading Time	Hours	15	45	-200%	-	-
Ship Turnaround Time	Hours	15	102	-580%	-	-
Idle time	Hours	12	57	-79%	-	-
Cost/Financial Indicators					-84%	-144%
Total Loading Costs	R/Ton	1	1,84	-84%	-	-
Productivity Indicators					-139%	-144%
Berth Utilisation	%	40	73	-83%	-	-
Ships Berthed per Day	Unit	6	2	-195%	-	-

6.3 Simulation Observations

The observations of the simulation include screenshots of the visual model as well as the logic of the model. These can be found in the Appendix A, A.4 to A.8 with the model Validation and Verification sections. The observations for all the scenarios are similar in nature and are excluded for brevity.

The choices of the scenarios come are based on the original state simulation and the results seen in section 7.2. The results show poor performance in the Railway, inventory management and shipping phases. The simulation results further show that there are excessive queues in the system due to coupling and recoupling of trains throughout the system. The Overvaal tunnel also poses a potential unnecessary delay as two way tunnels are common occurrences in the modern day. Therefore the modification of the Overvaal tunnel is also considered.

6.4 Simulated Scenario Comparisons

This section shows the comparisons of the simulated scenarios to the real life achieved level of performance. This section shows the comparison of each simulated model to the actual achieved values. The section flows in the following order: current state simulation, scenario A, scenario B and finally scenario C. The comparison of the current state model links closely to the validation and verification sections discussed briefly in section 6.3 and shown in the Appendix under heading A.4, in this report. The following tables show the observations of the simulated models when adapted to the framework.

Table 6-13: Table of Current State Simulated Performance to Actual Achieved Values

Quality Indicators	**Unit**	**Actual**	**Current State Simulation**	**Difference**	**Indicator Difference**	**Element Difference**
On Time departures Ermelo to mine	Minutes	43	43	0	1.4%	1.5%
On time Arrivals (mine)	Minutes	43	43	0		
% Shipments where quantity despatched equals quantity received	%	100	100	0		
% Shipments arriving in good condition	%	100	100	0		
Kilometres between accidents	km	57000	N/A	0		
On time arrivals (Port)	Minutes	134	121	9%		
Time lost due to breakdown (Traction)	Minutes per train	10	10	0%		
Response Time Indicators	**Units**	**Actual**	**Current State Simulation**	**Difference**	**Indicator Difference**	**Element Difference**
Average delivery time	Minutes	37	37	0%	5%	1.5%
Average vehicle loading time (Mine)	Hours	3.5	3.5	0%		
Average vehicle unloading time (Port)	Hours	12	11	8%		
Cycle Time	Hours	70	65	7%		
Vehicle drive time		16	16	0%		
Idle time		22	19	13%		

Cost/Financial Indicators	**Units**	**Actual**	**Current State Simulation**	**Difference**	**Indicator Difference**	**Element Difference**
Total transportation cost per km	R/km	1080.51	1080.51	0%	0%	1.5%
Average cost per weight	R/ton	76	76	0%		
Transport cost to value of product	Unit	0.20	0.20	0%		
Productivity Indicators	**Units**	**Actual**	**Current State Simulation**	**Difference**	**Indicator Difference**	**Element Difference**
Vehicle availability	%	100	100	0%	0%	1.5%
Vehicle capacity utilisation	000km/loco/ month	25925	25925	0%		
Fleet yield	Tons per hour	8261	8261	0%		
Loading rate	Tons per hour	5500	5500	0%		
Unloading Rate	Tons per hour	5500	5500	0%		
Train utilisation	Unit	1.8	1.8	0%		

Linking up with the verification and validation sections of this report, in the Appendix under section A.4 to A.8, is it seen that the current state simulated model represents the actual performance closely, with just a 1.5% difference in performance. The total amount of coal delivered is also closely represented as the model delivers 70.5Mt of coal compared to the real life value of 69M, a 2% difference.

Table 6-14: Table of Scenario A Performance to Actual Achieved Values

Quality Indicators	Unit	Actual	Scenario A	Difference	Indicator Difference	Element Difference
On Time departures Ermelo to mine	Minutes	43	43	0	1.4%	3.3%
On time Arrivals (mine)	Minutes	43	43	0		
% Shipments where quantity despatched equals quantity received	%	100	100	0		
% Shipments arriving in good condition	%	100	100	0		
Kilometres between accidents	km	57000	N/A	0		
On time arrivals (Port)	Minutes	134	121	9%		
Time lost due to breakdown (Traction)	Minutes per train	10	10	0%		
Response Time Indicators	**Units**	**Actual**	**Scenario A**	**Difference**	**Indicator Difference**	**Element Difference**
Average delivery time	Minutes	37	37	0%	12%	3.3%
Average vehicle loading time (Mine)	Hours	3.5	3.5	0%		
Average vehicle unloading time (Port)	Hours	12	12	0%		
Cycle Time	Hours	70	48	31%		
Vehicle drive time	Hours	16	16	0%		
Idle time	Hours	22	13	40%		
Cost/Financial Indicators	**Units**	**Actual**	**Scenario A**	**Difference**	**Indicator Difference**	**Element Difference**
Total transportation cost per km	R/km	1080.5 1	1080.51	0%	0%	3.3%
Average cost per weight	R/ton	76	76	0%		
Transport cost to value of product	Unit	0.20	0.20	0%		
Productivity Indicators	**Units**	**Actual**	**Scenario A**	**Difference**	**Indicator Difference**	**Element Difference**
Vehicle availability	%	100	100	0%	0%	3.3%
Vehicle capacity utilisation	000km/lo co/month	25925	25925	0%		
Fleet yield	Tons per hour	8261	8261	0%		
Loading rate	Tons per hour	5500	5500	0%		
Unloading Rate	Tons per hour	5500	5500	0%		
Train utilisation	Unit	1.8	1.8	0%		

Table 6-15: Table of Scenario B Performance to Actual Achieved Values

Quality Indicators	Unit	Actual	Scenario B	Difference	Indicator Difference	Element Difference
On Time departures Ermelo to mine	Minutes	43	43	0	1.4%	8.6%
On time Arrivals (mine)	Minutes	43	43	0		
% Shipments where quantity despatched equals quantity received	%	100	100	0		
% Shipments arriving in good condition	%	100	100	0		
Kilometres between accidents	km	57000	N/A	0		
On time arrivals (Port)	Minutes	134	121	9%		
Time lost due to breakdown (Traction)	Minutes per train	10	10	0%		
Response Time Indicators	**Units**	**Actual**	**Scenario B**	**Difference**	**Indicator Difference**	**Element Difference**
Average delivery time	Minutes	37	37	0%	33%	8.6%
Average vehicle loading time (Mine)	Hours	3.5	3.5	0%		
Average vehicle unloading time (Port)	Hours	12	4	67%		
Cycle Time	Hours	70	32	54%		
Vehicle drive time	Hours	16	16	0%		
Idle time	Hours	22	5	77%		
Cost/Financial Indicators	**Units**	**Actual**	**Scenario B**	**Difference**	**Indicator Difference**	**Element Difference**
Total transportation cost per km	R/km	1080.51	1080.51	0%	0%	8.6%
Average cost per weight	R/ton	76	76	0%		
Transport cost to value of product	Unit	0.20	0.20	0%		
Productivity Indicators	**Units**	**Actual**	**Scenario B**	**Difference**	**Indicator Difference**	**Element Difference**
Vehicle availability	%	100	100	0%	0%	8.6%
Vehicle capacity utilisation	000km/loco/month	25925	25925	0%		
Fleet yield	Tons per hour	8261	8261	0%		
Loading rate	Tons per hour	5500	5500	0%		
Unloading Rate	Tons per hour	5500	5500	0%		
Train utilisation	Unit	1.8	1.8	0%		

Table 6-16: Table of Scenario C Performance to Actual Achieved Values

Quality Indicators	Unit	Actual	Scenario C	Difference	Indicator Difference	Element Difference
On Time departures Ermelo to mine	Minutes	43	43	0	1.4%	9.0%
On time Arrivals (mine)	Minutes	43	43	0		
% Shipments where quantity despatched equals quantity received	%	100	100	0		
% Shipments arriving in good condition	%	100	100	0		
Kilometres between accidents	km	57000	N/A	0		
On time arrivals (Port)	Minutes	134	121	9%		
Time lost due to breakdown (Traction)	Minutes per train	10	10	0%		
Response Time Indicators	**Units**	**Actual**	**Scenario C**	**Difference**	**Indicator Difference**	**Element Difference**
Average delivery time	Minutes	37	37	0%	35%	9.0%
Average vehicle loading time (Mine)	Hours	3.5	3.5	0%		
Average vehicle unloading time (Port)	Hours	12	4	67%		
Cycle Time	Hours	70	32	54%		
Vehicle drive time	Hours	16	16	0%		
Idle time	Hours	22	3	86%		
Cost/Financial Indicators	**Units**	**Actual**	**Scenario C**	**Difference**	**Indicator Difference**	**Element Difference**
Total transportation cost per km	R/km	1080.51	1080.51	0%	0%	9.0%
Average cost per weight	R/ton	76	76	0%		
Transport cost to value of product	Unit	0.20	0.20	0%		
Productivity Indicators	**Units**	**Actual**	**Scenario C**	**Difference**	**Indicator Difference**	**Element Difference**
Vehicle availability	%	100	100	0%	0%	9.0%
Vehicle capacity utilisation	000km/loco/month	25925	25925	0%		
Fleet yield	Tons per hour	8261	8261	0%		
Loading rate	Tons per hour	5500	5500	0%		
Unloading Rate	Tons per hour	5500	5500	0%		
Train utilisation	Unit	1.8	1.8	0%		

7 Results and Discussion

This section discusses the results of the adapted framework, the simulation and the scenarios of the simulation. Verification and validation of the simulation is also done in this section.

7.1 Framework Results

The framework results are summarised and shown below. As all the gaps are negative in their orientation the absolute values are discussed. The negative value means that the KPI's are underperforming. From the results shown it is clear that the railway, inventory management and shipping phases perform poorly. None of the phases meet their respective target values.

7.1.1 Overall Supply Chain Performance

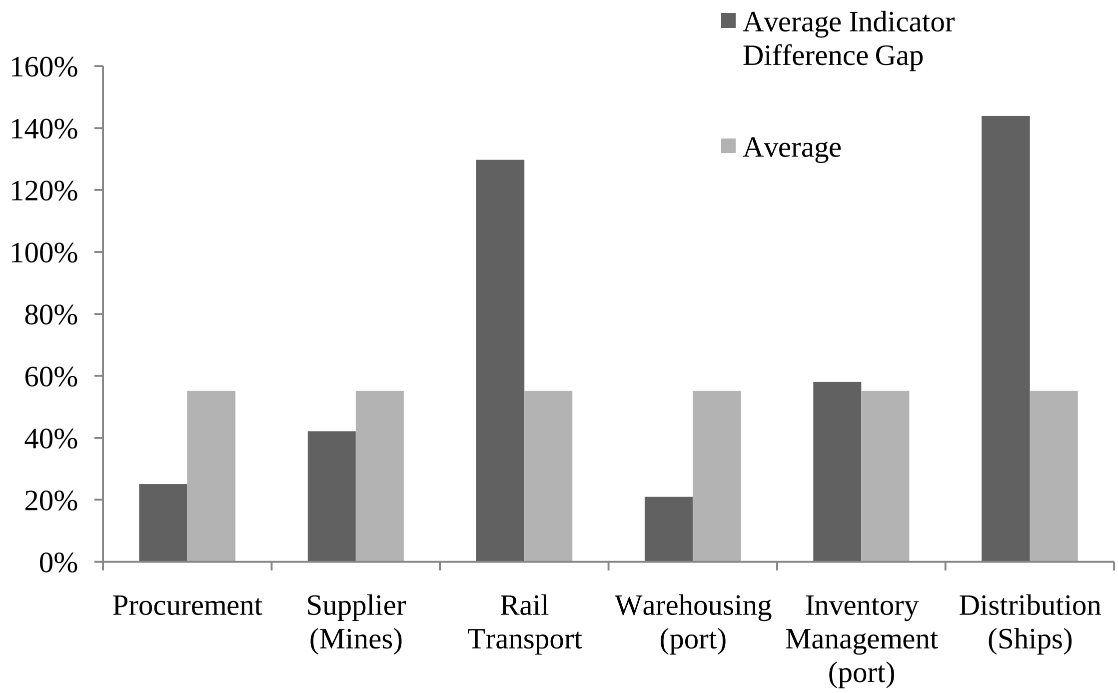


Figure 7-1: The Calculated Differences of the Overall Supply Chain Performance

Figure 7-1 shows the average performance of the entire supply chain and the comparison with each respective phase of the supply chain. As can be seen the worst performing Phases are rail transport and distribution (ships). Both Phases are well above the average of 58%, reaching 130% and 144%, respectively. The rail network performs poorly as it has complex processes and procedures which it follows. For example batching trains in 200 wagon lengths as opposed to 100 lengths makes complications throughout the network as the mines and Richards bay (the start and end point of the chain) cannot handle 200 wagon lengths due to the structure of the ports design. Therefore, coupling and uncoupling trains contributes to the time wasted in the network.

The shipping distribution, as mentioned before, has a significant amount of idle and anchorage time. The anchorage can be attributed to poor scheduling of ships into and out of the port. This is also seen by the poor berth utilisation and low number of ships berthed per day.

The best performing indicators, which are well below the average is warehousing at the port and procurement. The Richards Bay Coal Terminal has state of the art equipment (from wagon tipplers to conveyor systems and ship loaders) to ensure that a high level of service is delivered; however, the poor berth utilisation is a concern. This may be due to poor scheduling of incoming and outgoing ships by the port authority.

7.1.2 Procurement KPI Results

Table 7-1: Table of Procurement KPI Results

Procurement	Difference	Average Indicator Difference	Phase Difference
Quality Indicator		- 5%	-32%
Forecast Accuracy	-9%	-	-
% of product sourced for export market	-10%	-	-
Quality testing	0%	-	-
% of procured products that met regulations	0%	-	-
Financial		-59%	-32%
% Mark-up on products sourced (Profit Margin)	-70%	-	-
Local cost vs. international cost of product per km	-106%	-	-
Ratio of unit prices paid through an emergency procurement vs. competitive bidding process	0%	-	-

Table 7-1 summarises the performance results of Transnet's procurement element within the supply chain. The table only contains quality and financial indicators as the response time and productivity indicators defined in chapter 7 of this study have not been reported on by Transnet. From the quality indicators it can be seen that the highest performing indicator is the quality testing and percentage of procured products that met regulations. From the integrated report on Transnet (Transnet Integrated Report, 2014) it is understood that there were no quality issues regarding the procurement of export coal. This means that the quality of the export coal is adequate and in regulation with international standards.

The worst performing area is the "percentage of product sourced for export market" which is 25% below the target value. In 2014 it was forecasted that 77Mt (million tons) of coal would be demanded for export, but only 69.6Mt of coal was produced for export. Reasons for the discrepancy can be attributed to the need for thermal coal by the local electricity supplier (Eskom). Eskom increased its demand for coal in a bid to reduce energy concerns in Southern Africa. The average indicator difference for the quality phase is 9%, which is well below the average of the procurement element which is 34%.

The financial indicators used in the procurement element are % mark-up, % difference between Transnet costs and international market leaders and the % product sold as emergency stock vs. Stock sold in a competitive bidding process. The best performing indicator is the "% product sold as emergency stock vs. Stock sold in a competitive bidding process" which has a 0% difference as the target has been met for this year. The % mark-up and price difference between local and international markets have differences of 70% and 106%, respectively. Both of these differences are significantly higher than the average difference for the financial element, which is 59%.

One reason for the extra costs would be the purchasing of new equipment and large financial outlay by Transnet into infrastructure development which has affected prices. The increase in electricity prices and fuel prices has also affected the running costs of the business. Market leaders are running at a profit margin of approximately 5% where Transnet is currently running at a mark-up of 9%. Although this might not seem as negative at first glance it should be noted that transport in a value chain is a service which is essentially non-value adding and the associated costs to the end customer should be minimised as to ensure the longevity of the relationship with the customer.

Figure 7-2 shows the overall performance of the procurement phase and all the indicator types within. The quality indicator is the best performing indicator with a difference of 9%, whilst the financial indicator has a difference of 59%. This element of the supply chain is operating at 34% below target values.

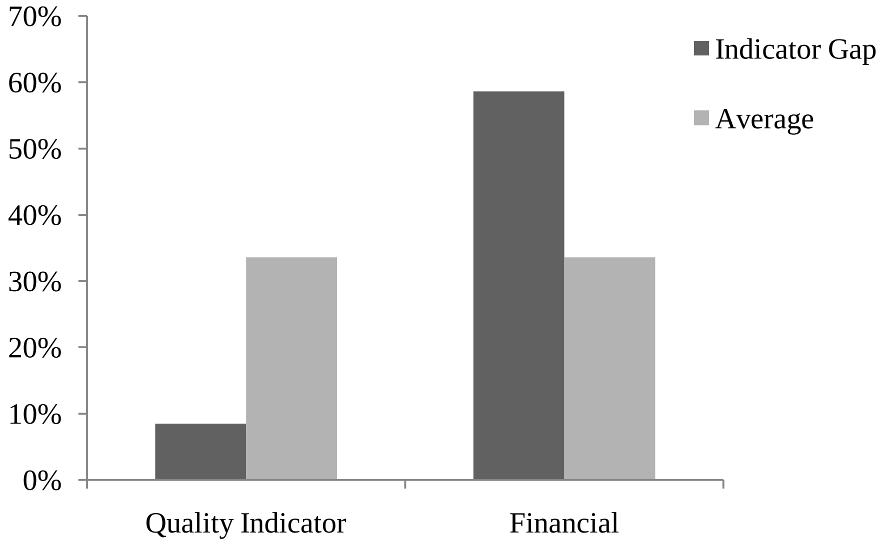


Figure 7-2: The Calculated Differences of the Procurement Phase.

7.1.3 Supplier KPI Results

Table 7-2: Table of Supplier KPI Results

Supplier (Mines)	Difference	Average Indicator Difference	Phase Difference
Response Time			
On Time delivery	0%	-117%	-42%
Supplier lead time	-233%	-	-
Financial	**-**	**-**	**-**
Total Supply Cost	0%	0%	-42%
Productivity	**-**	**-**	**-**
Supplier order fill rate	-10%	-10%	-42%
Supplier rate of production	-10%	-	-

Table 7-2 summarises the performance of the supplier element of the supply chain. Three indicator types of the framework are populated and show results; response time, financial and productivity. The on time delivery of coal to the loading bay is the best performing element with a difference of 0%. There is no acknowledgement in the reports presented that trains collecting coal from the mines are hindered by the non-availability of coal. The assumption is made that trains do not depart until there is product ready for departure.

The worst performing indicator of the entire supplier element is the supplier lead time with a difference of 233%. The supplier lead time is the time taken for a mine to fill 1 train of 16 800 tons. The lead time target is set at 0.6 hours per train load. This value is calculated based on the forecasted amount of coal that should have been exported, 77Mt. The supplier lead time is two hours per train. The average difference for the response time indicators is 117%.

The financial indicator used in this framework for the supplier is the total supply cost. This indicator meets the targets of the international markets.

The productivity indicators used are "supplier fill rate" and "supplier rate of production". Each indicator underperforms. The supplier fill rate underperforms at 100%, whilst the supplier rate of production underperforms by 10%. This implies that the supplier is unable to meet the forecasted demand. Reasons for this can be strikes. The average indicator difference in for productivity is 55%.

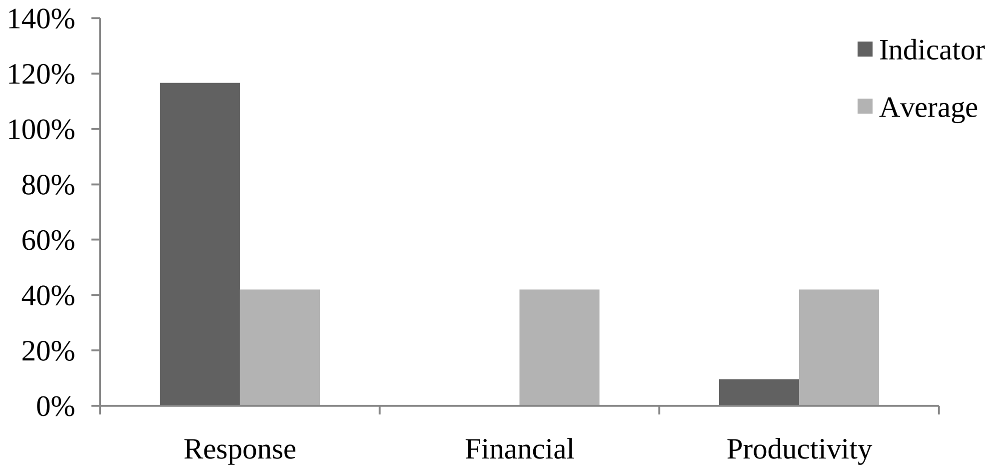


Figure 7-3: The Calculated Differences of the Supplier Phase.

The differences of each indicator type in the supplier phase are shown in Figure 7-3. The average difference for the supplier element of the supply chain is 42%. The response time indicators performed the worst with a difference of 117%, this is 65% worse than the average of the supplier element of the supply chain. This is largely due to the supplier lead time, which underperformed by 233%. This means that the ability to provide coal according to the forecasted demand is affected. Effects that were observed were the increase in demand for thermal coal by the local electricity power company, Eskom. Thermal coal is export grade coal.

The financial indicators performed the best having met their targets. The productivity indicators performed better than the response time indicators, but still had a difference of 10%. This difference is 32% better than the average difference of the supplier element of the supply chain. Thus, the areas which are in need of the most improvement are; supplier lead time, supplier fill rate and supplier rate of production.

7.1.4 Railway Distribution KPI Results

Table 7-3 shows the results of the railway phase of the supply chain. The results presented in this table are accompanied by figures comparing each indicator and the averages of each indicator type. This table and figures will be discussed together in the paragraphs following this table.

