FEASIBILITY STUDY OF THE CURRENT RAW MATERIAL SUPPLY SYSTEM IF A NEW FURNACE IS BUILT AT WEST PLANT

by

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I am capable of everything through Him that gives me power.

Summary

BHP Billiton, the worlds largest mining company, is planning on building a new furnace, M14, at one of their plants at Metalloys. The M14 project represents a significant investment to BHP Billiton and to ensure that the project is a success feasibility studies to determine the effect of the new furnace on other operations at Metalloys was mandated. One of the functional areas that needed to be assessed was the Raw Material Transport System (RMTS).

The RMTS is a complex system that needs to accommodate the new demand of M14 as well as continue to supply the current furnaces with an adequate supply of raw material. Guidelines from literature indicated that simulation can be used as a competent tool to help solve the problem. Different methodologies for solving the problem using different perspectives were analyzed using literature from the chosen simulation software, AnyLogic®.

The model proved to be relatively accurate to the real world system, with discrepancies in the outputs experienced because of the stochastic and human elements inherent to operating the system. After analysis of 30 outputs from the current scenario model versus the M14 scenario model it was concluded that the average material availability at all the plants will decrease by an average of 13% while the spread of the distribution will increase by an average of 5,8%.

A proposed modification of the stockyard layout was also tested using the simulation model. It was tested on the current and M14 scenario in order to determine and better explain changes stockpile locations will have on the system.

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List of Acronyms

AB	Agent Based
CV	Conveyor
DE	Discrete Event
MMD	Materials Management Department
MAD	Mean Average Deviation
RMTS	Raw Material Transport System
SCADA	Systems Controller and Data Acquisition
SD	System Dynamic
TH	Transfer House

Chapter 1

Introduction

1.1 Background

BHP Billiton is the world's largest mining company and consists of various customer sector groups (ABC News, 2010). Metalloys is a Ferro-Alloy smelter situated near Meyerton and is part of the Samancor corporation, a sector group within BHP Billiton. Samancor Manganese Pty Ltd is partly owned by Anglo American with BHP Billiton holding 60% of its shares. According to BHP Billiton (2010), Metalloys is one of the largest producers of manganese alloys in the world. Metalloys' end products are high quality manganese alloys that are used in carbon steel and some stainless steel manufacturing. All furnaces at Metalloys are submerged arch furnaces and are adaptable to smelt various types of manganese alloys. Some of the furnaces can be changed to produce either silicon manganese or ferromanganese depending on market conditions. Metalloys also has a furnace that produces low carbon ferromanganese with the help of an oxygen-blown converter. A constant and stable supply of raw materials is of vital importance to Metalloy's furnace operations. Many of the required raw materials for these furnaces are supplied by sector groups from within BHP Billiton, with the exceptions of coke and quartzite (BHP Billiton, 2010).

As an ever expanding company, BHP Billiton plans to expand its current capacity of furnace operations at one of the Metalloys plants and needs to determine the feasibility of raw material supply to the proposed and present furnaces. A new furnace which will produce high carbon ferromanganese, M14 at West Plant, is in the process of being commissioned. Metalloys approached a consulting company, Hatch, in May 2009 to assess their current raw material system. The proposal to have Hatch assess the raw material supply was not approved, as an economic recession forced Metalloys to shutdown some of the furnace operations. They resumed the project later in 2010.

This project was initiated as part of a feasibility study on the commissioning of the new furnace.

1.2 Overview of current system

Currently the Raw Material Transport System (RMTS) is controlled and managed by the Materials Management Department (MMD) at Metalloys. Their responsibilities start with the planning, procurement and delivery of raw materials to Metalloys and ends with the delivery of material to the respective plants' raw material silos. After procurement and delivery the material is put into the RMTS using a tippler. Figure 1.1 provides a simplified schematic outline of the RMTS.