Table 7-3: Table of Railway Phase KPI Results

Quality Indicators	**Difference**	**Average Indicator Difference**	**Phase Difference**
On Time departures Ermelo to mine	-186%	-370%	-130%
On time Arrivals (mine)	-186%	-	-
% Shipments where quantity despatched equals quantity received	0%	-	-
% Shipments arriving in good condition	0%	-	-
Kilometres between accidents	-43%	-	-
On time arrivals (Port)	-1237%	-	-
Time lost due to breakdown (Traction)	-940%	-	-
Response Time Indicators		-118%	-130%
Average delivery time	-85%	-	-
Average vehicle loading time (Mine)	0%	-	-
Average vehicle unloading time (Port)	-243%	-	-
Cycle Time	-46%	-	-
Vehicle drive time	0%	-	-
Idle time	-337%	-	-
Cost/Financial Indicators	**Difference**	**Average Indicator Difference**	**Phase Difference**
Total transportation cost per km	-14%	-26%	-130%
Average cost per weight	-14%	-	-
Transport cost to value of product	-49%	-	-
Productivity Indicators		-4%	-130%
Vehicle availability	0%	-	-
Vehicle capacity utilisation	-3%	-	-
Fleet yield	-11%	-	-
Loading rate	0%	-	-
Unloading Rate	0%	-	-
Train utilisation	-13%	-	-

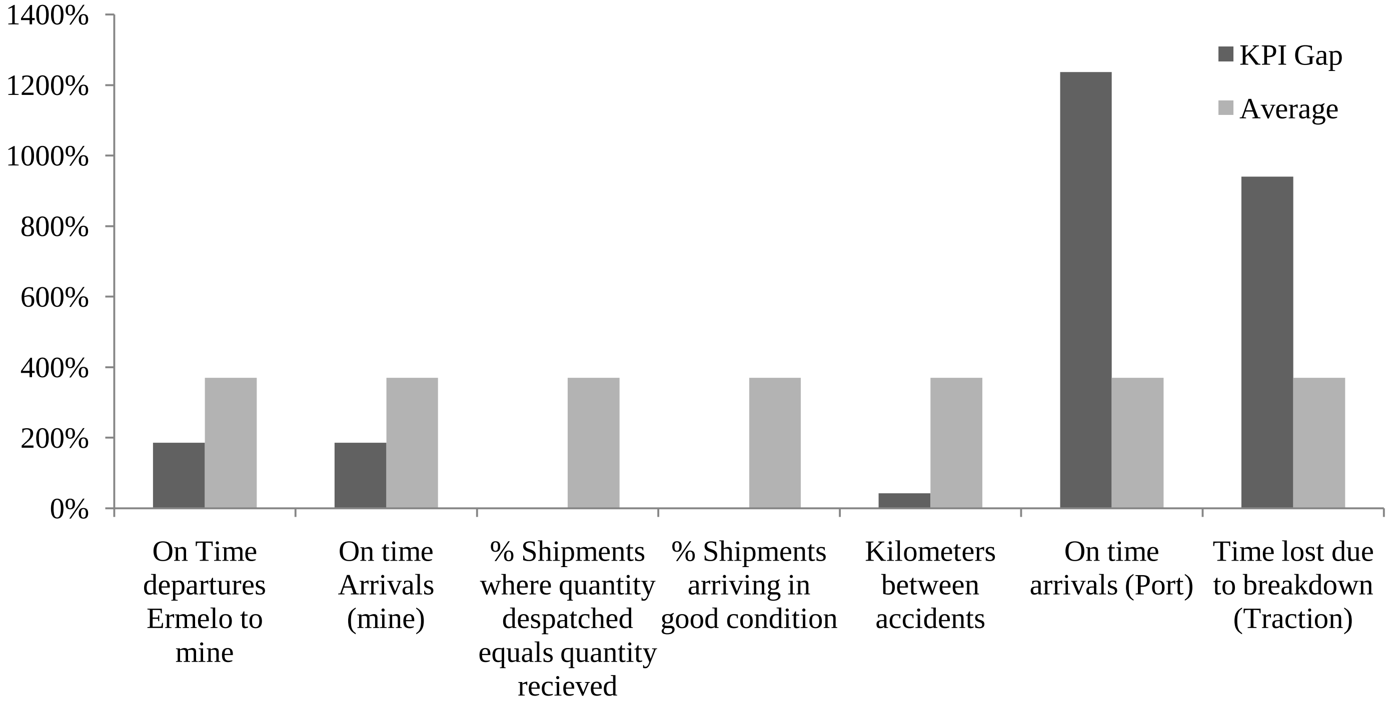


Figure 7-4: The Calculated Differences of the Railway Quality Indicator.

Figure 7-4 shows the performance of the railway element of the supply chain with regards to the quality of the service. The average indicator difference is 370%, which shows that this element of the supply chain has a significant negative effect on the quality of the service to the end customer.

The port on-time arrivals indicator underperforms by 1237%. This is mainly due to the knock on effect through the supply chain of late departures and arrivals through the supply chain, i.e. if the train leaves late from Ermelo to the mine then each stop after that will push the train further behind schedule. Possible reasons for late departures and arrivals are driver availability, locomotive (loco) and wagon availability or the complex yard system at Ermelo due to the change from AC (alternate current) locos to DC (direct current) locos.

The time lost to breakdowns is 940% worse than the target value. This shows that the trains, infrastructure and maintenance thereof are not performing at a level which will allow Transnet to achieve its targets. This can either mean that Transnet needs to continue upgrading infrastructure and train maintenance personnel to deliver a more reliable service or lower targets to a more realistic value.

The best performing indicators are the shipments arriving in good condition and the shipments where quantity received equals quantity despatched. This is partially due to the nature if the business environment that Transnet works in. The coal industry deals with large volumes of export quality coal from where the orders for coal are handled by the supplier. This means that when Transnet receives the request for a train from the supplier the paperwork and order details are being rechecked due to the *poke yoke* concept being implemented, i.e. due to smart process planning the inspection point is part of the process as opposed to a separate activity within the process. This effectively causes double checking which aids in eliminating the incorrect transporting of coal grades and shipment errors.

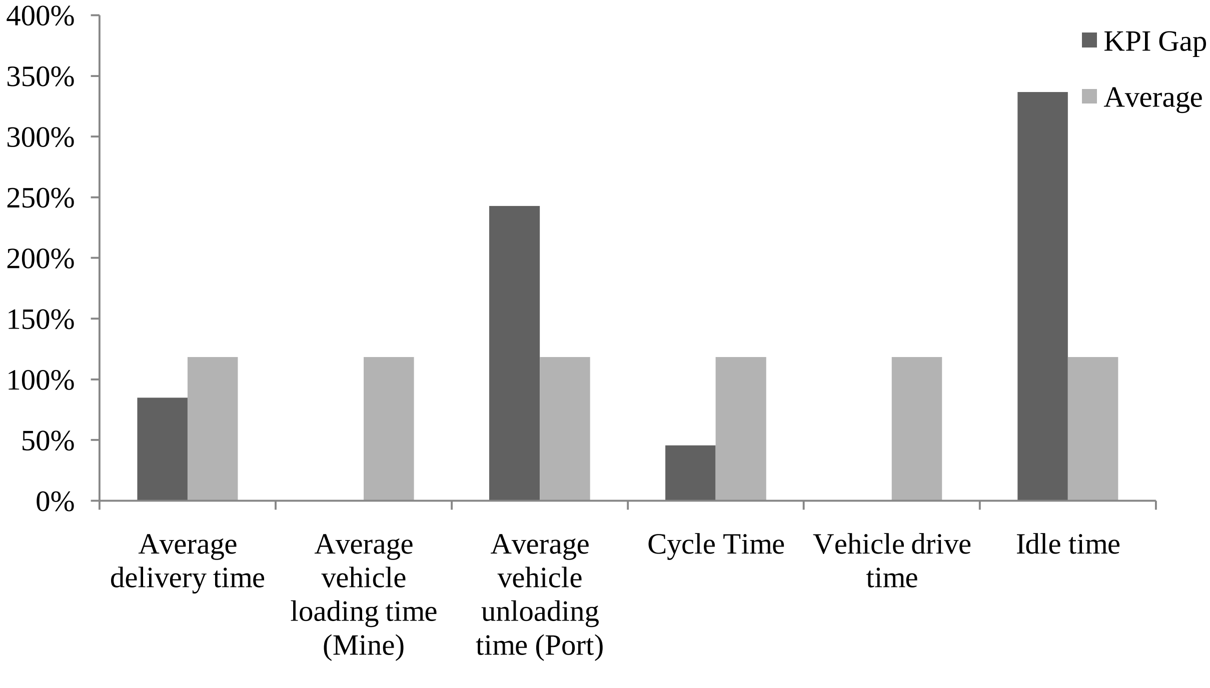


Figure 7-5: The Calculated Differences of the Railway Response Time Indicator.

The response time performance differences are shown in Figure 7-5. The average difference for this Phase is 118%. The worst performing indicator is the vehicle idle time. This could be attributed to the off loading process at the port where by the 200 wagon consist is broken down into two 100 wagon consists for unloading because the port cannot accommodate a train of 200 wagons within the yard. This aspect negatively effects the average unloading time as well. Other aspects which could influence the idle time are breakdowns, the knock on effects of late departures and arrivals. The late arrivals will cause complications in the offloading processes as the port may have already started loading ships or may already be on a shift change etc. Thus, when the train arrives the timing may be inconvenient for immediate offloading to commence.

The performance indicators that met their targets are vehicle drive time and vehicle loading time. The loading time meets its target value as it is machine operated and no break downs or issues were reported to have occurred. The vehicle drive time meets its target as the speed, acceleration and deceleration of the train is limited by the train's capabilities and the railways rules and regulations regarding speed and accelerations of heavy haul trains. Traction delays averaged 16 minutes per train. This delay can (on average) attribute up to 12% (16 minutes) to the 133 minute average delay that trains currently experience.

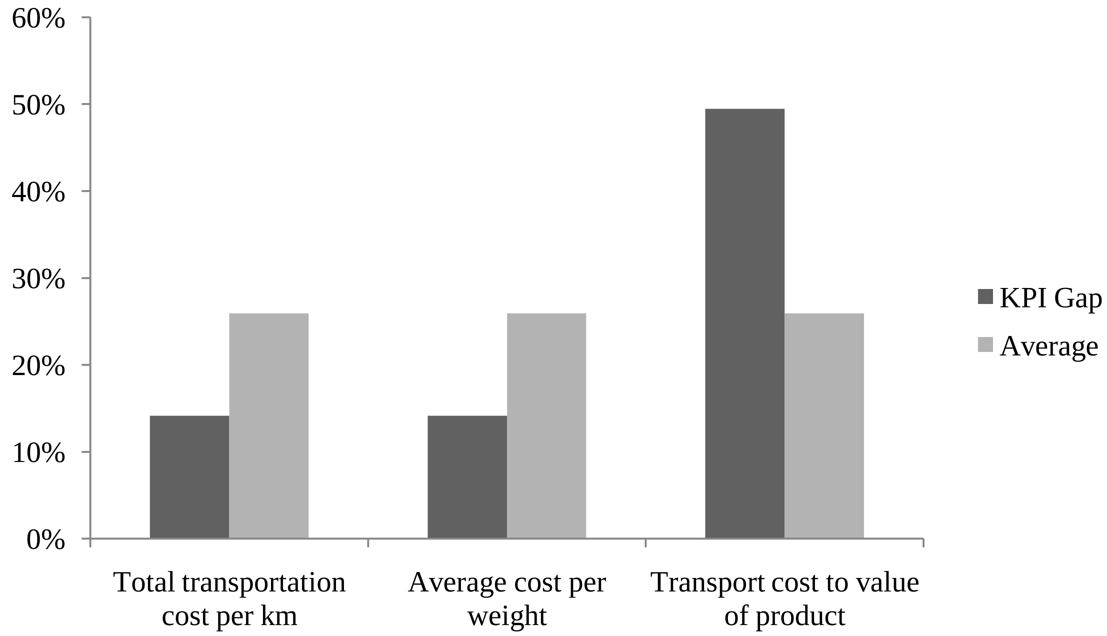


Figure 7-6: The Calculated Differences of the Railway Financial Indicator.

Figure 7-6 illustrates the average difference for the financial KPI's is 26%. It must be noted that these KPI’s measure the cost to Transnet of transporting coal to the RBCT. These financial KPI’s are the running costs experienced by Transnet, i.e. the ‘Cost Price”. The transport cost to value of product is the worst performing indicator with a difference of 49%. This difference is 35% worse performing than any other financial indicator. The cost per km and the cost per weight are both 14% more expensive than the international guidelines set out. The cost per km is R946 according to the international guidelines used. Transnet managed R1081/km for the 2014 year. The cost per ton is R76 for Transnet compared to R66/ton achieved by international companies providing the same services. Therefore, on average, the cost per km and cost per ton are closely related and are 14.2% and 15% more expensive than international market leaders, respectively (US Energy Information Administration, 2014).

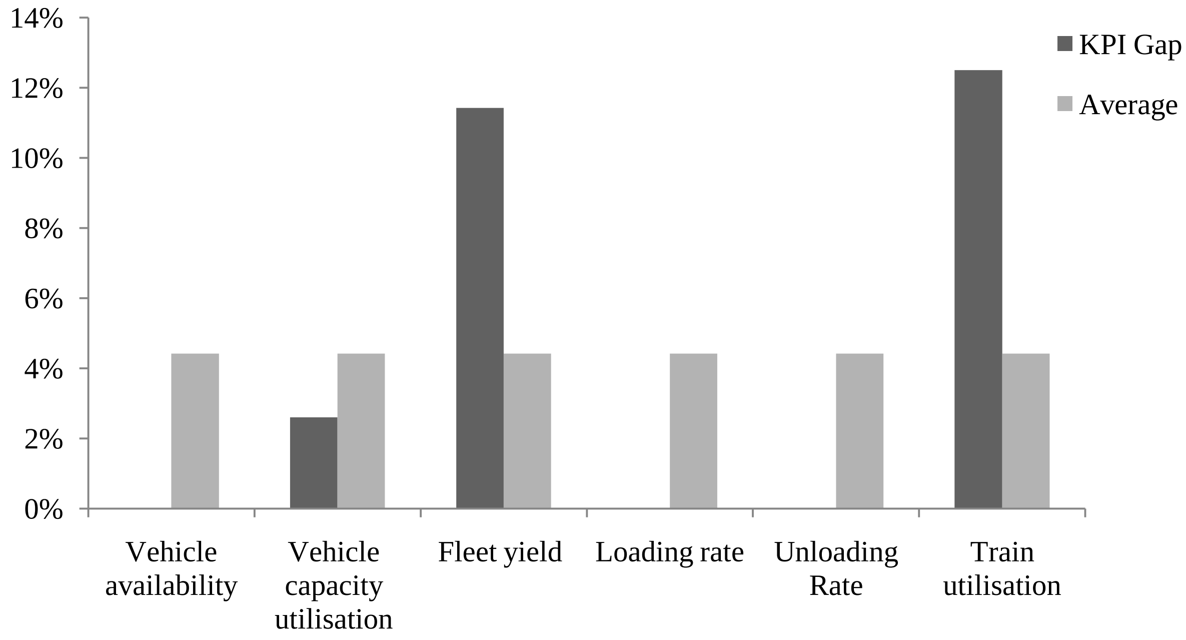


Figure 7-7: The Calculated Differences of the Railway Productivity Indicator.

The rail productivity average indicator differences are shown in Figure 7-7. The best performing indicators are the vehicle availability, loading rate and unloading rate, which are meeting their target values. The fact that the vehicle availability is meeting its target and on time arrivals and departures are not meeting their targets is a sign that the amount of locos and wagons is sufficient. However, there may be insufficient drivers available or the scheduling rosters of the drivers may not be maximised or there are breakdowns. Another element which may be affecting the on time arrivals and departures of trains to the port may be the infrastructure and the limitations of the current system where trains have to use the Ermelo depot as a major stoppage for constructing an entirely new consist before departing for the port.

The fleet yield and the train's utilisation indicators have the greatest differences in rail performance with approximately 11% and 12%, respectively. The average difference in the productivity is 4.4%. The train utilisation is underperforming which means that the Transnet may have an oversupply of trains. Another possible reason for the underutilisation of locos could be that the infrastructure of the coal line to RBCT from Ermelo cannot handle more capacity than what is currently on the line (16 trains per day) (Transnet Integrated Report, 2014). This means that for the utilisation of the locomotive arsenal to be improved the capacity on the line needs to be improved. This could be due to the long 200 wagon trains currently being used.

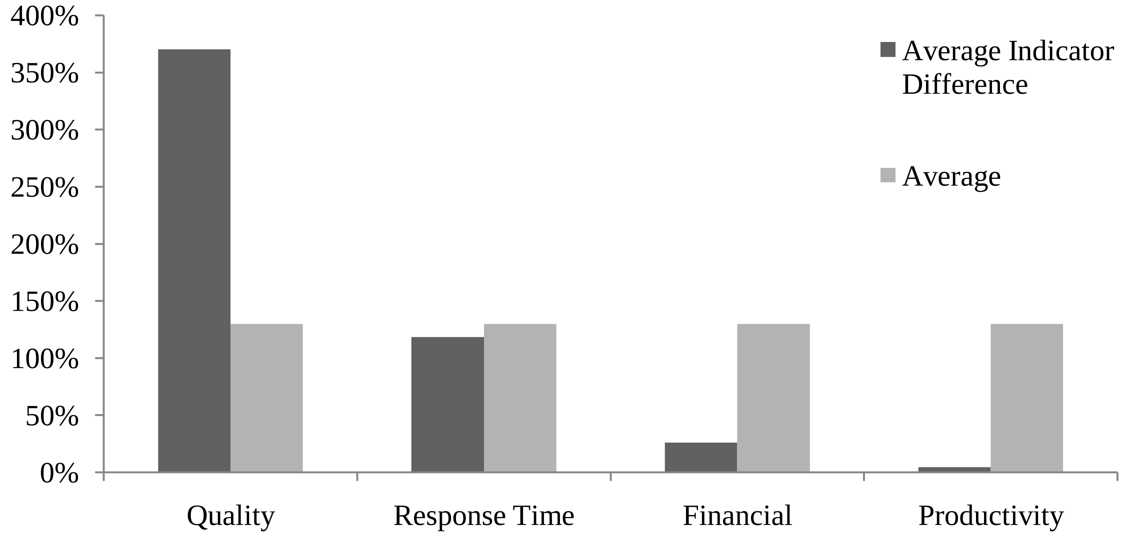


Figure 7-8: The Calculated Differences of the Railway Indicators.

Figure 7-8 shows the percentage differences for each phase relative to the average for the railway element of the supply chain. The average difference across all performance areas is 130%. The worst performing phase is the quality Phase, with an average difference of 370%. This is largely due to the large differences in performance with regards to on time arrivals and time lost due to traction. The response time difference is 118%. The erratic arrival and departure times cause unpredictable arrivals at the port. The result of prolonged offloading times can be seen by the average offloading time at the port, which has a difference of 245%. This difference is the largest contributor to the poor performance of the response time indicators within the railway element of the supply chain.

If the quality indicator is treated as an extreme outlier and expelled from analysis, then the average performance difference for the Phases is 50%. Even under these conditions the financial and productivity indicators are seen to perform adequately in comparison to the response time and quality indicators. Therefore, both the quality and response time Phases should be focussed on in order to improve the railway element of the supply chain.

7.1.5 Port Warehousing KPI Results

Table 7-4: Table of Warehousing KPI's and their Associated Performance Differences.

Warehousing (port)	Difference	Average Indicator Difference	Phase Difference
Quality indicators		-20%	-21%
Inventory accuracy rate	0%	-	-
Put away accuracy	0%	-	-
Picking accuracy	0%	-	-
Warehouse accident rate	-100%	-	-
Security measures	0%	-	-
Response Time Indicators		0%	-21%
Put away rate	0%	-	-
Cost/Financial Indicators		-42%	-21%
Total warehousing cost per ton	-84%	-	-
Value of damaged goods in warehouse	0%	-	-
Productivity Indicators		-22%	-21%
Units moved per hour	-66%	-	-
Stacking rate	0%	-	-
Reclaiming rate	0%	-	-

The quality indicators have an average indicator difference of 20%. This is due to the underperformance of the warehouse accident rate, which is 100%. The warehouse experienced an accident rate of 6 for the given financial year, where the target for the year was no accidents. The assumption is made that any breach of this target is a 100% failure to meet requirements. The warehouse accident rate is assumed to be a yes/no performance indicator.

The inventory accuracy rate, put away accuracy and picking accuracy are all performing within their targets. This is because of the way in which the coal is moved. The different grades are never mixed, i.e. when the train arrives at the port the coal is either stocked straight onto the ship or into a stockpile via conveyors. This conveyor network has its own dedicated control tower overlooking the stockyard. This method of dealing with large volumes allows the picking and packing of the coal to be done quickly and effectively.

The put away rate is machine defined and meets its target. The total warehousing cost per ton is 84% higher than its target. The cost per ton for the port is R1.84 per ton that passes through onto a ship. The cost for material handling should be R1 per ton. The value goods damaged met its target.

The productivity indicator "units moved per hour" underperforms by 66%. This is largely due to the offloading process at the port, which has a significant amount of idle time. This means that there could be long delays caused from coupling and decoupling trains or the conveyors from train to stockpile or ship are not always working causing a low rate of tons/hour.

The stacking rate and reclaiming rate is machine operated and no issues were reported regarding stacking and reclaiming from the stockpile. As in accordance with the process flow the stacking machine can only work when there is coal coming in from the conveyor.

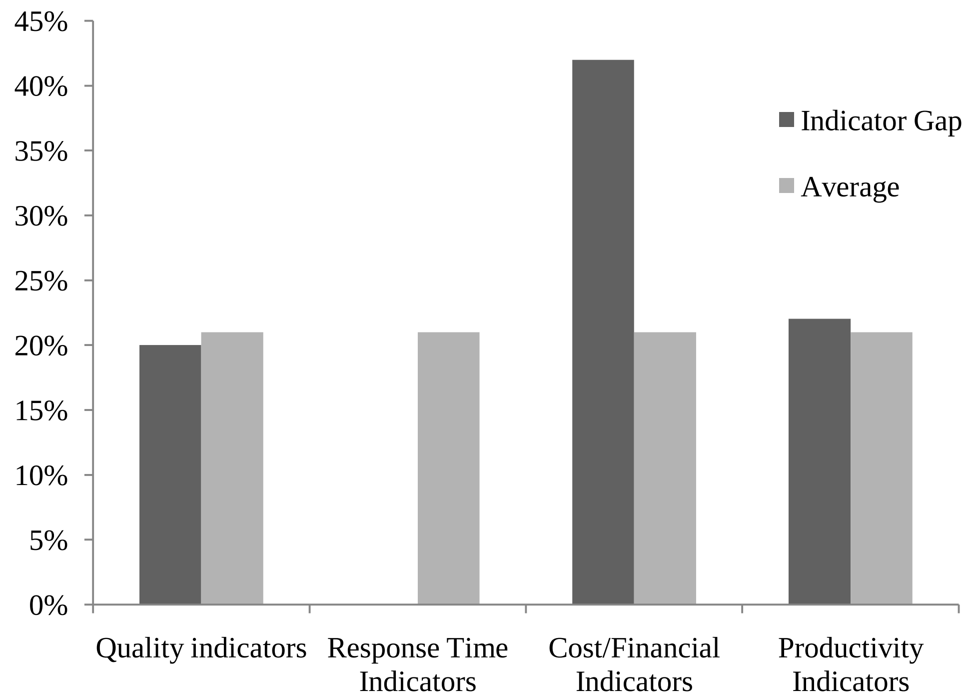


Figure 7-9 The Calculated Differences of the Warehousing Performance Indicators.

Figure 7-9 illustrates the performance differences of the warehousing element of the supply chain. The worst performing indicator is the financial indicator type as it underperforms by 42%. This is double the average of 21%. The productivity indicators have an average value of 22%. This is just above the average for this Phase. The quality indicators are at 20%, which is slightly less than the average of the Phase. The response time indicators have met their targets for the warehousing Phase.

7.1.6 Port Inventory Management KPI Results

Table 7-5: Table of Inventory Management KPI Differences (Port)

Inventory Management (Port)	KPI Difference	Average Indicator Difference	Phase Difference
Quality		-1%	-58%
Stock out rates	0%	-	-
Order fill rate	-7%	-	-
Inventory accuracy rate	0%	-	-
Stocked according to plan	0%	-	-
Plan for unpredictable demand	0%	-	-
Order entry accuracy	0%	-	-
Invoice accuracy	0%	-	-
Response Time Indicators		-173%	-58%
Order turnaround time	-200%	-	-
Order lead time	-147%	-	-
Cost/Financial Indicators		-42%	-58%
Inventory holding cost	-84%	-	-
Value of unusable stock	0%	-	-
Value of missing stock	0%	-	-
Average cost to fill an order	-84%	-	-
Productivity Indicators		-16%	-58%
Inventory turnover rate	-16%	-	-

The inventory management KPI's and their respective differences are shown in Table 7-5. The quality element has 7 KPI's in it. The stock out rate, stocked according to plan, inventory accuracy, plan for unpredictable demand, order accuracy and invoice accuracy all meet there targets. This shows good and effective inventory management at the port in terms of materials handling. This is not surprising as the process of off loading and loading is controlled centrally by a control tower. This means that all employees and operators have insight into all deliveries and departures of coal which means that each controller has a clear picture of where goods are coming and going. This means less instances of mishandling will occur.

The only quality Phase which is underperforming is the order fill rate. This rate is 8615 tons per hour where the actual theoretical capability of the equipment is 9250 tons per hour. This is a 7% difference in performance, which means that the ship loaders are essentially working 93% of the time. In practical terms this efficiency is acceptable. The quality Phase as a whole underperforms by 1%, which is negligible in comparison to the elements measured.

The response time indicators underperform in this element, as summarised by Table 7-5. The theoretical machine capability for loading is 15 hours per ship. The actual attained value for loading is 45 hours, which affects the ship turnaround time. This time may be attributed to the fact that ships are not permanently being loaded as there is time taken to berth and release the ships. The 15 hour target is the ideal time so it is expected that this time is not reached, however, the 15 hours is the value adding process and thus the non-value adding processes should be minimised as it forms 30 hours, which us 200% of the value adding time. The order lead time (for the overall chain) has an ideal value of 64 hours. This time is the time taken from when the coal is stockpiled until it arrives on the ship and passed over into the customers care. The achieved lead time is 158 hours. The difference in performance for this KPI is 147%.

The overall difference in performance for the response time indicators is 173%. This show a there is a significant amount of waiting or idle time in the value chain. At times there are processes whereby the value adding time is significantly less than the value adding time.

The financial indicators referring to the cost of unusable and missing stock meet their targets as there were no reported issues regarding the significant loss of goods due to damage or theft.%. The holding costs and average costs to fill an order are both underperforming by 84%. The target for each respective KPI is R1.

The productivity indicator, Inventory Turnover Rate, underperforms by 16%. The target set out by Transnet was 9.4; the international target is set at 10 for high volume products. The achieved level is 8.4.

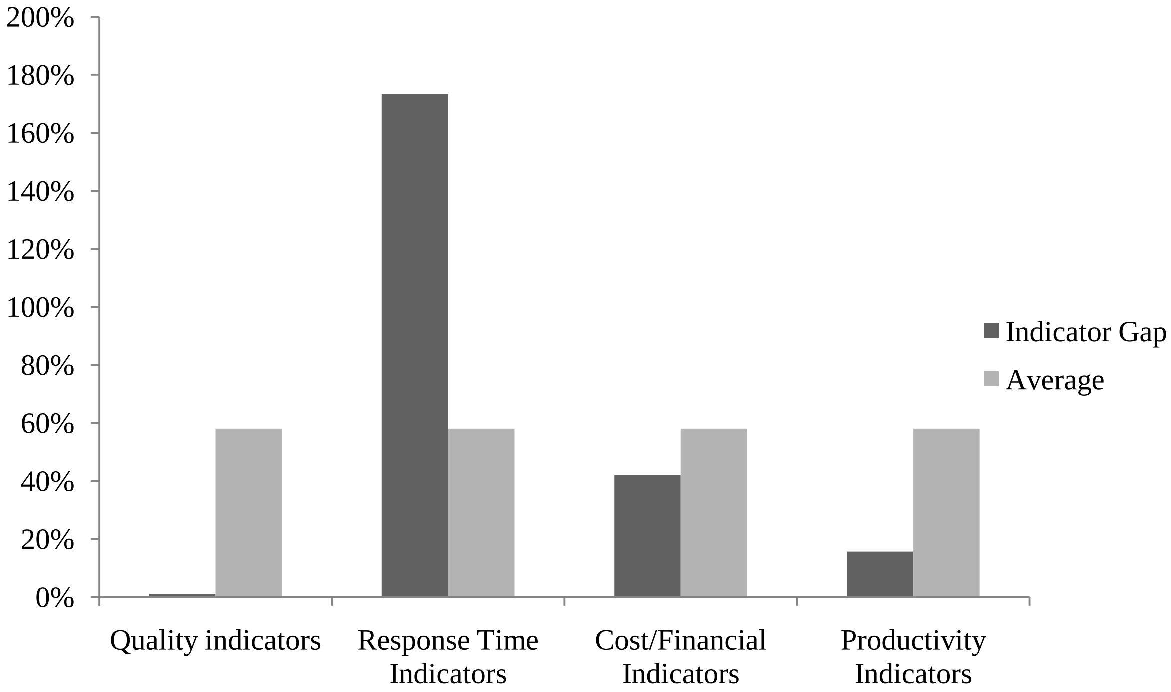


Figure 7-10: The Calculated Differences of the Inventory Management Performance Indicators.

Figure 7-10 shows the differences of each Phase. The quality Phase is the best performing Phase in this element of the supply chain, with a difference value of 1%. This is well below the average of 58% and can be considered negligible. The response time indicators are the worst performing indicators with an average difference across the Phase of 173%. This is nearly three times the average in this element. This is largely due to the large amount of anchorage time the ships have at the port. The port keeps a stockpile of 8.2 million tons on hand at the port throughout the year, therefore, a stock issue is non-contributory to the excessive anchorage experienced by the ships.

7.1.7 Shipping Distribution KPI Results

Table 7-6: Table of Shipping Distribution Differences

Distribution (Ships)	Difference	Average Indicator Difference	Phase Difference
Quality Indicators		-67%	-144%
On time Arrivals (Ship)	-100%	-	-
% Ships not loadable	0%	-	-
On Time departures (Ship)	-100%	-	-
Response Time Indicators		-286%	-144%
Average Loading Time	-200%	-	-
Ship Turnaround Time	-580%	-	-
Idle time	-79%	-	-
Cost/Financial Indicators		-84%	-144%
Total Loading Costs	-84%	-	-
Productivity Indicators		-139%	-144%
Berth Utilisation	-83%	-	-
Ships Berthed per Day	-195%	-	-

Table 7-6 summarises the performance of the shipping distribution Phase of the value chain. The Phase as a whole underperforms by 144%. All elements underperform; however, the greatest underperformer is the response time indicators with a value of 286% below the targets set. The ship turnaround time is over 500% below the target, whilst the loading time is 200% below the target, in terms of performance.

The least poor performing element is the quality indicators, although they still underperform by 67%. The poor performance of this Phase is of imperative importance as this is the customer facing Phase of the value chain. Too much idle time and high anchorage times by the ships have contributed most significantly to the underperforming of this Phase. Anchorage forms 79% of the total time spent in the care of the Transnet and the port.

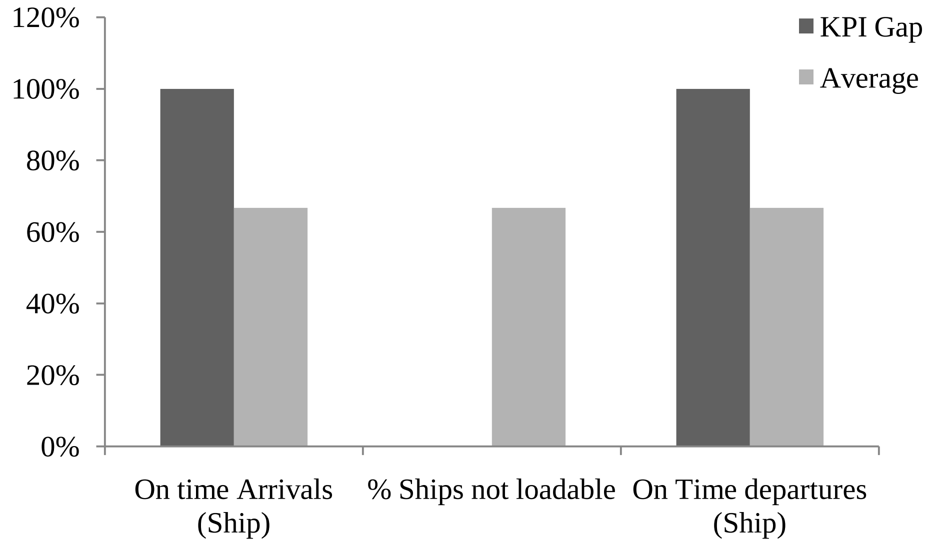


Figure 7-11: The Calculated Differences of the Shipping Quality Performance Indicators.

Figure 7-11 shows the differences in the quality element of the Shipping Phase. It is seen that the only aspect which is performing within in an acceptable range is the % ships not loadable. This is a measure which is out of Transnet's control as they do not own the vessels entering their ports. One time arrivals and on time departures are closely linked as if the scheduled time into the harbour is late, the scheduled out time will, in all likelihood, also be late. The excessive anchorage contributes largely to the underperformance of this element of the shipping Phase.

The berth utilisation and number of ships berthed per day is concerning as both of these indicators underperform significantly. The equipment and operation thereof, is of a quality standard. Thus, the most likely reason for the poor shipping performance is from the mismanagement of scheduling ships in and out of the port.

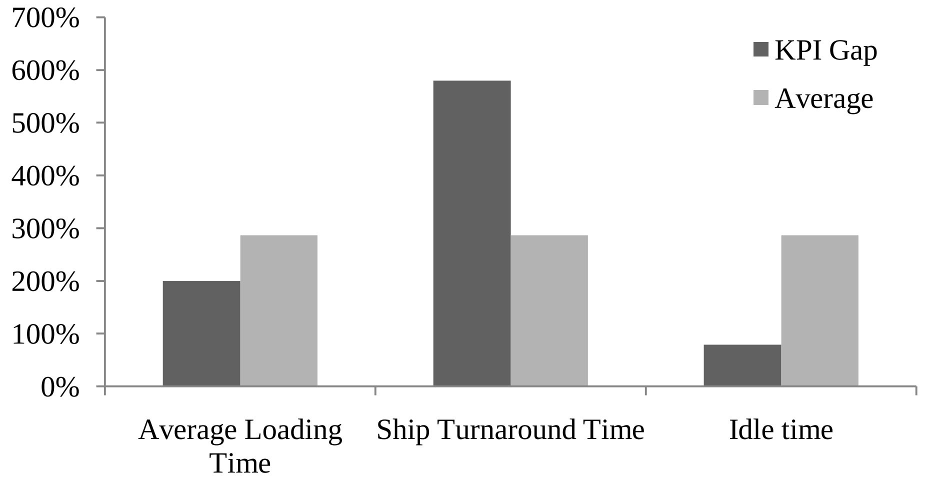


Figure 7-12: The Calculated Differences of the Shipping Response Time Performance Indicators.

The performances of the response time indicators are shown in Figure 7-12. This element is the worst performing element with an average difference of 286% when compared with the target values. The worst performing indicator is the ship turnaround time (580% underperformance), which reiterates the hypothesis above that the anchorage and idle time negatively affect the performance of these elements.

7.1.8 Supply Chain Performance Framework

The framework developed to calculate the overall performance of the supply chain is discussed in this section and the overall performance is calculated. The framework makes use of the capabilities of each phase of the supply chain to calculate the weighting that each phase of the supply chain has on the overall performance of the supply chain. Weightings are necessary because some companies in the supply chain may be using a greater percentage of their capability to meet the demand of the supply chain than the other. This can affect the flexibility of the supply chain as that company may not be able to deal with variations in demand as well as a company who is using less of its capability to meet the demand of the supply chain. This may lead to a decision of many suppliers vs. few suppliers; however, in this case, the only transporter available is Transnet.

Table 7-7: Table of Capabilities of Supply Chain Phases

Phase	Capability	Defining Mechanism	Minimum Capability	Weight
Procurement	84 Mtpa	Smallest value of system for Transnet	76 Mtpa	0.91
Supplier	76 Mtpa	Maximum Export production in the last 10 years	76 Mtpa	1
Railway	(24 trains X 16800 Tons X 344 Days) X 85% = 117 Mtpa	Amount of trains per day	76 Mtpa	0.65
Inventory Management	(5500 X 5) X (344 X 24) X 85% = 84 Mtpa	Wagon Tipplers	76 Mtpa	0.91
Warehousing	(6000 X2) X (344 X 24) X 85% = 84Mtpa	Reclaimers	76 Mtpa	0.91
Shipping	(344 days X 24 Hours)/(target Turnaround) X 80000 Tons = (8256) X (80000) / (27) = 98 Mtpa at 85% = 84 Mtpa	Ship Loaders	76 Mtpa	0.91

Table 7-7 shows the capabilities of each phase in the supply chain. Each capacity that is calculated using information regarding the infrastructure of Transnet is taken at 85% of its actual capacity. This is to leave capacity for the inherent variation in the system. The procurement phase is taken to be the phase in the supply chain with the smallest capability. This is done so that the procurement phase does not secure a quantity of work which cannot be handled by Transnet.

The supplier capability is taken as the highest amount of export coal produced in the last 10 years, which is 76Mt (South African Chamber of Mines, 2014). The railways, inventory management, warehousing and shipping capabilities were all calculated according to the operating time available and the capacity of the smallest machine in the phase. The phase with the greatest capacity (theoretically) is the railway. This is intuitive as they have a large arsenal of locomotives and wagons. This means that the infrastructure in the railway phase is significant enough to meet the demand, which implies that there is a greater issue with the utilisation of assets and the processes which the assets have to go through.

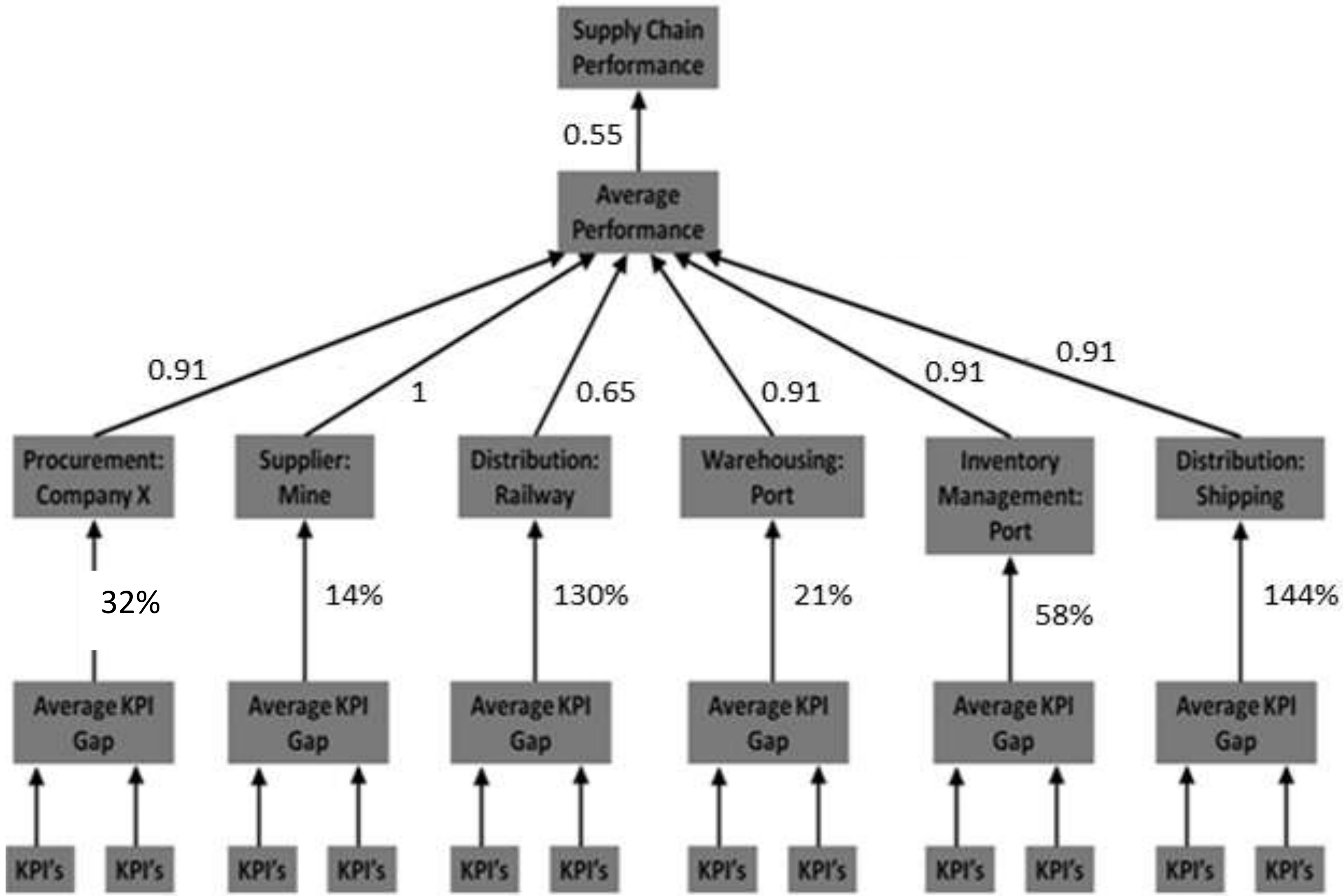


Figure 7-13: The Completed Supply Chain Performance Framework

Figure 7-13 shows the completed supply chain performance framework. The calculations of the weights are based on the capabilities of each Phase. The framework weights are calculated with reference to the smallest capacity. As with manufacturing, or any service or process where bottlenecks can occur, in order to have consistent an predictable flow one should strive to work according to the smallest capacity to avoid large build ups of work in progress and inventory. Thus, the supply chain is modelled similarly in order to minimise waste throughout the supply chain.

The actual performance of the supply chain is 1 – 0.55 = 0.45. This is because the closer the difference in performance tends to zero, the efficiency of the supply chain increases, whether the differences are positive or negative. This framework works o the principle that each phase should have KPI’s in line with the demand of the entire supply chain and work according to those targets with the difference tending to zero as efficiency tends to 100%. Each phase should work to efficiencies relevant to the need of the supply chain in order to achieve a predictable supply chain.

The frameworks short comings include that the entire supply chain must work as a single unit. Thus, the supply chain must work as seamless as possible, as if there is only 1 business unit working.

This framework does not take into the account if a company in the supplier chain has many suppliers and how the aggregated demands of each supplier will be met within the supply chain.

The framework is based heavy on the accurate prediction and calculation of targets. The framework does not account for the errors occurring by using inaccurate targets. It is only suggested that the user takes care in evaluating and researching the best practices for the relevant industry. Again, companies would need to forecast and calculate target values together in order to improve.

From the framework used it is clear that the rail and the shipping elements of the supply chain need to be improved. Through the mapping of the process and the KPI's which underperform it is noted that on time arrivals at the port, idle time of the trains, train utilisation, and unloading time at the port are significant contributors to poor performance. This may be attributed to the coupling and uncoupling of trains occurring throughout the supply chain.

The on time arrivals at the port are dependent on the processes preceding it. Constraints which have been documented and found relevant are the Overvaal tunnel (which is single track) and the need to change trains from AC to DC and vice versa at the Ermelo rail yard. The coupling and uncoupling procedure is time consuming.

Train utilisation can be attributed to the capacity at Ermelo and Overvaal. Ermelo is used as a hub for all trains after collecting the coal at the sidings. Thus, the number of trains and wagons in use is determined by the capacity of Ermelo. The design structure at Ermelo does not allow for multiple coupling (only two 100 wagon trains can be coupled to one 200 wagon train at a time) of trains which causes queuing. The Overvaal tunnel also has a part in the capacity available on the track as the single track is a clear bottleneck candidate.

The offloading at the port maybe be a machinery problem, however, there are five wagon tipplers which can uncouple a 100 wagon train in two hours. The processes around the unloading should be investigated, such as the need to decouple and couple trains at the port.

From the above findings and the findings in the paper authored by Govender et al, 2015, the following scenarios are formulated:

A) The improvement of Ermelo as a hub (suggested improvements are made by Govender (2015)),
B) The use of smaller 100 wagon consists (suggested by the findings on idle times and Govender (2015)),
C) The removal of Ermelo as a hub and the upgrading of the Overvaal single track (suggested by the findings on idle times and Govender (2015))

7.2 Simulation Results

In this section the model will be validated by means of a visual validation. Tables of the final data are provided and screenshots are taken of the model. Each scenario is validated in this section. The model is split into sections and validated section by section. Once the validation is completed then the results of the model are discussed.

7.2.1 Model Validation

The model was validated by running different scenarios through the simulation. The first scenario is the original case which represents how Transnet is currently operating. The scenarios mentioned at the end of section 8.1 are run in order from A to C. Both visual and numerical validation was done to ensure that the model behaves as expected and that all entities are accounted for either in the system or disposed having passed through the system. This section can be found in the Appendix A under section A4 to A8.

7.2.2 Current State Simulation

In the current state of Transnet the simulation model is designed and run as put forward in the methodology of this paper. The simulation of the supply chain is a simplified model and is done so in order to test the affects of scenarios which are aimed and improving throughput and optimising the performance of the supply chain. The model is run for the equivalent time of one working year (344 days). Cycle times, quantities and constraints are kept as close to the real world numbers as possible. As such the model runs on 12 trains 200 wagon trains per day (or as modelled, 24 100 wagon trains per day) and 900 ships per annum and working to export 69 million tons of coal from South Africa through the Richards Bay Coal Terminal. The completed throughput in a given year and the percentage throughput are shown in Figure 7-14.

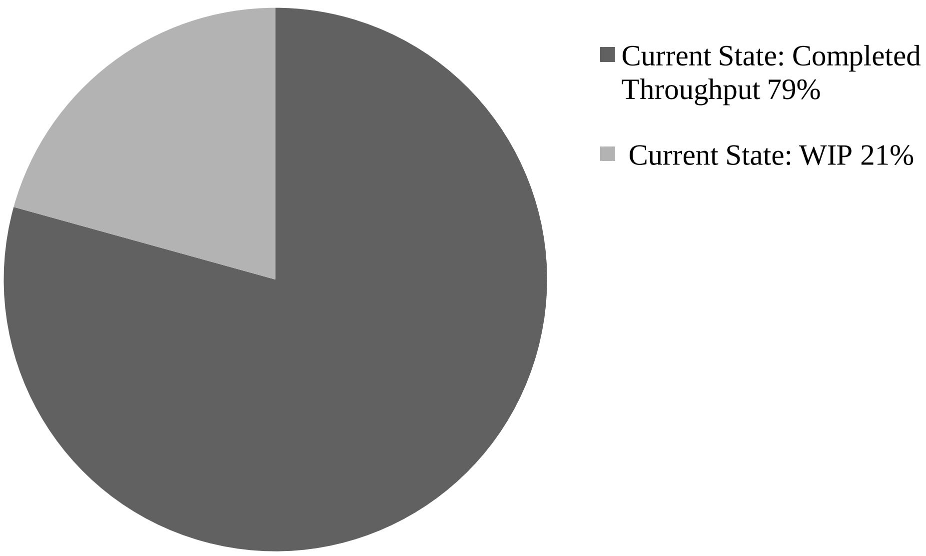


Figure 7-14: Total Throughput and Work in Progress for the Current State

In the current state the total number of trains available throughout the year is 8256, if the trains are made of 100 wagons. In the current state the trains entering the model are 8232, one day less due to starting from the zero state. The number of trains completing the cycle in the current state is 6528 (79%), which leaves 1704 (21%) trains in the system or 1704 trains regarded as work in progress (WIP). The amount of WIP of the system is 21%. This means that there is approximately 14.4 million tons of coal on the rail network.