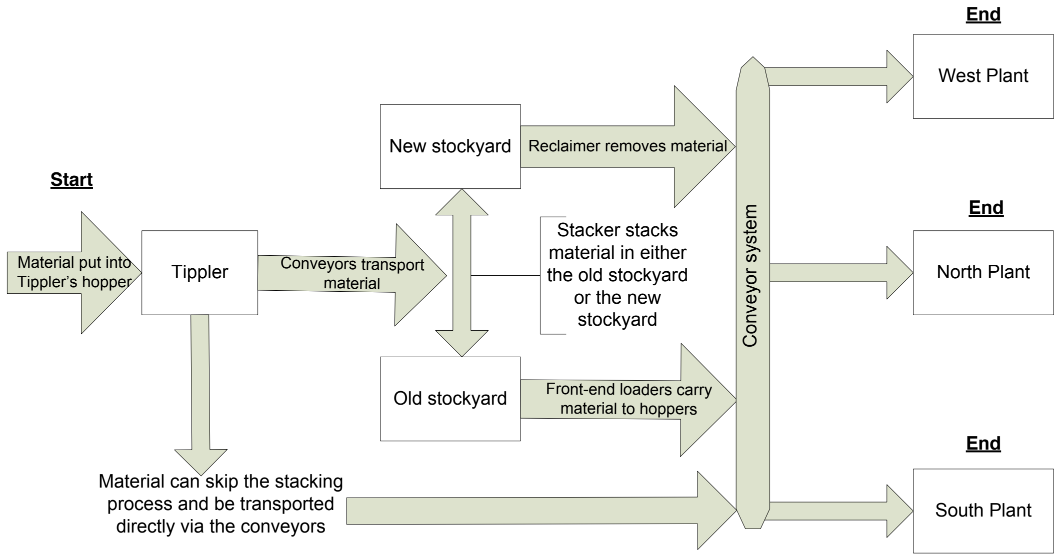

Figure 1.1: Schematic overview of the RMTS

Raw materials are delivered to Metalloys by either trains or trucks. By using the tippler, rail wagons are overturned to off-load material into the tippler hopper while trucks off-load their own material into the hopper. The tippler forms the start of the RMTS as illustrated in Figure 1.1. After materials have entered through the tippler it can either go directly to the various plants or be transported to the stockyards. To go directly to the plants, the conveyors route the material around the stacking process.

Materials that are transported to the stock yards are stacked into either the old stock yard or the new stockyard by a machine called a stacker. Material is kept in either one of the stockyards until needed by a plant. Material in the new stockyard can be retrieved by a reclaimer, which loads the material onto a conveyor. When material is stored in the old stock yard it is out of the reclaimer's reach and must be moved by front-end loaders. These front-end loaders carry the material to designated hoppers that channel material to a conveyor.

Once the material enters the different plant silos MMD's responsibility ends. Each plant has its own controlled system of transporting the different material to their respective furnaces. A layout of the system can be viewed in Appendix A, Figure A.1.

1.3 Reasons for feasibility study

The building of the new furnace at West Plant will require a vast amount of resources, time and money, hence management must determine all the repercussions the proposed furnace will have on the system. Specifically the effects of the new furnace on the auxiliary systems need to be determined before management can approve the building of the furnace. This project investigates the effects on the raw material supply if the proposed furnace is built and forms part of other feasibility studies that has been mandated as part of the whole M14 feasibility project. The main motivation of this feasibility study is to quantify the potential risks in raw material supply. This will allow management to identify potential improvements and required modifications to the system before M14 is built.

The project is capital intensive and will amount to a projected total cost of R700 million and will take approximately 18 months to complete. The new furnace will be a 45 MVA furnace and will need a separate raw material silo system. The proposed furnace is to be a replica of the one currently in use at West Plant and it is assumed that the new system will be identical to the current furnace system in every way. The introduction of the new furnace may cause a shortage of raw materials supplied to the different plants at Metalloys.

Fluctuations in raw material supply have the following effects on plants and the RMTS:

- Reduction of load on furnaces leading to higher power usage. This is due to the fact that furnaces are not allowed to tap molten metal if the material inside the furnace is not above a certain level.
- Planned maintenance on RMTS can be disrupted due to unscheduled usage of the system to accommodate new demand. The lack of planned maintenance can lead to safety risks.
- Overloading of the RMTS occurs if the system is used for long periods of time to sustain supply to various plants.
- A decrease in production takes place, leading to a loss of profits.

Many of these effects have cost implications and can seriously inhibit the future production at Metalloys.

Management at Metalloys needs to be aware of the effects of the increased raw material demand in order to make informed decisions. Without proper feasibility studies the effects could result in a loss in profit and/or safety risks. Before time and money is spent and the new furnace is commissioned, management has to be sure that the system is able to support it.

1.3.1 Research question

This study aims to assess the capacity and capability of the RMTS to effectively and sufficiently supply all furnaces including the proposed M14 furnace. This study will also give a quantative description of potential risks that may occur should M14 be built. In essence, the feasibility study needs to answer the following:

> If M14 is built, what will the effect be on the Raw Material Transport System (RMTS)?

A secondary objective for this project is to assess the potential improvement of a different stockyard layout that may enhance the supply as well as improve the efficiency and/or effectiveness of the RMTS. The development and implementation of other alternatives falls outside the scope of this project. This study will also provide guidelines for future work, so that future designs and implementation plans can easily be set in motion.

1.4 Methodology and deliverables

The main deliverable of this project is a simulation model to assess the impact of the new furnace on the RMTS. It will consist of a model simulating the current system and another model simulating the proposed system. Both models can also be used in future projects to evaluate new scenarios or determine statistics of various processes.

The solution methodology steps used in this project are adaptations of the theories by Kelton et al. (2007) and Carson (2005) and are discussed here.

System and Simulation Specification

This phase incorporates the sourcing of information to define the system. The quality of the information gathered greatly determines the accuracy of the model's results. It is necessary for the modeller to have an extensive knowledge of the system workings. Insufficient information could render the model inaccurate and ultimately useless. However, as it is impossible to gather complete information on the system, certain assumptions have been made during the modelling thereof. The RMTS processes have been simplified to produce the desired level of detail.

This phase also includes model boundaries and outputs of the model to be measured as well as constraints and variables that will be allowed to be changed during the additional experimentation phase.

Model Formulation and Construction

Formulating the model consists of the model design and contains a conceptual model which defines basic entities, resources, activities and basic processes. The modelling effort is partitioned into phases with a blend of top-down and bottom-up approaches, with each model building phase being verified by MMD personnel.

Verification and Validation

This phase of the solution methodology is of critical importance as the model needs to be an accurate representation of the current system before experimentation can start. The model must first be verified by comparing it to the conceptual model constructed in the model formulation phase. The model must then be validated by comparing the model outputs to the real world outputs. This will ensure that the model is refined enough to correctly evaluate the proposed scenario with an acceptable validity.

Experimentation and Analysis

Once the model is verified and validated, the experimentation phase commences and modifications to the system are made. For this specific problem the author starts by modelling an extra 45MVA furnace identical to the one currently at West Plant (M12).

Presenting and Disseminating the Model

In this phase the findings of the experimentation phase are presented and a conclusion is drawn with regards to the research question. For this specific problem, limitations, exclusions and possible extensions are discussed to determine the future prospects for which this model can be used or modified. The RMTS is a dynamic system and is always prone to change. As a result this model can be used in the future to help solve other problems or analyze other proposed changes. The model can also be modified to help with operational planning and scheduling.

All of the steps listed above were under constant review and reassessment to ensure early fault finding in the logic and modelling approach and to also ensure success (Grabau and Sadowski, 1999).

1.5 Document overview

Chapter 2 analyses literature regarding the use of simulation in similar problems, the problem confronted in this feasibility study is classified and key simulation viewpoints are discussed. The model building methodology steps for creating the feasibility study model are examined in Chapter 3. The succeeding model testing steps, consisting of verification and validation, are discussed in Chapter 4. Chapter 5 provides conclusions and future work to be done.