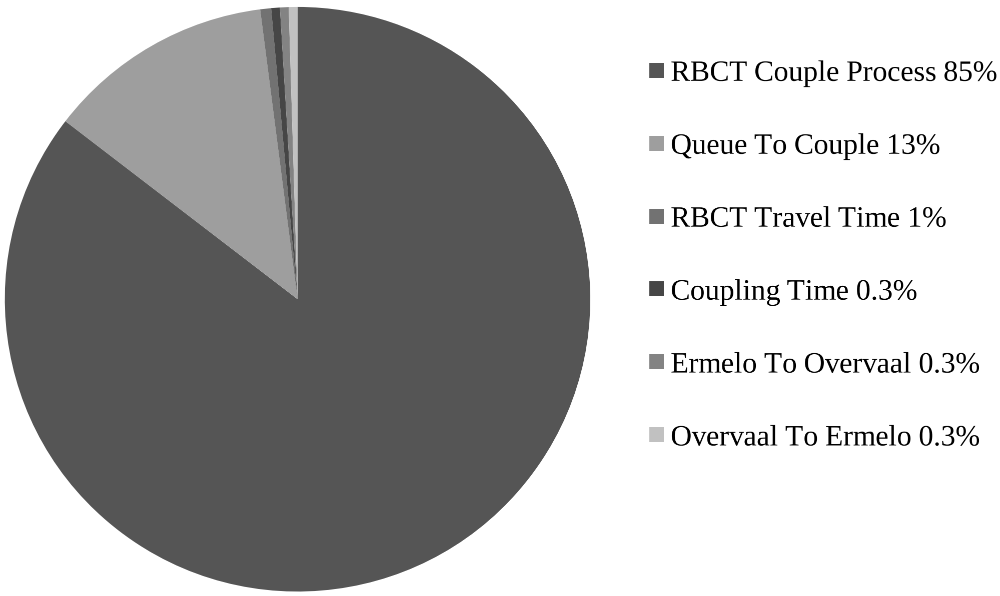


Figure 7-15: The WIP Percentage of the Current State.

A breakdown of the WIP is shown in Figure 7-15. The greatest contributor to the WIP of the current state is the queue caused by the coupling of trains at the Richards Bay Coal Terminal. This queue contributes to 83.5% of the overall WIP of the system. This value is high, however, it does emphasise the time wasted in the system due to coupling and decoupling. For example, at the Richards Bay Terminal, the train is decoupled and then waits while one trains is being unloaded then the unloaded train waits for the loaded train to be unloaded causing unnecessary queuing.

The coupling and decoupling of trains throughout the model creates a timely and labour intensive process. Although the use of 200 wagon trains is beneficial in minimising the affect of the Overvaal single track tunnel, the cycle times associated with coupling and decoupling trains creates queues and constraints within the system.

Recalling the evaluation of the rail distribution in section 7.1.4, Railway KPI Results, it can be seen that the unloading time at the port and idle time of the trains are the worst performers in the response time indicators. The on time arrivals are also a significant contributor to the overall poor performance of the rail network and are dependent on the processors before it. The decoupling and coupling of trains unnecessarily can be a contributing factor.

7.2.3 Scenario A: Improved 200 Wagon Consist Structure

The idea behind this scenario is that the consist is structured in such a way that the coupling from Ermelo has a much quicker turnaround time. This involves changing the structure of the consist from 6 locos and 200 wagons to a 4 loco-100 wagon-4 loco-100 wagon structure. The completed throughput and work in progress is shown in Figure 7-16.

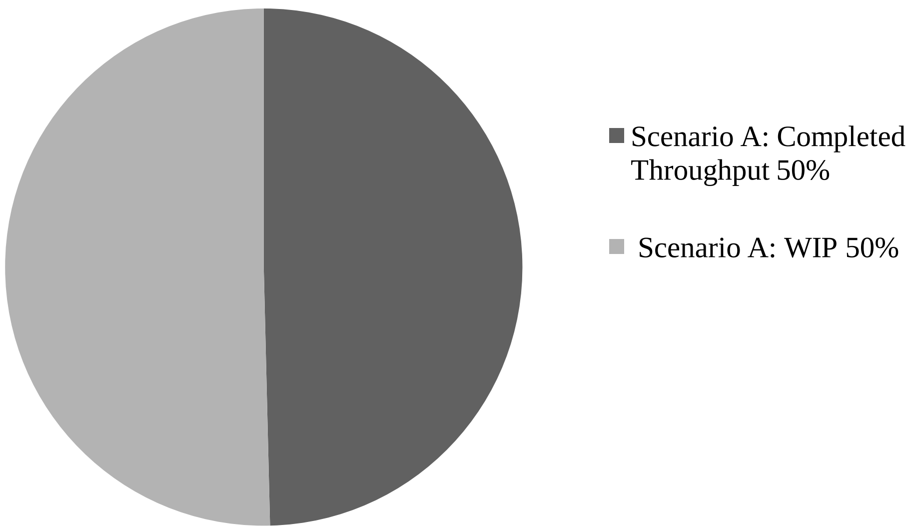


Figure 7-16: Throughput and WIP for Scenario A.

For scenario the result shows an increased amount of WIP when compared with the current state, with WIP accounting for approximately 50% of the overall entries. This is extraordinary, however, it must be noted that although the scenario drastically reduces the turnaround time at Ermelo, the time taken at the port is significantly higher due to the complexity of coupling and decoupling during the unloading processes.

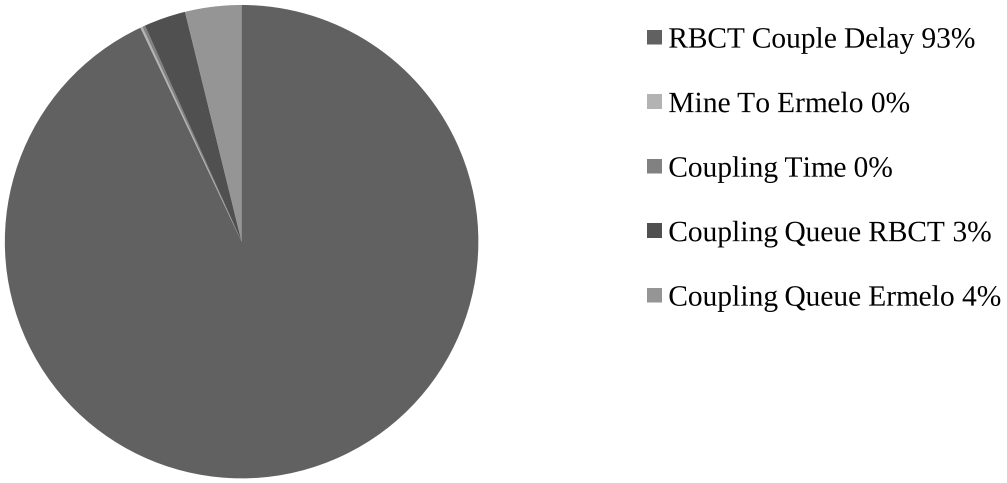


Figure 7-17: WIP Percentage Scenario A

From Figure 7-17 it can be seen that once again the coupling process at the port is a significant contributor to the percentage of work in progress. The coupling process accounts for 92% of the total WIP. Upon further investigation it is seen that the coupling process at the port is significantly longer than in the current state. Although the coupling process at the Ermelo rail yard is greatly reduced, this is of little significance as the Ermelo rail yard has a greater capacity than that of the Richards Bay Coal terminal, in the process of coupling and decoupling. Thus, this scenario does not optimise the throughput.

7.2.4 Scenario B: 100 Wagon Consists Only

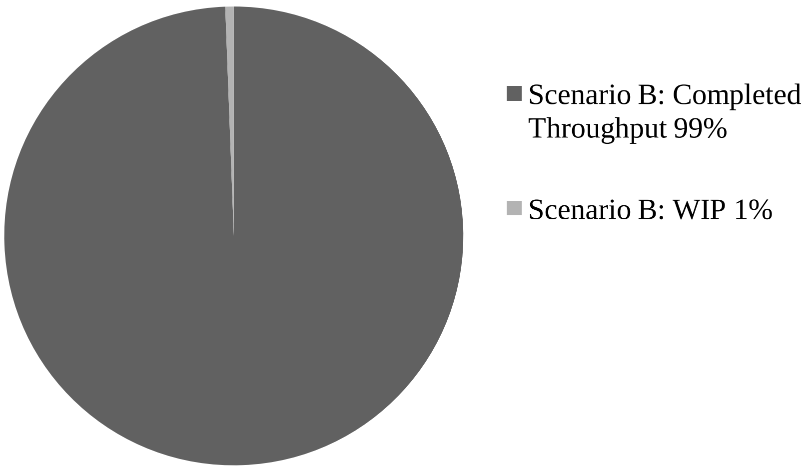


Figure 7-18: Total Throughput and WIP for the 100 Wagon Consist Scenario B.

Figure 7-18 shows the completed throughput and WIP for the scenario using 100 wagons consists. The WIP contributes only 0.5% to the overall entries. This is a significant drop in comparison to two of the 200 wagon consist theories. The decrease in the number of queues has a significant effect on the waiting time of the entries, thus causing less WIP. This is shown by Figure 7-19 which shows the breakdown of the WIP. Queuing accounts for just 6% of the WIP, a significant drop in comparison to 83% and 92% in the current state and improved 200 wagon consist scenario, respectively. This is a more ideal situation as the vast majority of the WIP is located in "delay" blocks symbolising travel times between locations. This means that although there is WIP, it is moving between destinations, which essentially mean that Transnet is adding value to the entry. I.e. the definition of Transnet is to provide a logistics service by moving commodities from A to B as quickly and cost effectively as possible.

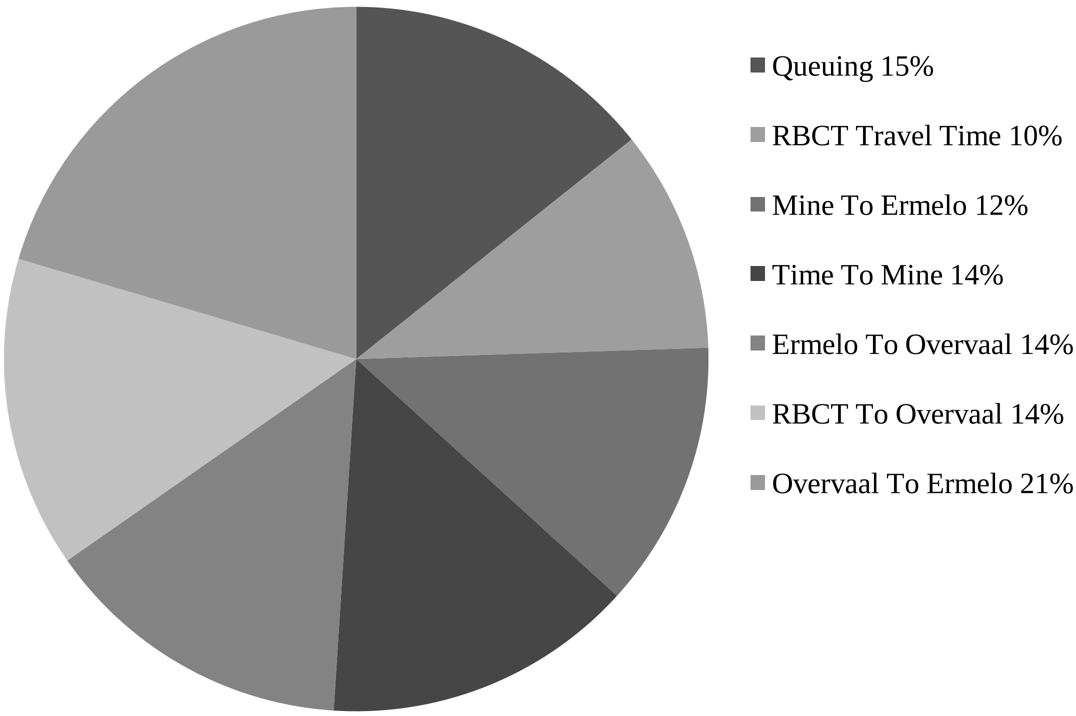


Figure 7-19: WIP Breakdown for the 100 Wagon Consist Scenario B.

There is, however, a negative aspect in this scenario as with the increased number of trains on the network the Overvaal tunnel will become a significant problem. The model built does not account for the Overvaal constraint in enough detail for the effect to become as apparent as it would be in a practical environment. The Overvaal constraint has not been an issue in the 200 wagon consist scenarios as there is much greater waste which occurs causing it to be overlooked somewhat.

7.2.5 Scenario C: 100 Wagon Consist and Upgrading the Overvaal section

This scenario holds similar results to the previous scenario. The WIP accounts for only 5% of the total entries. This means that the conversion rate from entry to finished product is 95% for the given period. Furthermore, the elimination of the Overvaal section has reduced the queuing to 0, as seen by Figure 7-20.

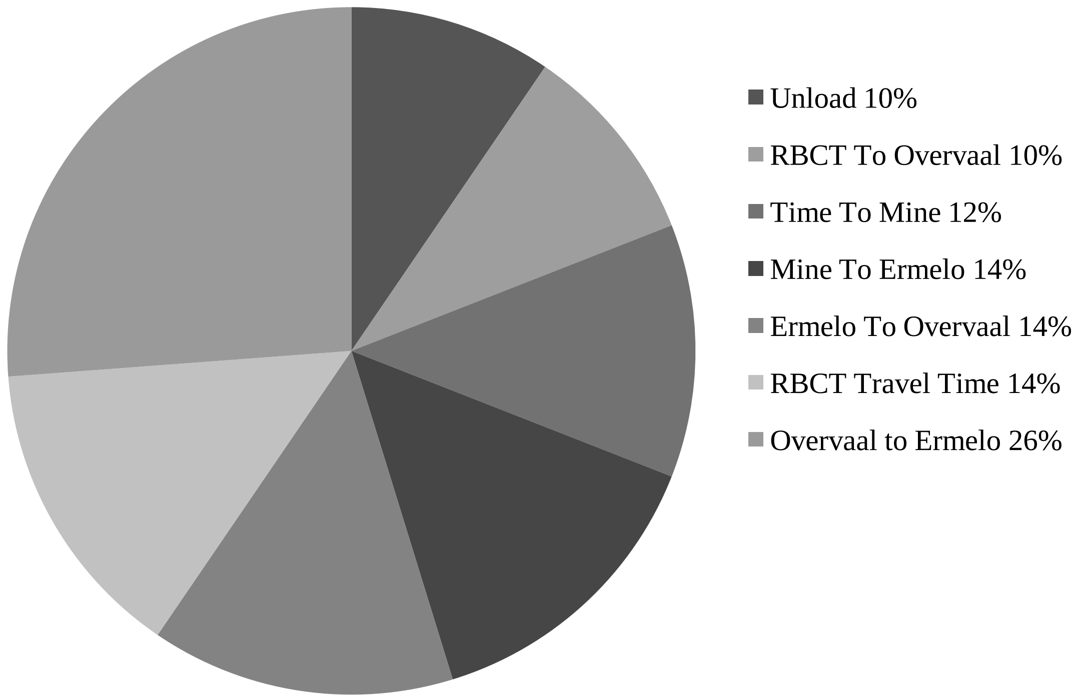


Figure 7-20: The WIP Percentage for Scenario C.

All the WIP is being transported on the network or is undergoing a process of material handling. Thus, the idle time and queuing time is minimised. This, however, is a theoretical model which has not taken into account the headway between trains, the signalling mechanism of the network and the possibility of breakdowns, failure or human error. This scenario is based on the principles of lean, in that the batches are made smaller and the flow more even across the network. This allows processes to be followed with minimal queuing and wastage in the system.

7.2.6 Comparison of Scenarios

The 100 wagon consist scenarios (B and C) produce a much more efficient network with over 95%, as shown by the total throughputs in Figure 7-21. The throughput bettered the original state and scenario A by 20% and 50%, respectively. Although the scenario utilising a 200 wagon consist restructure is the worst performing, it should be noted that the majority of the WIP is empty trains.

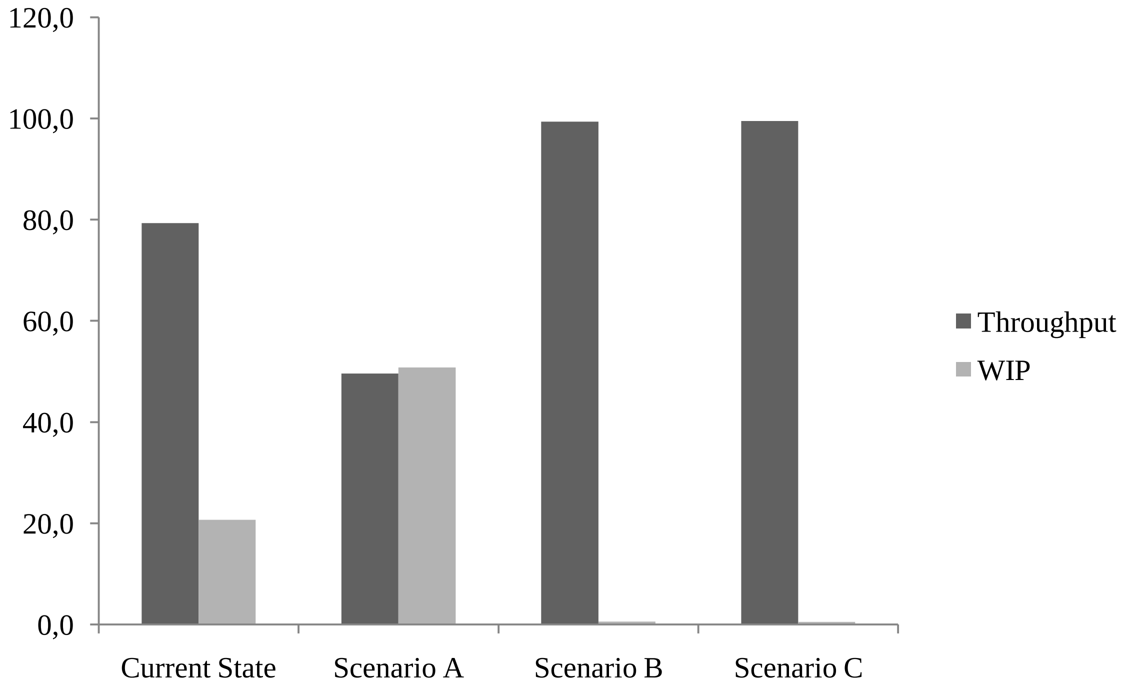


Figure 7-21: Percentage WIP vs. Throughput Comparison.

Scenario B and C achieve a 20% better throughput conversion than the current state. This means that should future demand for local coal increase to the expected demands then 100 wagon consists may be a viable option in order to meet the demand.

The model focussed significantly on the rail network and the shipping network as these two elements were the worst performing elements when evaluated in the framework of this study. Improvements to the response time and quality indicators are possible for both elements should these scenarios be investigated further.

7.2.7 Adapted Framework Scenario Comparison

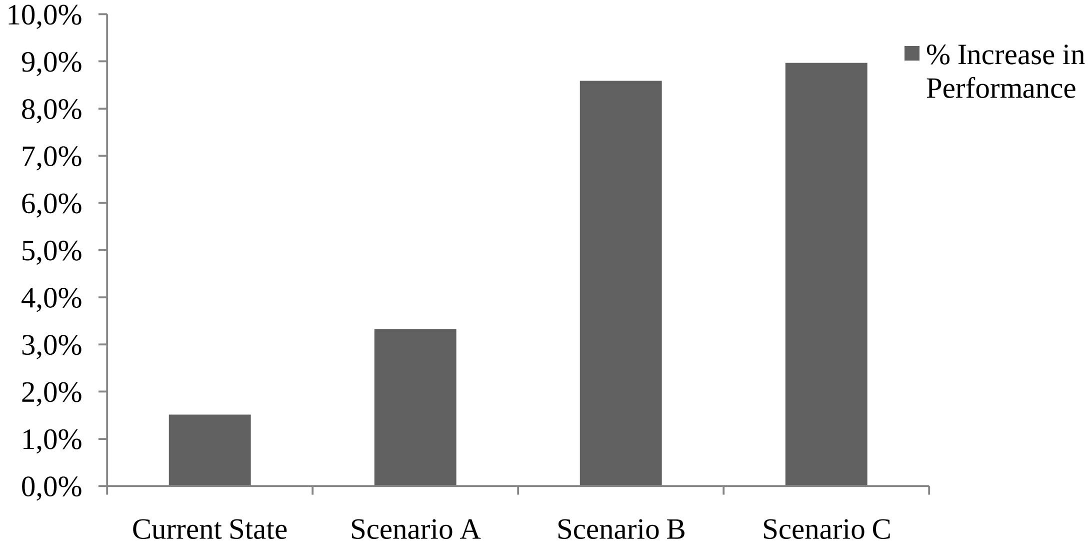


Figure 7-22: Adapted Framework Comparison of All Simulated Scenarios.

Figure 7-22 shows the performance of each scenario once evaluated in the adapted framework. Here it is seen that scenario C is the top performing scenario with an increase in rail performance of 9%. The greatest contributor to the increase in performance (over the entire rail division) is the large reduction in idle time, which is 19 hours in the current state simulation and just 3 hours in scenario C. This reduction in the idle time translates to a significant reduction in the cycle time. The cycle time reduces 48 hours in the current state to 32 hours in scenario C.

Furthermore, it should be noted the running 200 wagon consists seem to add on to both the idle time and the cycle time due to the cumbersome process of coupling and decoupling of trains across the network. Unloading times at the port are significantly reduced when coupling is not necessary.

Figure 7-23 show the phase differences of scenario C and the actual achieved values for each element when compared to the target values. The quality and response indicators both show a significant increase in performance. The quality element shows an increase of 17% (reducing the gap from 307% to 235%). This is largely due to the improvement in the on time arrivals. The response time indicators show a significant increase in performance of 104%. This is due to the reduction in idle time form 22 hours in the actual achieved values and just three hours in scenario C. This out performs the target value of five hours. The elimination of coupling and recoupling processes throughout the system and the initiating of a two way tunnel at Overvaal are the main contributors to the increase in performance.

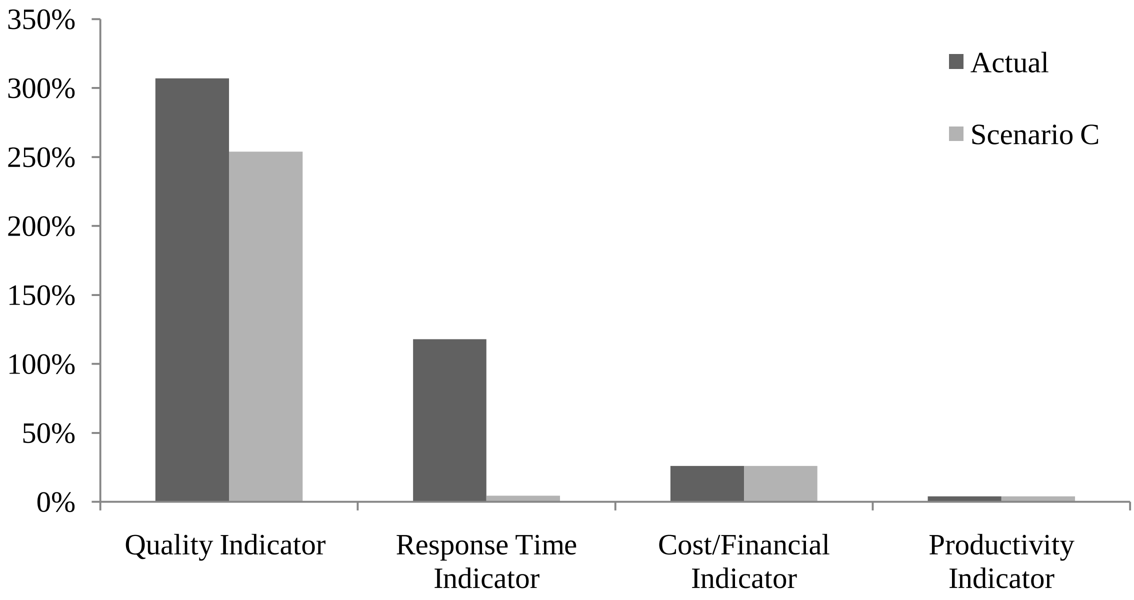


Figure 7-23: Indicator Comparisons between the Actual Performance and the Performance of Scenario C.

Furthermore, the overall performance of the supply chain is calculated. If the elements in scenario C were to be realised the impact on the performance of the overall supply chain would be 7%. The new value chain performance would be 0.51 instead of 0.55. This figure may seem like a small increase, however, it must be stated that this is the increase in performance across all six phases of the value chain.

8 Recommendations

Based on the research conducted in this study the following recommendations are proposed for the adapted framework used to provide a single KPI. This section focuses heavily on attaining more detailed information regarding all phases of the value chain. The framework itself has modifications suggested which would make it a more practical tool for real world companies to use. Recommendations to both the framework and simulations are made.

8.1 Framework:

- The framework does not make provision for multiple suppliers. The affects of multiple suppliers and customers on a supply chain should be investigated and included into the framework.
- The framework is heavily dependent on the accurate calculation and forecasting of target values. Further investigation should be made into utilising predictable KPI's to increase the accuracy of the framework, i.e. machine operated KPI's as opposed to KPI's that need forecasting.
- To verify the modification of the framework more companies should be used and their performance evaluated using the framework. Historical data should then be used to see if the company's trend and the trend of the framework have similar results.
- The framework should include a severity coefficient, which would remove the assumption that all KPI’s impact the system equally. This means that the framework will become more accurate.
- In future it is recommended that the performance values are standardise, i.e. all negative for underperformance and positive for over performance. Normalising a dataset collected over a year will assist in strengthening the accuracy and clarity of the data inputted into the framework.

8.2 Simulation Model

- The model should use the geographical locations of the pickup points, Ermelo, Overvaal and RBCT. The model should also utilise the actual train speeds and distances as opposed to modelling travel time as a delay. This would make the travelling of the trains more lifelike and introduce other characteristics like gradient, breaking and accelerating behaviour. The geographical locations of the rail network could also be used to identify points in the network most susceptible to breakdowns or accidents. Utilising the actual length on the geographic position of the coal network would allow for both 100 wagon and 200 wagon consists to be modelled accordingly. The following information would assist the refining of the model:

  - Determining the exact location of the rail networks utilised for the coal export industry. Then using the GIS (Geographical Information System) in Anylogic,
  - Attaining train by train information for the measured KPI’s will prove invaluable in eliminating the risk of using average KPI values.

- The model should include the contribution of trucks as well. This should include of the deliveries of coal to the mine sidings and to RBCT via road.
- Modelling the overall tunnel should include each process at the tunnel and their associated the cycle times to get exact delay times per train. This will help quantify the financial affect the tunnel has on the rail network.
- The Richards Bay Coal Terminal should be modelled to include all processes and their interdependencies. This is to increase the efficiency and reliability of the material handling processes. Reasons for large stock piles and only 14% of coal delivered directly onto the ship should be investigated and the percentage passed onto the train directly should increase as expected from a pull system. Port operations and material handling processes should be accurately replicated on a micro scale and identify where the port can increase export capacity.

9 Conclusion

A framework based on the model used by Aronovich (Aronovich, et al., 2010) was adapted to model a supply chain. The worst performing element of the supply chain was the railway and shipping phases, which both underperformed by 130% and 144%, respectively. The best performing phase was warehousing. The overall performance of the Transnet Value Chain for the coal corridor was 45%. Significant delays were observed in areas where coupling and decoupling occurred.

Improvement scenarios were based on minimising the coupling and decoupling, eliminating the Overvaal tunnel. It was concluded that for the best performance Transnet should remove Ermelo as a central hub, upgrade the Overvaal tunnel and utilise consists of 100 wagons instead of 200 wagons. Based on these results, the Transnet owned coal corridor could increase its performance by 20% and the overall performance of the value chain would increase by 7%. A cost analysis of buying more land for the Overvaal upgrade must be done in order to confirm the practicality of implementing such a solution. In addition a list of recommendations for the framework and modelled rail network were proposed.

10 References

Abrahamsson, M. and Rehme, J. (2010) ‘The Role of Logistics in Retailers’ Corporate Strategy-a Driver for Growth and Customer Value’, *Supply Chain Forum: International Journal*, 11(4), pp. 14–22. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=80437171&site=ehost-live.

Akkermans, H. and Oorschot, K. Van (2002) ‘Developing a Balanced Scorecard with System Dynamics’, in *Proceedings of the 20th International Conference of the System Dynamics Society*, pp. 1–22. Available at: http://www.systemdynamics.org/conferences/2002/proceed/papers/Akkerma1.pdf.

Anylogic Company (2014) *Anylogic 7*. Available at: https://www.anylogic.com/blog/anylogic-7-released/.

Aronovich, D. *et al.* (2010) *Measuring Supply Chain Performance: Guide to Key Performance Indicators for Public Health Managers, U.S. Agency for International Development*.

Bazghandi, A. (2012) ‘Techniques, Advantages and Problems of Agent Based Modeling for Traffic Simulation’, *International Journal of Computer Science Issues*, 9(1), pp. 115–119.

Brailsford, S. and Hilton, N. (2001) ‘A comparison of discrete event simulation and system dynamics for modelling health care systems’, in *Proceedings from ORAHS 2000*, pp. 1–11. doi: 10.1504/IJBIS.2010.034001.

Brown, J. (2016) ‘On time delivery ratio- OTD’, *AFN*, p. 1. Available at: http://www.leanmanufacture.net/kpi/ontimedelivery.aspx.

Caro, J. J. and Möller, J. (2016) ‘Advantages and disadvantages of discrete-event simulation for health economic analyses’, *Expert Review of Pharmacoeconomics & Outcomes Research*. Taylor & Francis, 16(3), pp. 327–329. doi: 10.1586/14737167.2016.1165608.

Castle, C. J. E. and Crooks, A. T. (2006) *Principles and concepts of agent-based* *modelling for developing geographical simulations, CASA working paper series*. doi: ISSN: 1467-1298.

Chheda, J. A. (2015) *Manufacturing Systems*. doi: 10.17226/1867.

Coyle, R. G. (1996) *System Dynamics Modelling: A practical Approach*. Chapman and Hall.

Durkacova, M., Lavin, K. and Karjust, K. (2012) 'KPI Optimization for Product Development Process', *Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium*, 23(1), pp. 1079–1084.

Frost and Sullivan (2015) *Material Handling and Productivity*.

G2 Incorporated (2017) *How Long Should Carrier Negotiations Really Take ?* Available at: http://www.g2inc.com/telecom-sourcing-insight/how-long-should-carrier-negotiations-really-take/.

Govender, T. (2015) 'the Evolution and Operational Impact of Ac-Dc Wire Distributed Powered Trains on the South African Coal Export Line', in *IHHA 2015 Perth, Australia*, pp. 1–8.

La Grouw, G. (2009) 'Unraveling KRA's , KRI's , PI's and KPI's', *Ezine Articles*, pp. 1–4.

Guerrero, C. N., Schwarz, P. and Slinger, J. H. (2016) *A recent overview of the integration of System Dynamics and Agent-based Modelling and Simulation*.

Jakeman, A. J. *et al.* (2013) 'Decision support systems : experiences , lessons and recommendations', in, pp. 12–15.

Janssen, M. (2005) *Agent-based modelling, Modelling in Ecological Economics*. doi: 10.1016/j.patrec.2007.06.021.

Kaplan, R. S. (2010) 'Conceptual Foundations of the Balanced Scorecard', *Harvard Business School*, pp. 1–36. doi: 10.1016/S1751-3243(07)03003-9.

Kuys, W. (2011) 'Heavy Haul operations in south africa', in *IHHA 2011*, pp. 3–30.

Letcher, K. (2012) *Selecting Among Six Modelling Approaches for Integrated*

Environmental Assessment and Management.

Macal, C. and North, M. (2006) 'Modeling and Simulation.', in *MCS LANS Informal Seminar*. Argonne National Laboratory, pp. 1–3. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED153596&site=ehost-live&scope=site.

Maidstone, R. (2010) *Discrete Event Simulation , System Dynamics and Agent Based Simulation : Discussion and Comparison*.

Maidstone, R. (2012) *Discrete Event Simulation, System Dynamics and Agent Based Simulation: Discussion and Comparison, System*.

Matloff, N. (2006) 'Introduction to discrete-event simulation and the simpy language', in *Introduction to discrete-event simulation and the simpy language*, pp. 3–6. doi: 10.1007/978-0-387-68612-7_10.

May, A. *et al.* (2014) 'Optimisation of key performance measures in air cargo demand management', *Journal of Transport and Supply Chain Management*, 8(1). doi: 10.4102/jtscm.v8i1.125.

Miller, B. Y. P. (2012) 'Ten Characteristics of a Good Teacher', *Journal English Teaching Forum*, 25(1), pp. 1–3.

Murby, L. (Cima) and Gould, S. (Cima) (2005) *Effective Performance Management with the Balanced Scorecard-Technical Report, Cima*.

Park, N. K., Yoon, D. G. and Park, S. K. (2014) 'Port capacity evaluation formula for general cargo', *Asian Journal of Shipping and Logistics*, 30(2), pp. 175–192. doi: 10.1016/j.ajsl.2014.09.003.

Pierce, F. (supplychaindigital) (2013) 'Top 10 Global Rail Networks'. Available at: https://www.supplychaindigital.com/top-10/top-10-global-rail-networks.

Richards Bay Coal Terminal (2015) 'The Impact of Infrastructure and Logistics on the Coal Industry in Southern Africa', in *Mining Magazine*, pp. 2–30.

Robinson, A. (2014) 'Why Logistics Efficiency is More Important Than Ever for Manufacturers', *Cerasis*, p. 1. Available at: http://cerasis.com/2014/06/09/logistics-efficiency/.

Salem, Milad Abdelnabi , Dr. Norlena Hasnan, D. N. H. O. (2012) 'Balanced Scorecard: Weaknesses, Strengths and its Ability as a Performance Management System Versus Other Performance Management Systems', *Journal of Environment and Earth Science*, 2(9), pp. 1–10. doi: 10.1016/S0361-3682(02)00097-1.

Transnet (2014) *Transnet Integrated Report 2014*, *Investor Relations*.

Transnet Freight Rail (2014) *Rail development Plan*.

Transnet National Ports Authority (2010) *Port of Richards Bay*. Available at: https://www.transnetnationalportsauthority.net/OurPorts/RichardsBay/Pages/Overview.aspx.

Transnet National Ports Authority (2016) *National Ports Plan 2016*.

Tseng, Y., Yue, W. L. and Taylor, M. A. P. (2005) 'The role of transportation in logistics chain', *Eastern Asia Society for Transportation Studies*, 5, pp. 1657–1672. doi: 10.1017/CBO9781107415324.004.

US Energy Information Administration (2014) *Power Plant Operations Report*. doi: EIA - 923.

Velimirovic, D., Velimirovic, M. and Stankovic, R. (2011) 'Role and importance of key performance indicators measurement', *Serbian Journal of Management*, 6(1), pp. 63–72. doi: 10.5937/sjm1101063V.

Weber Logistics (2014) *Understanding Commercial Warehouse Pricing. How shippers can turn pricing knowledge into lower rates*. California: http://creativecommons.org/licenses/by/3.0/us/.

De Weille, J. and Ray, A. (1974) 'The Optimum Port Capacity', *Journal of Transport Economics and Policy*, pp. 244–259. doi: 132.72.23.208.

Williams, M. A. (2005) *Underground coal mining: factors, cost, and time considerations*. Available at: http://www.thecoalinstitute.org/ckfinder/userfiles/files/Fall_Skelly_Loy.pdf.

Workman, D. (worldstopexports) (2018) 'Coal Exports by Country', p. 2018. Available at: http://www.worldstopexports.com/coal-exports-country/.

A. Appendix A

This chapter includes elements which are not directly needed in the research; yet provide a more detailed explanation of certain sections within the report. Flowcharts of the process flow of information and materials through the supply chain model are included in the chapter. Following the flowcharts of the supply chain model is the model architecture and model logic creation. These subsections show a step by step process of how to model the simulation model in Anylogic 7.

Furthermore, the model verification and validation for all scenarios are shown in this chapter with all model observations and explanations.

A.1) Model Flowcharts

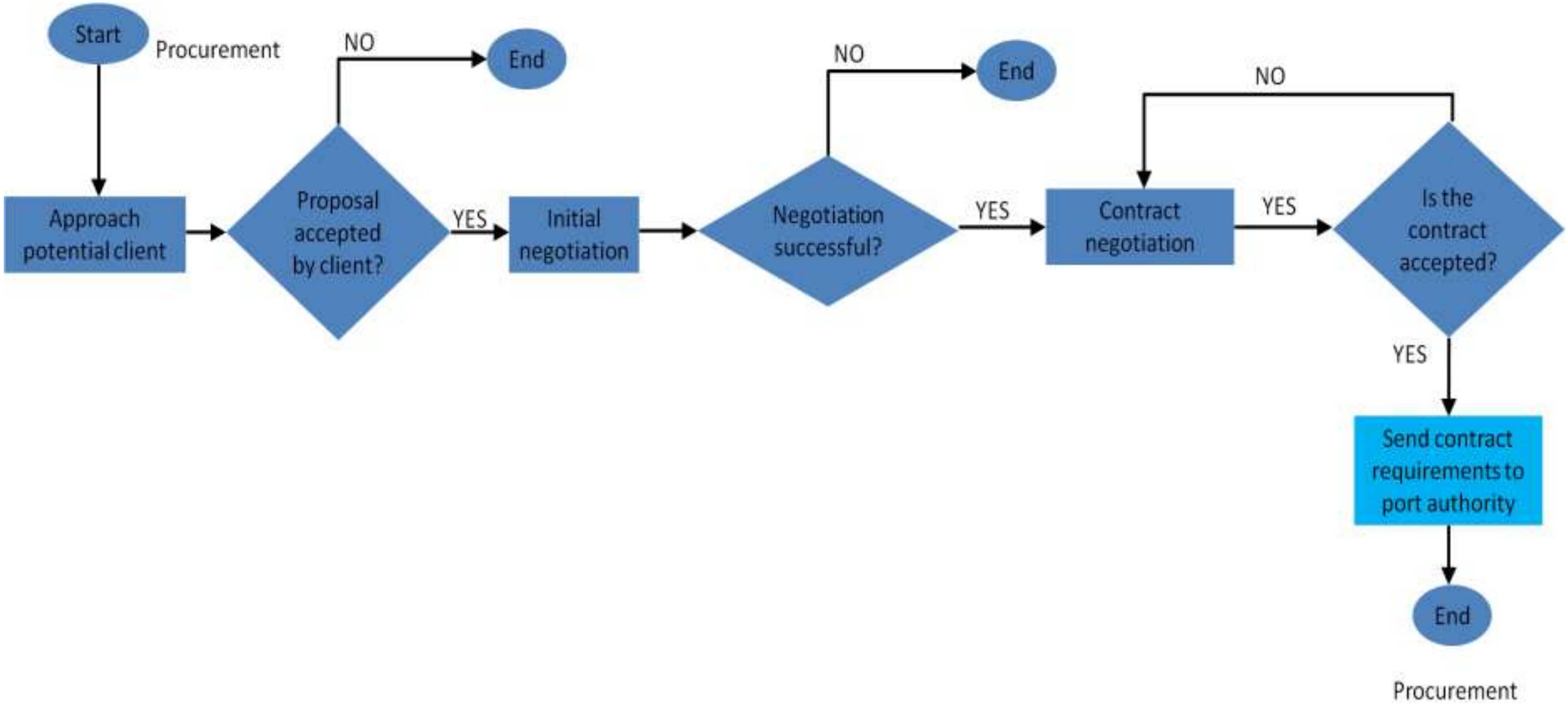


Figure A-1: A Flowchart of the Procurement Process of Transnet.

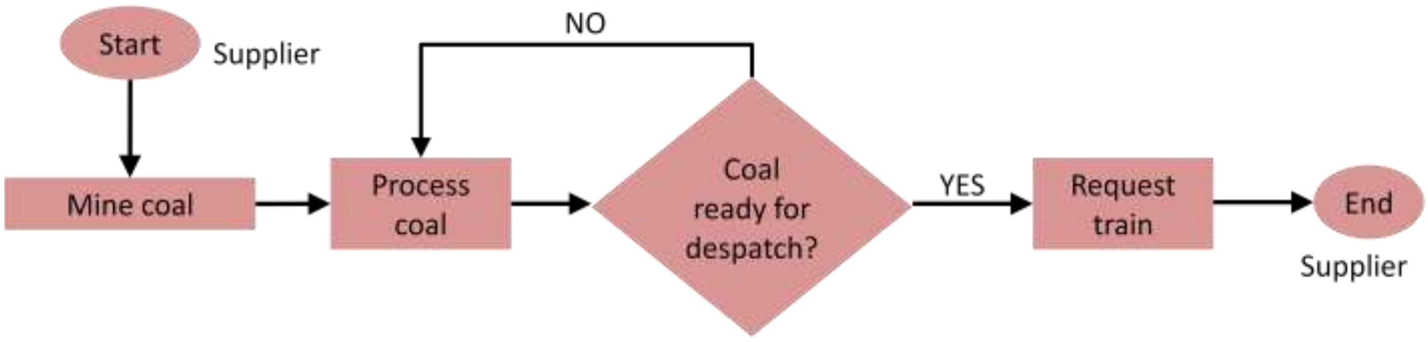


Figure A-2: A Flowchart of the Supplier Process of Transnet.

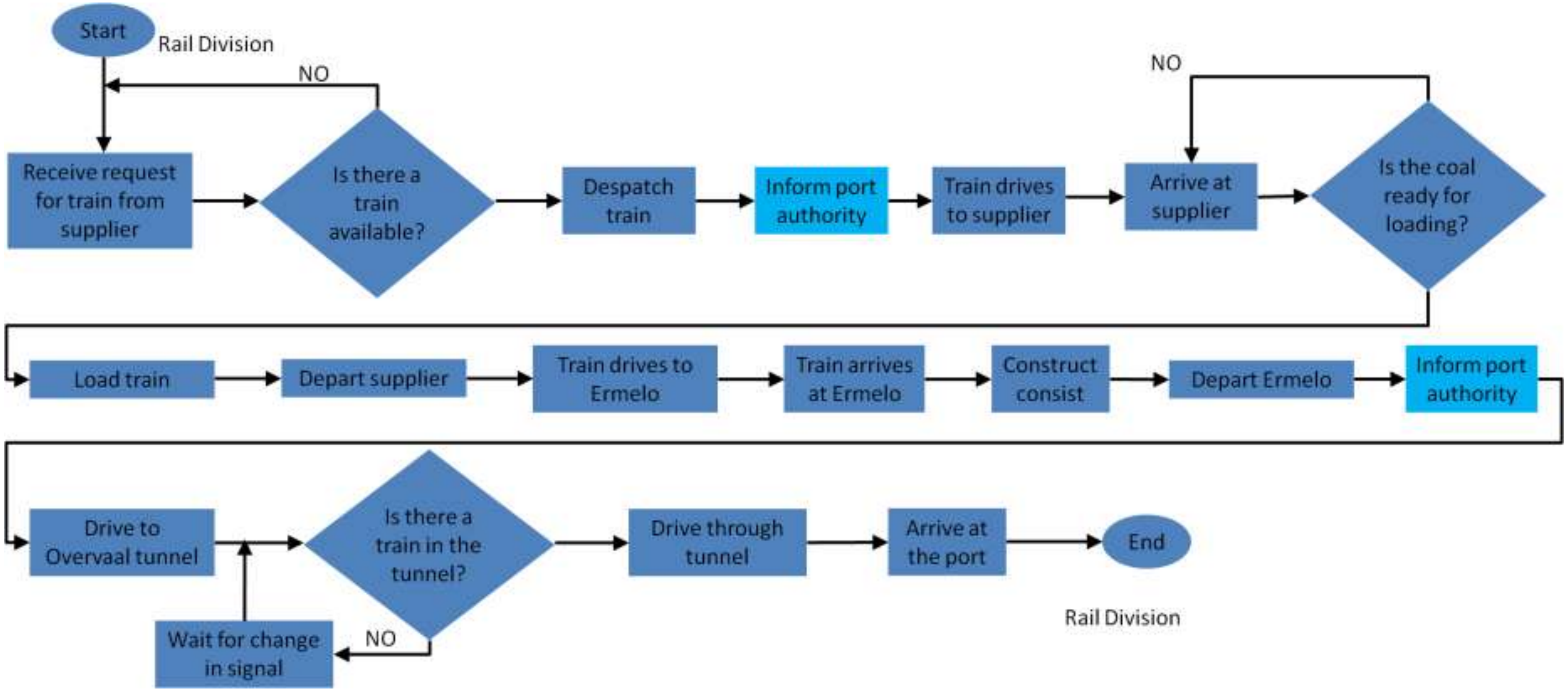


Figure A-3: : A Flowchart of the Rail Division Process of Transnet

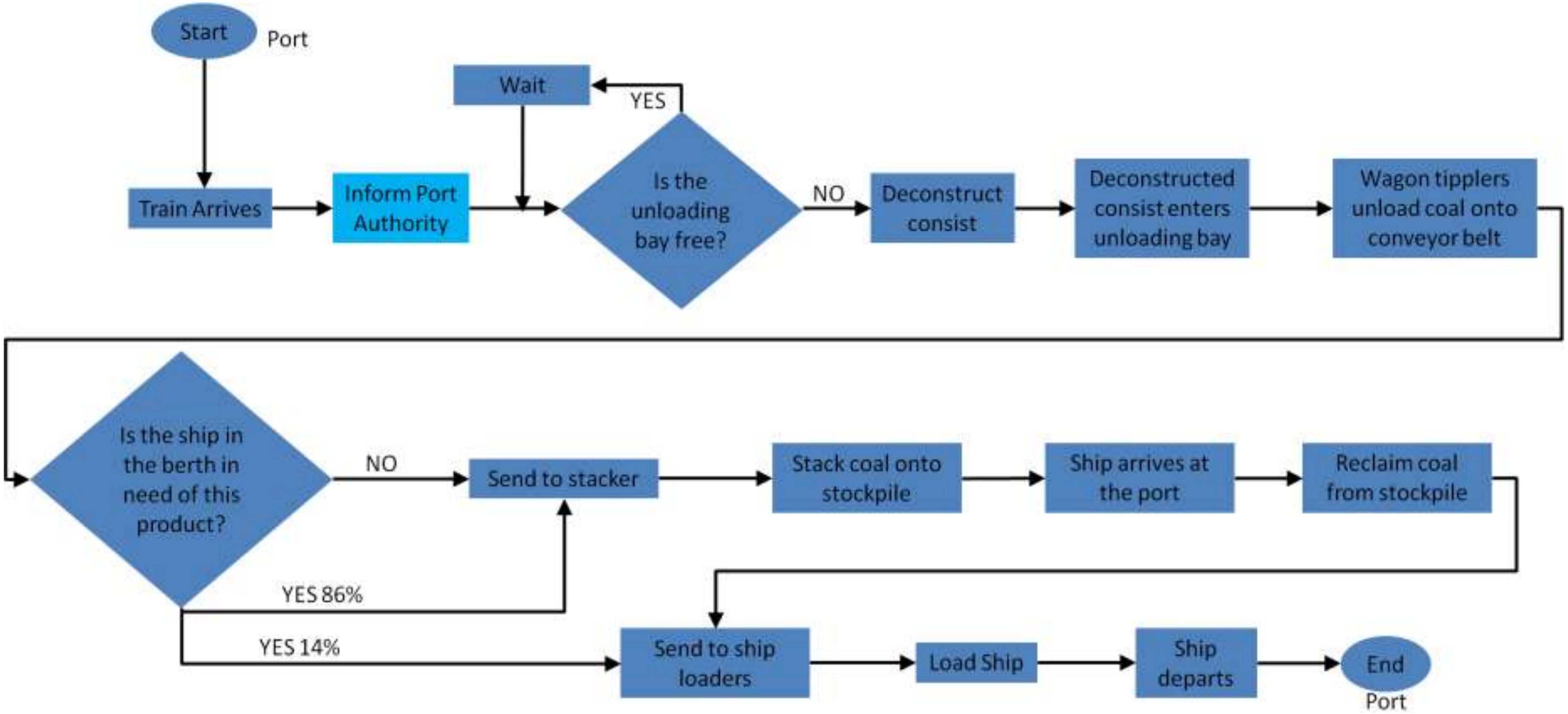


Figure A-4: : A Flowchart of the Port Process of Transnet

A.2) Model Architecture

This subsection explains the development of the simulation model in Anylogic 7. Step by step instructions are shown for creating the exact model used in this research. This model is only concerned with the creation of the environment or structure of the model. The model logic will be shown in the subsection after this one.