Chapter 2

Literature Review

2.1 Use of simulation for problem solving

Simulation as a problem solving technique has many types of problems to which it can be applied successfully (Smith, 2003). The reasons why this is the chosen problem solving technique for this project is discussed by using the guidelines set by Carson (2005). The analogies between systems where simulation can effectively be used and the Raw Material Transport System (RMTS), will be drawn to conclude why simulation is chosen as problem solving tool. Six of the seven criterion stated by Carson (2005) apply to the current problem.

- When no simple analytical model is available or can be constructed to accurately analyze the system, simulation is a suitable tool. One can argue that an analytical model can be constructed to represent the system, but because the RMTS is a relatively complex system it will not be simple nor will it be easy to construct the model. Usually it is difficult to apply classical mathematical solution methods to such complex systems. According to Chrystall et al. (1990), simulation has become the widely acceptable, effective and powerful alternative solution methodology to that of analytical modelling. Smith (2003) reasons that because material handling system design problems have complex interactions and it is difficult to use analytical modelling, simulation is an appropriate tool. Hatch consulting engineers defines the RMTS in their proposal for raw material supply analysis as definitely a complex system requiring significant planning in design and operation.

- Simulation is appropriate if the system in the real world is not out of control and shows strong signs of recurring events. The processes performed by the RMTS are repeated on a regular basis, as the demand of the various plants are fairly constant. Supplying different plants is a stochastic process, although the events thereof are relatively similar differing only in the amount and type of material transported each time.

- Simulation is suitable if the system has intricate interdependencies between activities and other system components. As is the case with the RMTS, these interdependencies then result in complexity, making it difficult to quantify the changes in outcome if the system is modified. In the RMTS the supply to one plant is dependent on the availability of the conveyor system, which in turn is dependent on the supply to another plant. The supply to the different plants depends on the individual demands which fluctuate randomly as it is dependent on other processes at each plant. With the RMTS the sheer size of the system makes it even more unpredictable.

- When management is planning on changing a current system's layout, operating rules, designing a new system or working with a different demand, simulation works well. When the new furnace is built there will be a new demand for raw materials on the system. The new furnace will also change the operating procedure because of the new demand. Smith (2003) also references many works that uses simulation to aid the solving of manufacturing system design problems. In his treatise about the use of simulation he notes that it is the complexity of systems that makes simulation a well suited design and analysis tool.
- When changes to the system require a large investment and there is a probability of loss of capital, simulation can be used to quantify risks. The costs of building the new furnace is an estimated R700 million and could amount to millions more should the changes on the system affect the productivity of the current furnaces negatively. This feasibility study needs to quantify the potential risks and impact on the RMTS.
- Simulation is a tool that can visually, through animation and statistics, show the effect of changes in the system to people for a common understanding. This is very valuable when presenting and disseminating the model and results to management. Although it is not the primary objective of the project a visually pleasing project embellished with animation and statistics results in a better understanding of the project by everyone involved.

The consulting engineers from Hatch describe in their proposal to asses the raw materials system at Metalloys the rationale of using a dynamic simulation model. They refer to simulation as being the favourable methodology used when assessing complex systems, because it encapsulates process interactions, process variation, stochastic processes, logistical parameters and allows for a realistic assessment.

2.2 Methodologies for similar problems

2.2.1 Selection of simulation software

The software available to the author is either Rockwell Automation's ARENA® simulation software or XJ Technologies' AnyLogic®. AnyLogic® has a more extensive object library than Arena® and is Java based which enables a wider range of code use. Models created in AnyLogic® can be exported as a working Java based model that can be run in a web browser (AnyLogic, 2010c). This functionality allows for a working model to be handed over to management for analysis without them having to buy a license for the program.

The model can then be used in future projects or in presentations concerning the RMTS. To accurately represent the RMTS one needs to combine the different modelling approaches. To do this in a single modelling approach based software like ARENA®, always requires workarounds[1]. AnyLogic® is well suited at modelling hybrid systems because of its multi-paradigm platform (Borshchev et al., 2002). This allows for changing the levels of abstraction and viewpoints for different parts of the model.