A) Ermelo Rail Yard

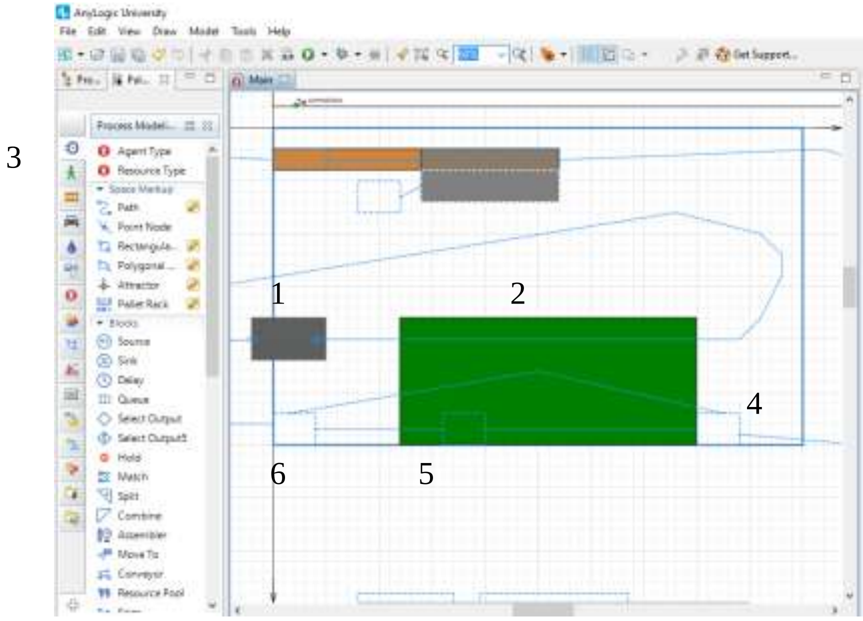
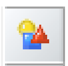


Figure A-5: The Modelled Ermelo Rail Yard

The modelled Ermelo rail yard is represented by the green block shown in Figure A-5. The Ermelo storage yard is shown by 1 and the Ermelo working yard is represented in green. The Ermelo working yard is where the coupling and decoupling takes place as well as switching trains from AC to DC and vice versa.

The Ermelo rail yard is made as follows:

1. Begin by opening the presentation button on the palette . Drag and drop 2 rectangles for the storage yard and the working rail yard. Size them accordingly. One is named Train Store and the other Ermelo Rail Yard
2. On the process library button, shown by 3. Drag the point node onto the smaller storage yard. This node is where trains will emerge from. The node is named Train Source.

3. Connect the node to a path and draw the path accordingly. The path will represent the track for the trains to travel on.
4. Draw the path around to the mine siding and back to Ermelo.
5. As mentioned above the trains unload the coal before the Ermelo yard, this is done at the label 4. To create the rectangular nodes simply drag it off the process library. Label 4, 5, 6 are all rectangular nodes named "Drop Off Coal", "Couple Ermelo" and "Picks Up Coal", respectively.
6. The train then moves to the label 5 and waits for a second train to come so that it may be coupled. The new 200 wagon consist then moves to the label 6.
7. At 6 the coal is reloaded and the train departs for Overvaal.

The logic attached to this diagram will be shown later, along with the logic for the mine siding.

B) Mine Siding

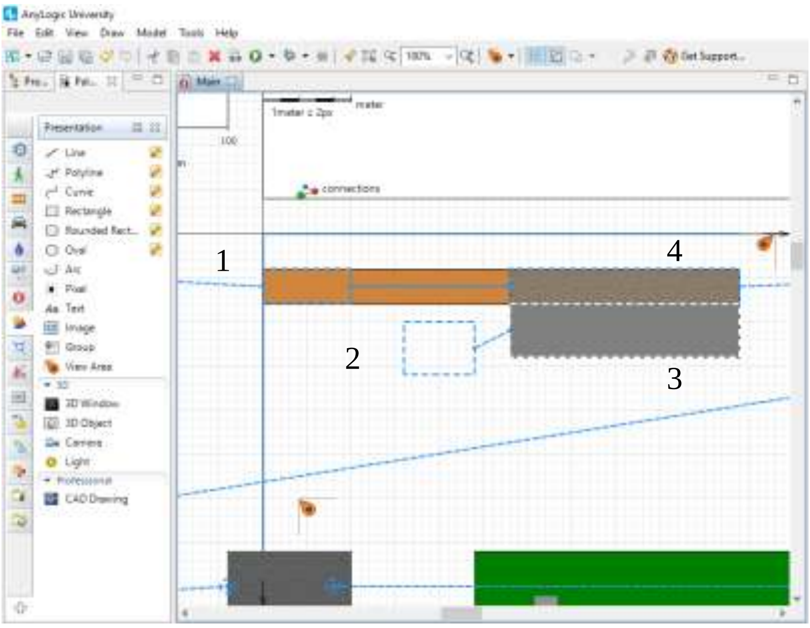


Figure A-6: The Modelled Mine Siding

The mine siding is shown in Figure A-6. As before all the nodes and paths are dragged onto the main screen from the process library or presentation palette. The mine siding is structured as follows:

1. Drag and drop three rectangular shapes onto the main diagram using the presentation palette. Label them SidngQueue (brown), LoadingBay (brown-grey) and Siding (grey).
2. Drag and drop four rectangular nodes from the process library palette and connect them as shown.
3. Labels 1 and 4 are connected and named "MineQueue"and "MineLoading", respectively. These are the elements which account for the travel time from Ermelo and the laoding time at the mine. The coal will be loaded at the node named "MineLoading".
4. Labels 2 and 3 are connected and named "CoalMine" and "Mine", respectively. These are the elements which produce the coal for collection.

C) Richards Bay Coal Terminal and the Overvaal Tunnel

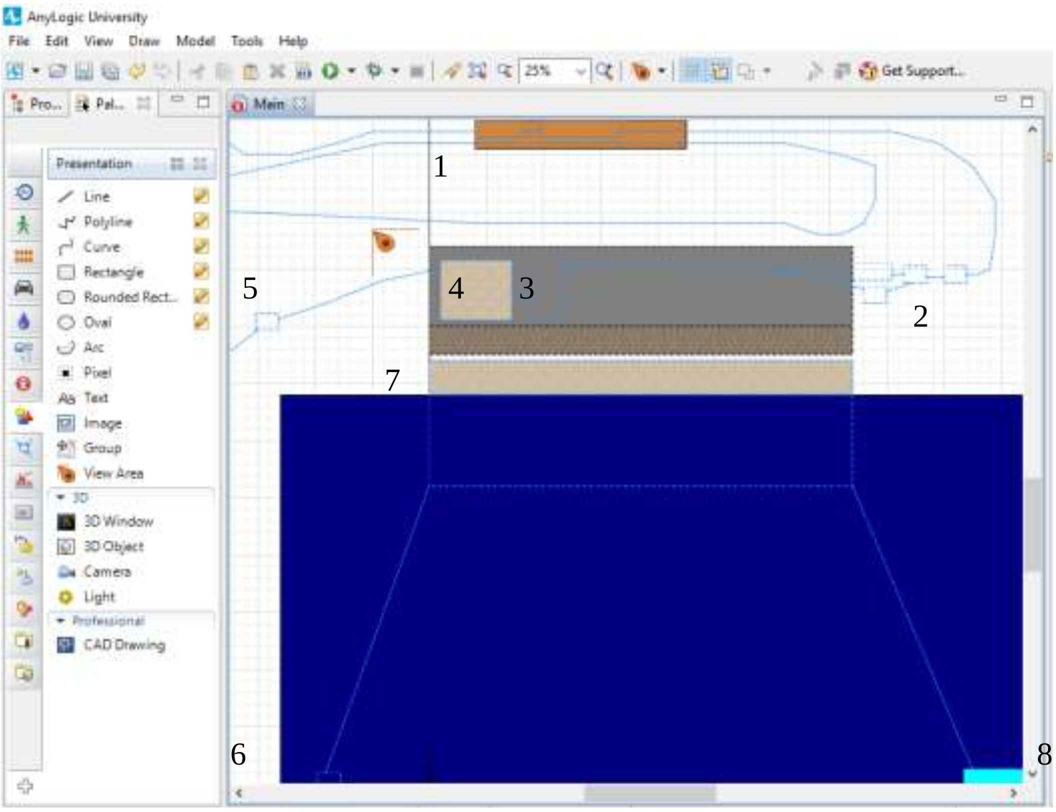


Figure A-7: The Modelled Richards Bay Coal Terminal

Figure A-7 shows the modelled Richards Bay Coal Terminal and the Overvaal tunnel. As before all the nodes, paths and rectangular elements are dragged onto the main diagram from the palette on the left. The Overvaal tunnel and the RBCT are structured as follows:

1. The rectangle representing the Overvaal tunnel is placed at label 1. The nodes are dragged and dropped on the tunnel and represent the queue at the tunnel and the travel time to the tunnel. From the Overvaal tunnel the train then moves to the RBCT.
2. Drag and drop four rectangular nodes and connect them as shown in Figure A-7. From right to left name these nodes as follows: RBCT Decouple Queue, RBCT Decouple, RBCT Queue and the node below is named Decouple Wait.
3. The nodes labelled 3, 4 and 5 are named as follows: RBCT Unload Queue, RBCT Drop Off, and RBCT Recouple.
4. Drag the rectangular node onto the blue rectangle near label 6 and connect the network as follows. Name the nodes at label 6, 7 and 8 "Ship Source", "Berths" and "Sea".

A.3) Model Logic

This subsection explains the model logic in a step by step approach allowing the reader to create a model replica in Anylogic 7. The model logic from the loading of agents to the processes at each route stop is shown.

A. Loading Agents and Resource Pools

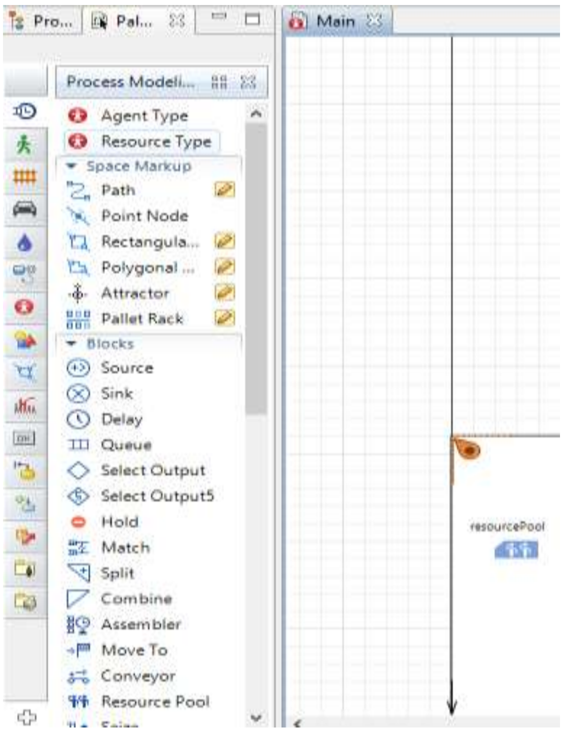


Figure A-8: Loading Agents and Resources

1. Drag and drop an agent type from the process library palette and use the 3d object library  to choose a suitable look for your agent. In this case the agent look is a Gondola car 70.4' and the agent is renamed Train.
2. Drag and drop a resource type from the process library palette. Similarly, use the 3D object library and choose an acceptable look for your resource. In this case the look chosen is a sphere and the resource type is renamed Coal.
3. Drag and drop a Resource Pool icon onto the main diagram. Set the resource type as "portable" and the capacity as 8500. The new resource unit can be selected as Coal and the agents' home location as mine.

B. Train Processes from Ermelo to the Mine

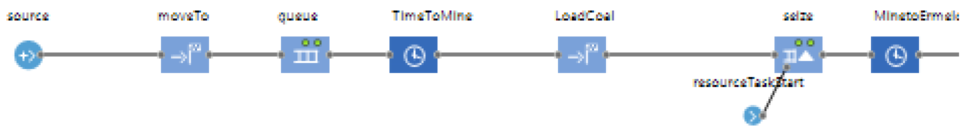


Figure A-9: Logic: Ermelo to Mine

Figure A-9 shows the logic diagram of the trains' movement from Ermelo to the mine. The logic elements are discussed below. All of these elements are found in the Process Library.

1. Source: the source "makes" the trains, each of which is a 100 wagon consist represented by a single wagon, for simplicity. The inter-arrival time for trains is per 60 minutes and the home node is the "Train Source" node.
2. Move To: this logic block moves the train to the queue at the mine. Select "GIS/Node" and set the destination to "Mine Queue".
3. Queue: set the capacity to maximum capacity and the agent location to "Mine Queue".
4. Delay: Set the capacity to 10 and the agents' location to "Mine Queue". Set the delay time to a triangular distribution (6, 7, 8) hours. This delay represents the travel time to the mine and the loading time.
5. Load Coal (Move To): This block moves the train to the mine where it loads the coal. Set the destination to the "Mine Loading" node.

6. Seize: This block orders the train to seize the coal which has been produced at the mine. Set the seize option to units of the same pool and to seize the whole set at once. Set the resource pool option to "Resource Pool". The agent location is Mine Loading. The queue capacity can stay as default at 100.
7. Resource Task Start: this element starts the tasks of resources. Set the unit type to coal and the resource pool to "Resource Pool".
8. Mine to Ermelo: This is another delay block. Set the capacity to maximum and the delay time to a triangular distribution (6, 7, 8) hours. The agent location is Mine Loading.

C. Train Processes from the Mine to Ermelo and onto Overvaal

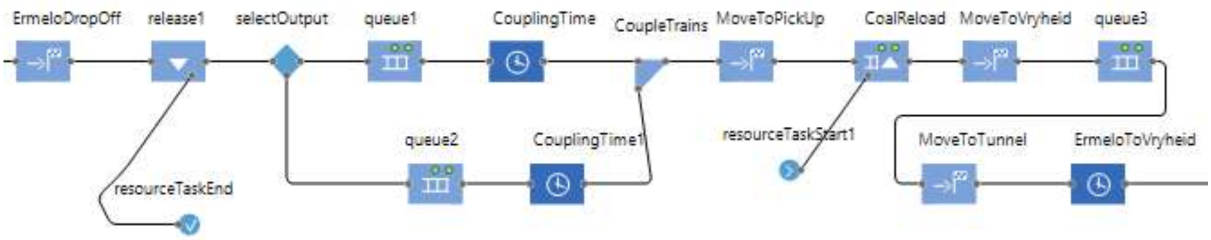


Figure A-10: Logic: Mine to Ermelo to Overvaal

1. Ermelo Drop Off: Here the train is moved to the drop off zone at Ermelo. Set the destination node to Drop off Coal.
2. Release1: Choose the release mechanism to be "All resources seized by given seize block(s)". Choose the seize block as seize and the agent type is train.
3. Resource Task End: This block ends the task of the resources
4. Select Output: This is the start of the coupling process. Trains are split equally amongst the 2 exit nodes of the Select Output block. Select the probability to 0.5 and the agent type to train.
5. Queue 1 and Queue 2: both queues are located at the Couple Ermelo node and their capacities are 100.
6. Coupling Time and CouplingTime1: This is a delay block and the delay time is set to triangular distribution (4, 5, 6) hours. The agent location is set as Couple Ermelo.
7. Couple Trains: This is a combine block in the process library. Set the new agent to "train" and the agent location to "Couple Ermelo".
8. Move to Pickup: Set the agent destination to Pickup Coal.

9. Coal Reload: This is a seize block. Set up this seize block as above, but set the resource pool to "ResourcePool1" and the agent location to the Pickup coal node.
10. Resource Task Start: this starts the resource task once again.
11. Move to Overvaal: Set the agent destination to Overvaal Queue.
12. Queue3: This is the queue before the tunnel at Overvaal. Set the capacity to 100 and the agent location to Overvaal Queue.
13. Move to Tunnel: Set the agent destination to Overvaal.
14. Ermelo to Overvaal: This is the delay block for the travel time and the waiting time at the tunnel. Set the agent location to Overvaal and the delay time to triangular distribution (6, 7, 8) hours.

D. The Decoupling and Unloading Processes at RBCT

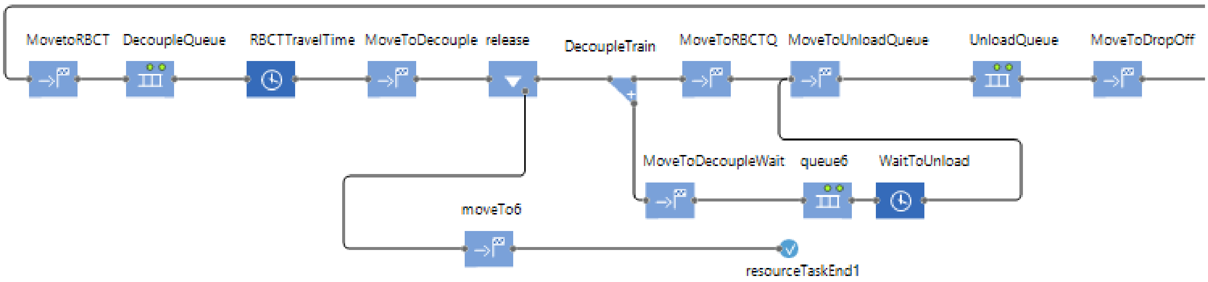


Figure A-11: Logic: RBCT Unloading

1. Move to RBCT: Set the agent destination to RBCT Decouple Q.
2. Decouple Queue: Set the agent location to RBCT Decouple Q. This creates a queue of trains waiting to be decoupled.
3. RBCT Travel Time: Set the delay time to triangular distribution (5, 6, 7) hours. The location of the agent is RBCT Decouple Q.
4. Move to Decouple: Set the agent destination to RBCT Decouple.
5. Release: This releases the resource (Coal). In the logic the coal has to be released before the decoupling can commence. Choose the release mechanism to be " All resources seized by given seize block(s)". Choose the Coal Reload seize block.
6. MoveTo6: Set the destination as the Coal Yard where the ship will pick up the coal once it arrives.
7. ResourceTaskEnd1: This ends the resources task.
8. Decouple Train: This is a split logic block from the process library palette. The split function decouples the train, in principle. Set the number of copies to 1 and the agent to train.

9. Move to Decouple Wait: Set the agent destination to Decouple Wait.
10. Queue6: Set the agent destination to Decouple Wait.
11. Wait To Unload: Set the destination to Decouple Wait and the delay time to "Until Stop Delay () is called". This will cause the train to wait until the other train is finished unloading before it is permitted to enter the port.
12. Move to RBCTQ: Set the destination to RBCT Queue.
13. Move to Unload Queue: Set the agent destination to RBCT Unload Queue.
14. Unload Queue: Set the agent location to RBCT Unload Queue.
15. Move to Drop Off: Set the agent destination to RBCT Drop Off.

E. The Unloading and Coupling Processes and Travelling to Ermelo

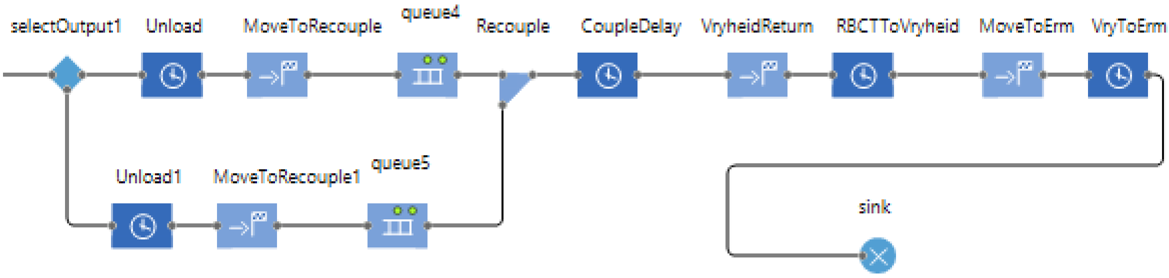


Figure A-12: RBCT Unloading, Coupling and Travelling to Ermelo

1. SelectOutput1: Set probability to 0.5, which means trains, will be split equally amongst the exit ports.
2. Unload and Unload1: Set the agent location to RBCT Drop Off and the delay time to triangular distribution (2, 4, 6) hours.
3. Move to recouple and MoveToRecouple1: Set the agent destination to RBCT Recouple.
4. Queue4 and Queue5: These queues ensure that only 1 train is coupled at a time, as in the real world.
5. Recouple: This is a combine logic block from the process library palette. Set the new agent to Train.
6. Couple Delay: This delay time represents the time it takes to couple the trains. Set the agent location to Delay Couple RBCT and the delay time to triangular distribution (2, 3, 4) hours.
7. Overvaal Return: Set the agent destination as Overvaal Empty
8. RBCT to Overvaal: Set the agent location as Overvaal Empty and the delay time as triangular distribution (5, 6, 7) hours.

9. Move to Ermelo: Set the agent destination to Train End.
10. Overvaal to Ermelo: set the agent location to Train End and the delay time to triangular distribution (9, 10, 11) hours.

F. Logic: Shipping

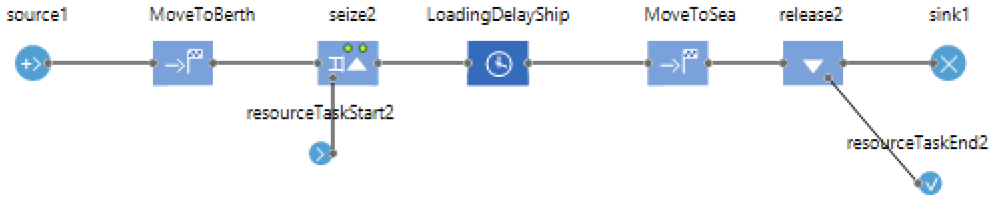


Figure A-13: The Shipping Logic

1. Source1: This is the source of the ships. Set the agent location as Ship Source and the rate of arrival as 2.6 per day.
2. Move to Berth: Set the agent destination as Berth.
3. Sieze2: This block orders the ship to seize the coal which has been produced at the mine and trained to the RBCT. Set the seize option to units of the same pool and to seize the whole set at once. Set the resource pool option to "ResourcePool2". The agent location is Coal Yard. The queue capacity can stay as default at 100.
4. Loading Delay Ship: This is the turnaround time for the ships. Set the agent location to Berth and the delay time to triangular distribution (100, 102, 104) hours.
5. Move to Sea: Set the agent destination to Sea.
6. Release2: this releases the coal as the ship cannot enter the sink whilst still attached to the resource. Choose the release mechanism to be "All resources seized by given seize block(s)". Choose the "Sieze2" block.
7. ResourceTaskEnd2: Ends the task of the coal being transported.
8. Sink1: This removes the ship from the simulation.

A.4) Model Validation and Verification: Current Scenario – 200 Wagon Consist Scenario

Table A-1: Table of Results from the Current State

Block	Type	Agents In	Agents WIP	Agents Out	Ave Queue Length	Actual WIP
Source	Source	-	-	8232		
Move To	Move To	8232	1	8231		1
Queue	Queue	8231	0	8231		0
Time To Mine	Delay	8231	6	8225		6
Load Coal	Move To	8225	0	8225		0
Seize	Seize	8225	0	8225		0
Mine To Ermelo	Delay	8225	7	8218		7
Ermelo Drop Off	Move To	8218	0	8218		0
Release	Release	8218	0	8218		0
select Output	Output	8218	0	8218		0
queue	Queue	4106	0	4106	4,63	0
Coupling Time	Delay	4106	5	4101		5
Queue	Queue	4112	2	4110	32,18	2
Coupling Time	Delay	4110	8	4102		8
Couple Trains	Combine	4102	1	4101		1
Move To Pick Up	Move To	4101	0	4101		0
Coal Reload	Seize	8202	0	8202		0
Resource Task Start	Resource Task Start	8202	0	8202		0
Move To Overvaal	Move To	4101	0	4101		0
Queue	Queue	4101	0	4101		0
Move To Tunnel	Move To	4101	0	4101		0
Ermelo To Overvaal	Delay	4101	4	4097		8
Tunnel Wait	Queue	4097	0	4097		0
Overvaal	Delay	4097	0	4097		0
Move to RBCT	Move To	4097	0	4097		0
Decoupling Queue	Queue	4097	0	4097		0
RBCT Move Time	Delay	4097	5	4092		10
Move To Decouple	Move To	4092	0	4092		0
Release	Release	4092	0	4092		0
Move To	Move To	8184	0	8184		0
End Task	Resource Task End	8184	0	8184		0
Decouple Train	Split	4092	0	4092		0
Move To Decoupling Exit Queue	Move To	4092	0	4092		0
Queue	Queue	4092	0	4092	0,13	0

Wait To Unload	Delay	4092	0	4092		0
Move To RBCT Queue	Move To	4092	0	4092		0
Move To Unload Queue	Move To	8184	0	8184		0
Unload Queue	Queue	8184	0	8184		0
Select Output	Output	8184	0	8184		0
Unload	Delay	3987	2	3985		2
Move To Recouple	Move To	3985	0	3985		0
Queue	Queue	3985	0	3985		0
Unload	Delay	4197	2	4195		2
Move To Recouple	Move To	4195	0	4195		0
Queue4	Queue	4195	209	3986	119,68	209
Recouple	Combine	3986	1	3985		1
Queue	Queue	3985	712	3273	371,71	1424
Couple Delay	Delay	3273	2	3271		4
Overvaal Return	Move To	3271	0	3271		0
RBCT To Overvaal	Delay	3271	3	3268		6
Move To Ermelo	Move To	3268	0	3268		0
Overvaal To Ermelo	Delay	3268	4	3264		8
sink	Sink	3264	0	3264		0
Total				**3264**		**1704**

Table A-1 summarises the original scenario for the original model. The model begins by creating 8232 agents, which is in line with the expected number of arrivals for the given period. The agent then moves through the system as expected (as seen visually). All resources that were seized were released. The model needs to combine two of the 100 wagon trains after releasing the resource the first time and entering the output block. The model successfully does this using the select Output block to the number of agents from 8218 to 4106 and 4112. These agents go along the same physical path and processes; however, logically they are split into two queues and then combine 2 agents using the couple trains logic block. The split is not equally made because of the distribution of the coupling times. Here one arm of the output block may take longer than the other causing the logic to pick the shortest queue.

A screenshot of the model in action can be seen in Figure A-14. The figure shows the agents (trains) being split into two branches going through the same processes and then being combined in by the couple trains block. The numbers represent the transient state of the model. As it can be seen all the agents entering equal the number of agents exiting plus the agents inside the process block.

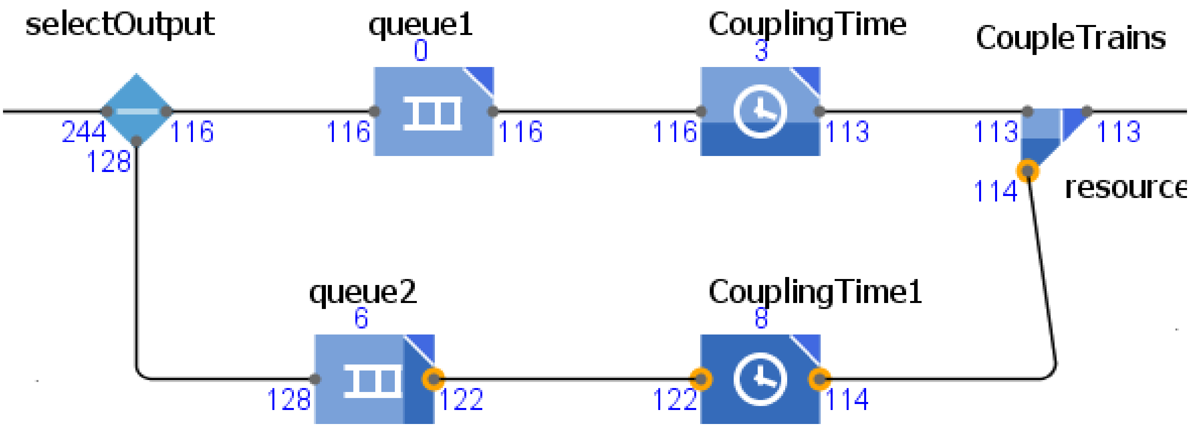


Figure A-14: A Screenshot of the Coupling Logic taken whilst the Simulation is Running (Anylogic Company, 2014)

The coal is then picked up from the "pickup coal" node. This is done using the coal Reload block. The coal can be seen being produced in the pickup Coal node in Figure A-15. The train seizes the coal and continues on route to RBCT through the Overvaal tunnel.

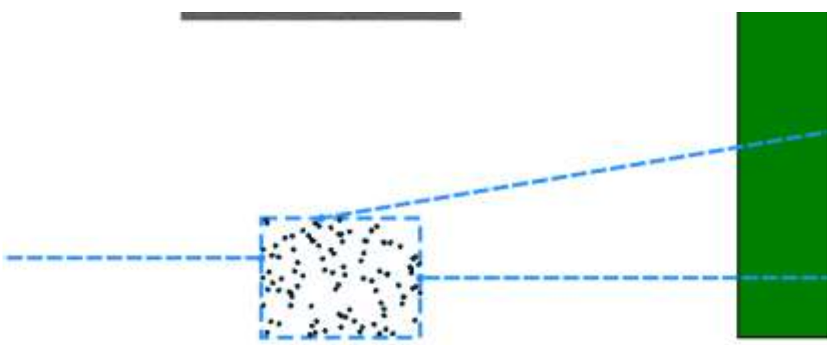


Figure A-15: A screenshot of Coal being produced at the Pickup Coal Node (Anylogic Company, 2014).

Figure A-16 is a screenshot of the model in action showing the logic route of the trains from Ermelo to RBCT. The agents entering each logic block, those already there and those exiting the block are together sum of the entirety of the agents in the system. This means that each agent is accounted for and is acting as predicted.

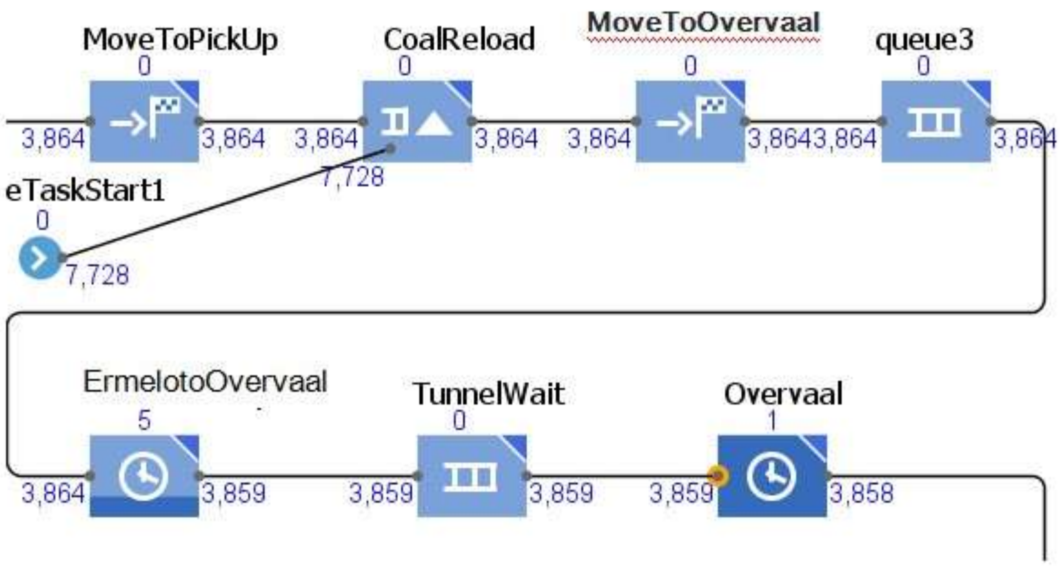


Figure A-16: A Screenshot of the Logic Route to the Richards Bay Coal Terminal (Anylogic Company, 2014).

The train reaches RBCT and begins the process of queuing for decoupling and unloading. The trains are decoupled using the decouple Train block, which is a split type logic block. Before the train can be decoupled the train must release the resource. Once the resource is released the model decouples the train. The model releases 8194 resources (100 wagon trains) from 45092 wagons and moves them to the coal yard node. The flow ends using the resource Task End function.

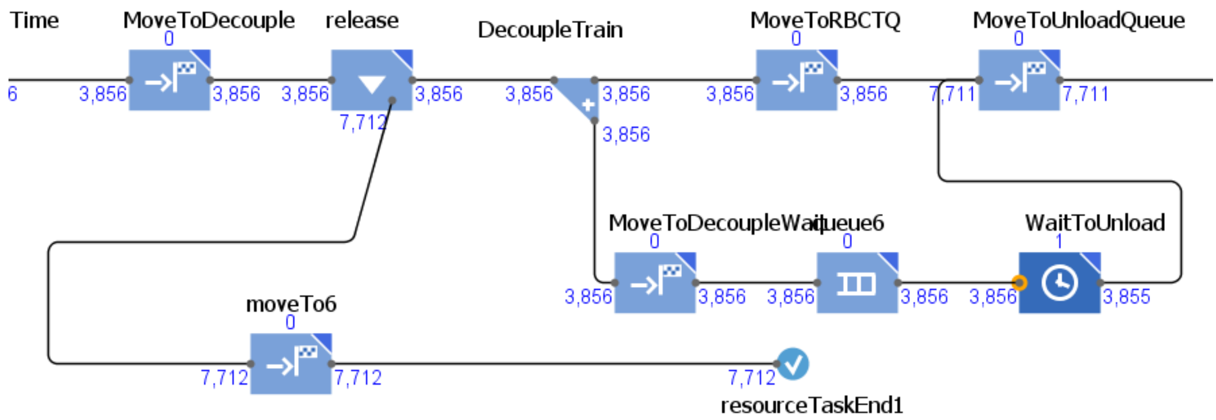


Figure A-17: A Screenshot of the Model Releasing Coal and Decoupling Trains at the Richards Bay Coal Terminal (Anylogic Company, 2014).

The functionality of the release block and the decoupling of the trains can be seen in the screenshot taken in Figure A-17. The decoupling is done using the Decouple Train block. The train is split into two train and these two follow different logic paths which go through similar processes. The only difference is that the train which passes through the bottom output of the decouple Train block goes through a Wait to Unload block. This makes the train wait until there is space in the RBCT to be offloaded.

It can be seen that the model is splitting the trains evenly between the logic blocks and the Wait to Unload block holds 1 train until the 3856th train from the upper branch moves to be unloaded. The model does this because of the capacity available at the decoupling station, which is one.

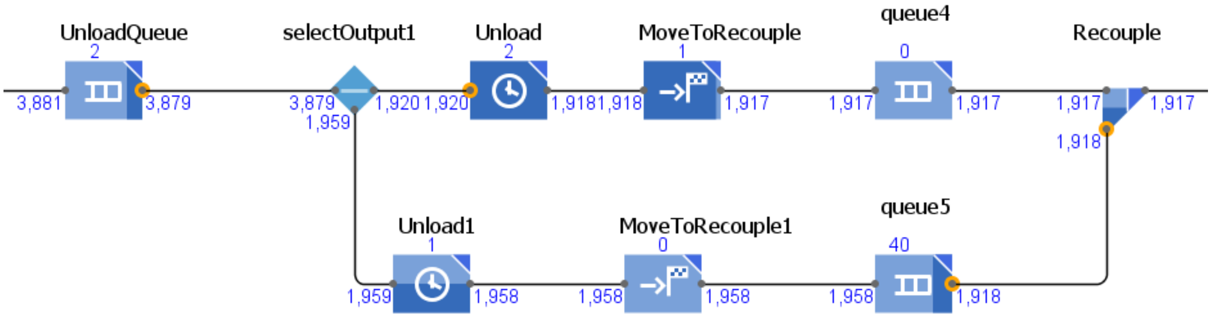


Figure A-18: A Screenshot of the Unloading Process and Recoupling Process at the Richards Bay Coal Terminal

Figure A-18 shows the logic behind the loading and re-coupling at the RBCT. As it can be seen the selectOutput1 block routes the trains along 2 different logic branches which have the same processes. The offloading process is completes after passing through the Unload and Unload1 blocks. The trains then move to a queue for coupling. The combine type block named Recouple then combines the trains. It can be seen that at this exact moment in the simulation that the Recouple bock is waiting for the 1918th train in the top exit branch of the output block to pass through the rail network to the re-coupling node for processing. After the re-coupling process 2 trains are merged into 1 as can be seen by comparing the figures at the entrance and exit of the Recoupling block.

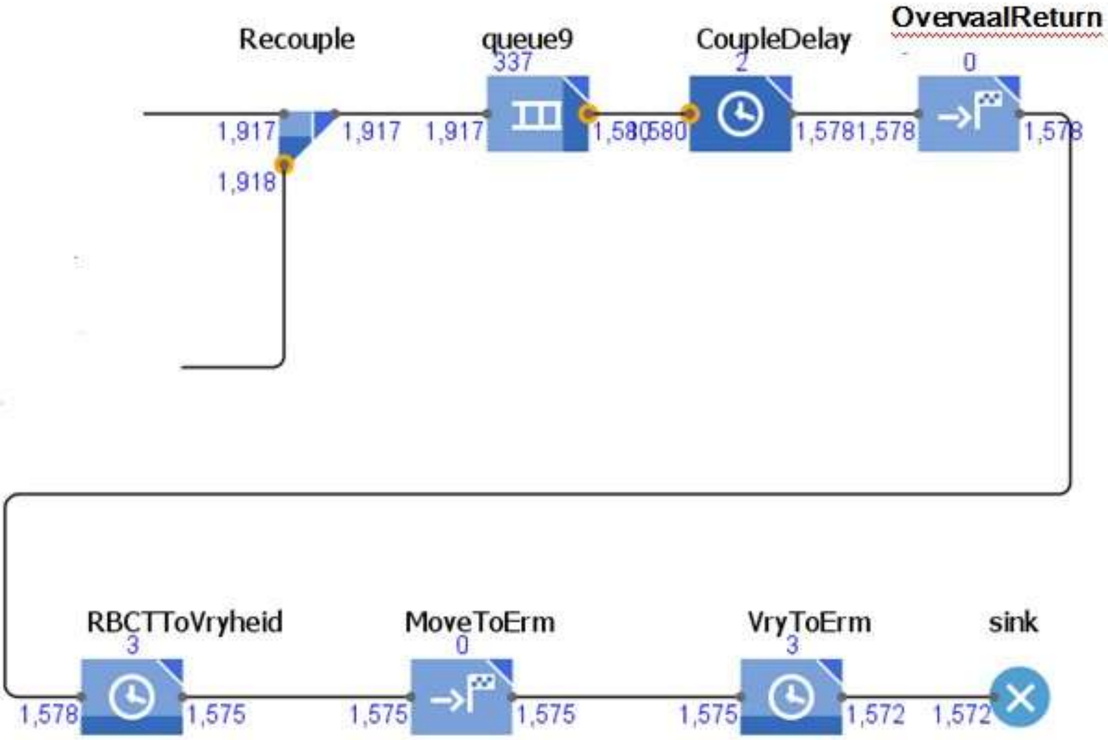


Figure A-19: A Screenshot of the Trains Moving from Richards Bay Coal Terminal to Ermelo Rail Yard (Anylogic Company, 2014).

Figure A-19 shows a screenshot of the model moving the trains back from RBCT to the Ermelo rail yard. In this case it can be seen that all trains have been accounted for throughout the section shown. The couple Delay is the delay from the recoupling process and has a capacity of two, thus showing a queue building up as there are already two trains being processed.

Figure A-20 shows the visual picture of the model at work. The train is seen being drawn from the stock yard and moving through the Ermelo Railyard to the mine siding where it waits to be loaded. The coal is made at the mine and taken to the siding, as shown. Here it is stockpiled and collected by the trains. The coal is then released (as per the logic) before being seized after coupling. This takes zero time. On the return to Ermelo there is seen to be a back log at the coupling station. This is validated by the logic model which shows a queue length of 32. The visual observations and the logic observations concur.

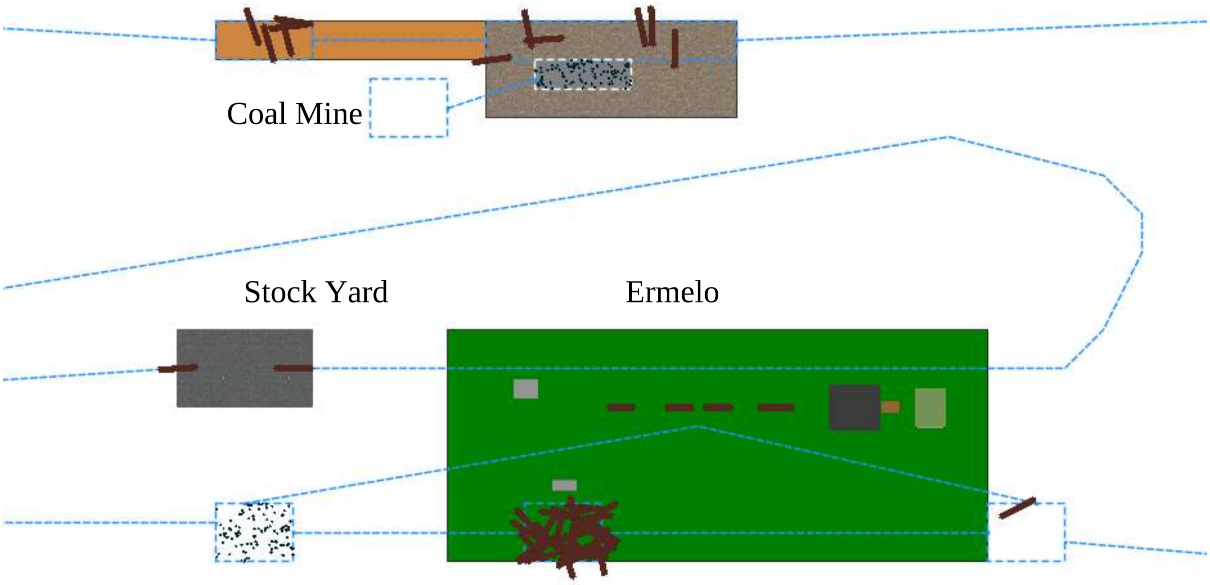


Figure A-20: Visual Observations Current State - Mines and Ermelo

Figure A-21 shows rail network through Overvaal and the RBCT. It is seen that the Overvaal tunnel causes some delays having four trains stuck at the tunnel. The greatest delay is as expected, at the RBCT decoupling station and the off loading bay. These findings concur with the logic results and are further confirmed by the increase in throughput provided by the 100 wagon train scenarios that follow.

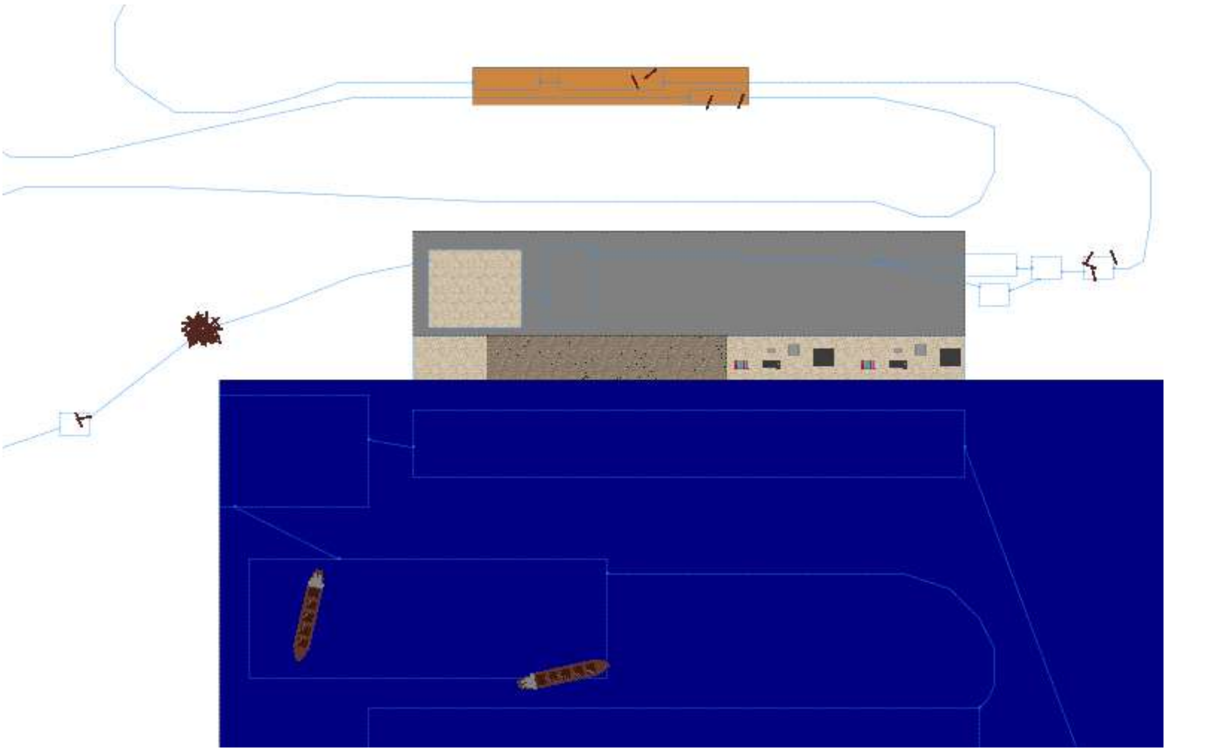


Figure A-21: Visual Observations Current State - Overvaal to RBCT.

A.5) Model Validation and Verification: Scenario A – 200 Wagon Restructure

Table A-2: Table of Results from the 200 Wagon Consist Restructure

Block	Type	Agent In	Agent WIP	Agents Out	Ave Queue Length	Actual WIP
Source	Source	-	-	8232		0
Move To	Move To	8232	1	8231		1
Queue	Queue	8231	0	8231		0
Time To Mine	Delay	8231	5	8226		5
Load Coal	Move To	8226	0	8226		0
Seize	Seize	8226	0	8226		0
Mine To Ermelo	Delay	8226	6	8220		6
Ermelo Drop Off	Move To	8220	0	8220		0
Release	Release	8220	0	8220		0
select Output	Output	8220	0	8220		0
Queue	Queue	4193	158	4035	43,635	158
Coupling Time	Delay	4035	8	4027		8
Queue	Queue	4027	0	4027	1,476	0
Coupling Time	Delay	4027	1	4026		1
Couple Trains	Combine	4027	1	4026		1
Move To Pickup	Move To	4026	0	4026		0
Coal Reload	Seize	8052	0	8052		0
Resource Task Start	Resource Task Start	8052	0	8052		0
Move To	Move To	4026	1	4025		2
Queue	Queue	4025	0	4025	0	0
Move To Tunnel	Move To	4025	0	4025		0
Ermelo To	Delay	4025	5	4020		10
Tunnel Wait	Queue	4020	0	4020	0,103	0
	Delay	4020	0	4020		0
Move to RBCT	Move To	4020	0	4020		0
Decouple Queue	Queue	4020	0	4020	0	0
RBCT Travel Time	Delay	4020	2	4018		4
Move To Decouple	Move To	4018	0	4018		0
Release	Release	8036	0	8036		0
Move To	Move To	8036	0	8036		0
Resource Task End	Resource Task End1	8036	0	8036		0
Decouple Train	Split	4018	0	4018		0
Move To Decouple Wait	Move To	4018	0	4018		0
queue6	Queue	4018	0	4018	0,123	0
Wait To Unload	Delay	4018	1	4017		1

Move To RBCTQ	Move To	4017	0	4017		0
Move To Unload Queue	Move To	8035	0	8035		0
Unload Queue	Queue	8035	0	8035	5,69E-05	0
Select Output	Output	8035	0	8035		0
Unload	Delay	4077	1	4076		1
Move To Recouple	Move To	4076	0	4076		0
Queue	Queue	4076	117	3959	4,81E+01	117
Unload	Delay	3958	0	3958		0
Move To Recouple	Move To	3958	0	3958		0
Queue	Queue	3958	0	3958	0,329	0
Recouple	Combine	3959	1	3958		1
Queue	Queue	3958	1911	2047	972,789	3822
Couple Delay	Delay	2047	2	2045		4
Return	Move To	2045	0	2045		0
RBCT To	Delay	2045	1	2044		2
Move To Ermelo	Move To	2044	0	2044		0
To Ermelo	Delay	2044	2	2042		4
Sink	Sink	2042	0	2042		0
Total				**4084**		**4148**

The 200 wagon consist restructure scenario is made by changing the cycle times according at the Ermelo rail yard from 12 hours to 1 hour and the unloading time at the port from 7 hours to 12 hours. The effects of the different scenarios are seen when comparing Table A-1 and Table A-2.

It can be seen that both set of results are very similar in nature until the Queue (this is the queue trains wait in to be recoupled after offloading at RBCT) logic block. This is due to the change in cycle time for decoupling and coupling at the Richards Bay Coal Terminal. This is because there is a change from 7 hours to 12 hours between the 2 scenarios. Logically the average queue length of Queue in the 200 wagon consist restructure should be the longest, which it is. Similarly, Queue2 has the second highest WIP and the second highest average queue length. These points are valid in both the 200 wagon consist scenarios.

The source creates all the entities in both cases and all entities are accounted for. As can be seen there are 2 columns for WIP, the initial value and the actual value. As the entity is combined in certain places around the network (into 200 wagon consists) and the source is making 100 wagon consists the process block reads each entity as singular.

This means that when the consist is 200 wagons it must be counted as two entities instead of one. The disposed entities (entered the sink) plus the WIP must add up to the total entities created by the source. In both cases these values add up to 8232, which is the total amount of entities created.

A.6) Model Validation and Verification: Scenario B– 100 Wagon Trains

Table A-3: Table of Results for the 100 Wagon Consist Scenario

Block	Type	Agents In	Agents WIP	Agents Out	Average queue length
Source	Source	-	-	8232	
Move To	Move To	8232	1	8231	
Queue	Queue	8231	0	8231	
Time To Mine	Delay	8231	7	8224	
Load Coal	Move To	8224	0	8224	
Seize	Seize	8224	0	8224	
Move To Ermelo	Delay	8224	0	8224	
Ermelo Queue	Queue	8224	0	8224	
Mine To Ermelo	Delay	8224	6	8218	
Move To	Move To	8218	0	8218	
Move To Tunnel	Move To	8218	0	8218	
Queue	Queue	8218	0	8218	0
Ermelo To	Delay	8218	7	8211	
Queue	Queue	8211	3	8208	1,901
	Delay	8208	1	8207	
Move to RBCT	Move To	8207	0	8207	
Decouple Queue	Queue	8207	0	8207	0
RBCT Travel Time	Delay	8207	5	8202	
Move To Unload Queue	Move To	8202	0	8202	
Unload Queue	Queue	8202	0	8202	
Unload	Delay	8202	2	8200	
Release	Release	8200	0	8200	
Move To	Move To	8200	0	8200	
Resource Task End	Resource Task End	8200	0	8200	
Return	Move To	8200	0	8200	
RBCT To	Delay	8200	7	8193	
Move To Ermelo	Move To	8193	0	8193	
To Ermelo	Delay	8193	10	8183	
Sink	Sink	8183	0	8183	

As can be seen by the results summarised in Table A-3 all agents produced are accounted for in the model. The total number of agents produced is 8232, which is the same as the number produced in all scenarios. The model then had 49 WIP agents when the model is stopped producing 8183 finished products or services.

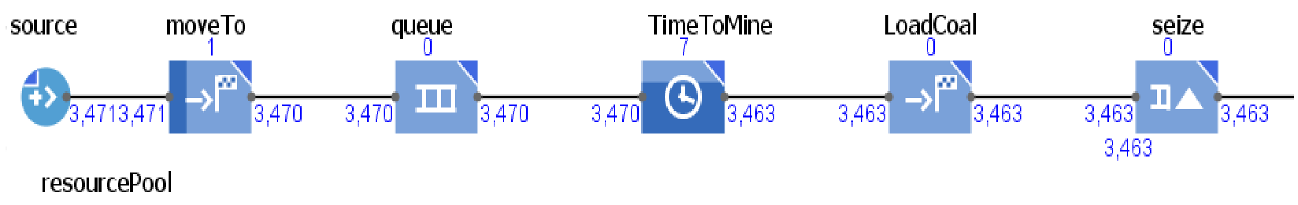


Figure A-22: A Screenshot of the seize procedure of the 100 Wagon Consist Scenario (Anylogic Company, 2014).

The seizing process at the mine is shown in Figure A-22. As it can be seen the number of seized resources equals the number of trains passing through the seize logic block. The number on the bottom of the seize block is the number of resources that have been seized by the trains. Before this we can see that the number produced for is equal to the number at the exit of the seize block plus the WIP in the system of 8.

Figure A-23: A Screenshot of the Movement to Ermelo and on to (Anylogic Company, 2014).

The model shows the movement of the trains through Ermelo when the trains are switched between AC and DC, as required. The agents in the model are once again accounted for in all processes.

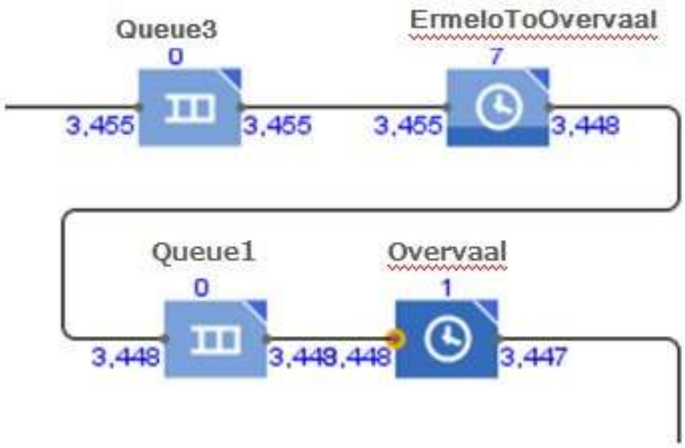


Figure A-24: A Screenshot of the Tunnel (Anylogic Company, 2014).

Figure A-24 shows the processes at the tunnel. The tunnel has a capacity of 1 and it is seen by the highlighted input or entrance to the block that the capacity is a maximum so the other trains will have to wait for the train to pass through the tunnel before they can continue. The input is 3448 and the output is 3447 from the logic block.

Figure A-25: Screenshot of the Train Moving to the Richards Bay Coal Terminal (Anylogic Company, 2014).

In comparison with the scenarios containing 200 wagon consists Figure A-25 shows difference in logic needed for a 100 wagon consist. The process is much simpler and the model logic shows the train moving to the decoupling queue, even through the train does not need to be decoupled. This means the train is following the predetermined track to the RBCT. The train experiences a travel time delay for the time taken to arrive in Richards Bay from the tunnel. Once again all the agents are accounted for in the model.

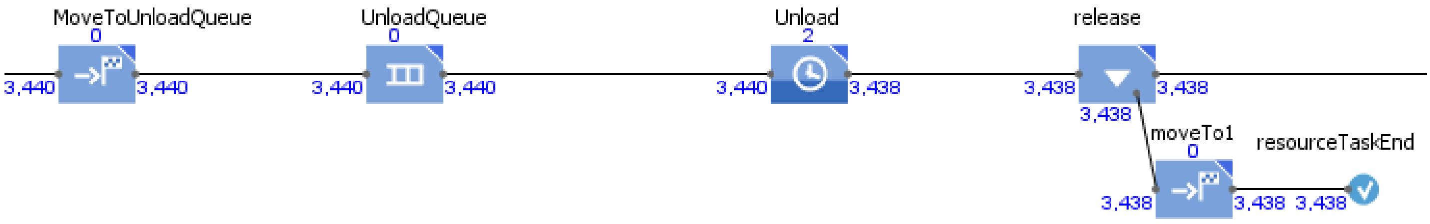


Figure A-26: Screenshot of the Offloading Procedure at the Richards Bay Coal Terminal (Anylogic Company, 2014).

Figure A-26 shows the offloading procedure at RBCT. The train goes through the queues at RBCT and reaches the Unload block. Here the train experiences a delay symbolizing the unloading of the coal. The releasing of the coal is done at the release block. It can be seen that 3438 trains have entered the block and 3438 have left the block with 3438 resources being release at this point. All agents are accounted for in this section.

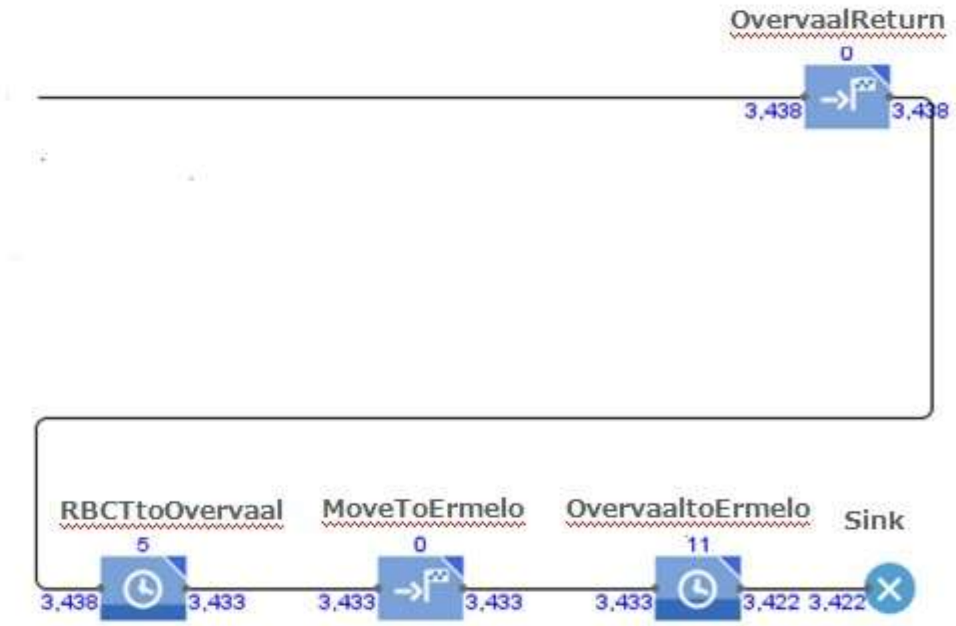


Figure A-27: Screenshot of the Trains Returning to Ermelo form Richards Bay Coal Terminal (Anylogic Company, 2014).

The final logic route that the train takes is shown in Figure A-27. It is seen that all agents are once again accounted for with the travel time to and Ermelo having queues growing as the number of trains' increases. The number of trains coming through is 3438 and the number exiting the system after completion is 3422 with 16 WIP.

A.7) Model Validation and Verification: Scenario C – Removal of Ermelo as a Hub, 100 Wagon Trains and Upgrade of the Tunnel

Table A-4: Table of Summarised Results for the 100 Wagon Consist with no Ermelo Hub or

Block:	Type	Agents In	Agents WIP	Agents Out
Source	Source	8232	0	8232
move To	Move To	8232	1	8231
queue	Queue	8231	0	8231
Time To Mine	Delay	8231	5	8226
Load Coal	Move To	8226	0	8226
seize	Seize	8226	0	8226
Move To Ermelo	Move To	8226	0	8226
Ermelo Queue	Queue	8226	0	8226
Mine To Ermelo	Delay	8226	6	8220
Move To Tunnel	Move To	8220	0	8220
Ermelo To	Delay	8220	6	8214
Move to RBCT	Move To	8214	0	8214
Decouple Queue	Queue	8214	0	8214
RBCT Travel Time	Delay	8214	6	8208
Move To Unload Queue	Move To	8208	0	8208
Unload Queue	Queue	8208	0	8208
Unload	Delay	8208	4	8204
Release	Release	8204	0	8204
MoveTo1	Move To	8204	0	8204
Return	Move To	8204	0	8204
RBCT To	Delay	8204	4	8200
Move To Ermelo	Move To	8200	0	8200
To Ermelo	Delay	8200	11	8189
Sink	Sink	8189	0	8189

The results summarized in Table A-4 are for a 100 wagon consist that can travel direct to the RBCT from the mine and the tunnel is upgraded to a two way. These changes are made and it is seen that there is a slight improvement overall. The results are as expected with WIP forming at the travel time delays. The queuing time is reduced completely showing an increase in the overall capacity. The number of trains produced is 8232 and the number of services completed is 8189 with a WIP of 43. All agents are accounted for in the model and the model behaves as predicted. The tunnel section has been removed allowing for greater capacity, albeit the assumption that the travel time between the mine and is made. In the real world the train may well be able to move to the port quicker if it is geographically closer to RBCT.

A.8) Model Validation and Verification: Shipping

The shipping logic flow is the same for all scenarios. The results of the shipping element are shown in Table A-5.

Table A-5: Table of Shipping Results

Block:	Type	Agents In	Agents WIP	Agents Out
source1	Source	920	0	920
Idle Time	Delay	920	4	916
Move To Anchorage	Move To	916	0	916
queue7	Queue	916	0	916
Anchorage Wait	Delay	916	7	909
Move To Berth	Move To	909	0	909
queue8	Queue	909	0	909
Loading Delay Ship	Delay	909	0	909
seize2	Seize	9090	0	9090
resourceTaskStart2	Resource Task Start	909	0	909
Move To Sea	Move To	909	0	909
release2	Release	909	0	909
resourceTaskEnd2	Resource Task End	9090	0	9090
sink1	Sink	909	0	909

In all scenarios the shipping logic works as predicted and produces similar results. Changes are only observed due to the random number generation done by the Anylogic program. The initial stage of the shipping process is shown in Figure A-28.

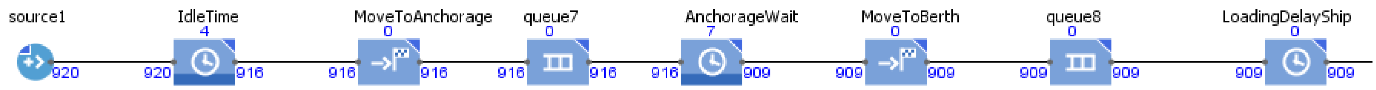


Figure A-28: Screenshot of the Idle and Anchorage Stages of the Shipping Process

The model produces 920 ships which sit idle for a set period before moving into anchorage closer to the port. The visual representation in Figure A-29 shows the ships sitting idle (4), the ships sitting in anchorage (7) and the coal sitting in the coal yard waiting for collection. The total of all WIP is in the idle and anchorage state and sums to 11. A seen, there are no ships loading at this current point in the model.

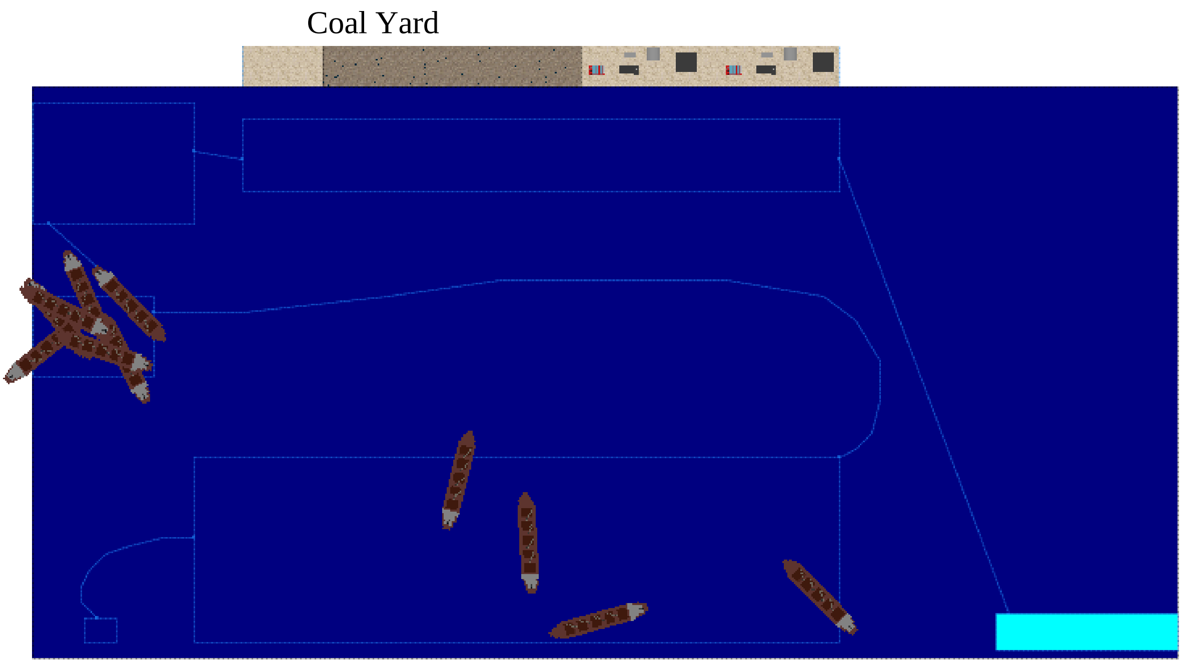


Figure A-29: Visual Reprentation fo the Shipping Logic

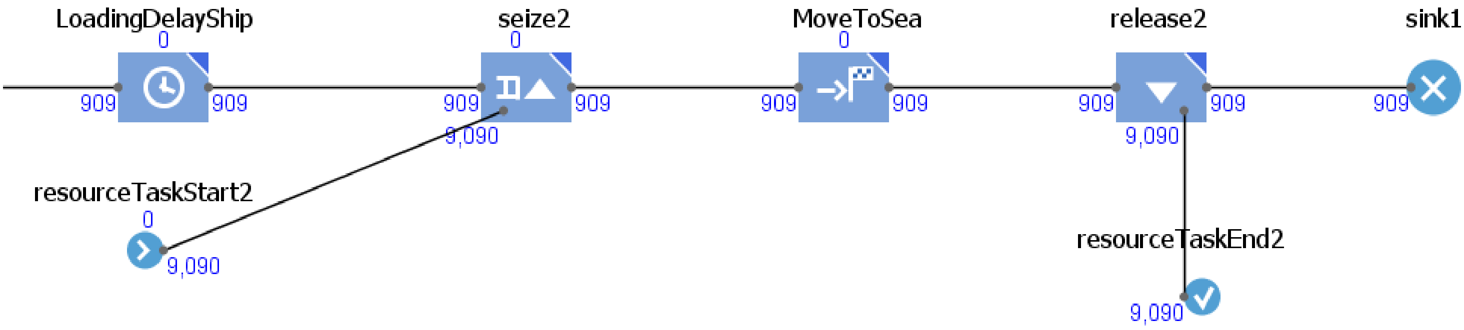


Figure A-30: The Loading Element of the Shipping Process

Figure A-30 shows the loading and departure elements of the shipping process. The seizing of the resources shows the seizing of 9090 resources. This is because there are approximately 10 train loads of coal on each ship. Thus, for 909 ships to pass through the system 9090 resources of coal are seized. The ship then moves out to sea and before the shipping process can be concluded the resource is released. This is purely a modelling requirement and has no affect on the conceptual integrity of the model as once the coal is loading and the ship departs, the involvement of Transnet is completed, thus the ship is disposed. As seen, all agents and resources are accounted for, 909 ships are disposed with 11 WIP and 920 produced. All 9090 resources that are seized are also released before the disposal of the ship.