It was decided to use AnyLogic® because it can incorporate all three major modelling approaches in one platform and creates a stand alone model.

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[1] Using modelling software for other purposes than what they were made for to overcome limitations

2.2.2 Defining the problem

Problem classification

This feasibility study can be broken down as a system design problem because it involves a long term strategic decision and not short term operational decisions (Smith, 2003). A more specific classification for the problem is a Material Handling System Design Problem. Future work with the model might be used to help Metalloys in creating schedules for raw material transportation and thus help with operational planning decisions more frequently. According to Smith (2003) this will classify the type of problem as a system operation problem, with characteristics different from a system design problem.

Simulation Viewpoints

In the world of dynamic simulation modelling there are three major perspectives of the modelling process. According to AnyLogic (2010d) these perspectives are: System Dynamic (SD), Process-centric or Discrete Event (DE) and Agent Based (AB). These three viewpoints can be divided into two major categories: continuous aggregated and discrete disaggregated. SD fits into the continuous category while Process-centric and AB fits into the discrete disaggregated category. DE is the term commonly used to describe what XJ Technologies refer to as a Process-centric simulation. The reason why they define Process-centric as a view on its own is because DE simulation is actually a broader term that incorporates Process-centric and AB simulation modelling. In this report the term Process-centric will be used to describe the traditional DE simulation perspective.

Figure 2.1 illustrates how the same system can be viewed from the different perspectives of simulation modelling.

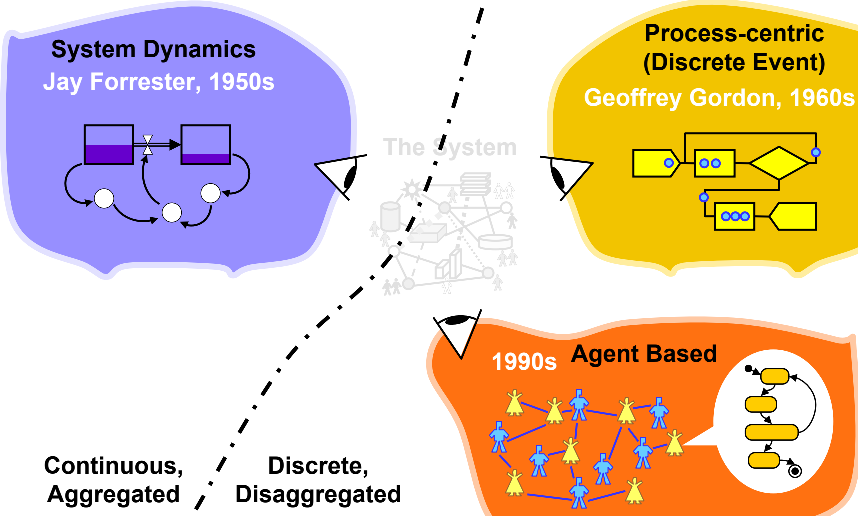


Figure 2.1: Main simulation modelling perspectives (Source: Borshchev (2007)).

System Dynamic - was first introduced by Jay Forrester in 1950 (Borshchev, 2007). It is a simulation view suited for various levels of detailed modelling. For example, SD can be used to model a pendulum at a micro level with low abstraction as well as urban dynamics at a macro level with much less detail (Borshchev, 2007). SD modelling is used to represent and help one better understand the dynamics and structure of complex systems (Sterman, 2000). As illustrated in Figure 2.2, SD assumes a high level of aggregation; people, products and events lose their individual characteristics and are only represented by quantities (AnyLogic, 2010b). This level of abstraction might be sufficient for representing the RMTS but its better to record individual details of the different types of raw materials that will be in the system.

There are a few only a few conferences where SD is discussed, one of which is the International System Dynamics Conference (Borshchev, 2007). This conference is more concerned with the macro- and strategic level uses of SD.

Agent Based - modelling started in 1990 (Borshchev, 2007) and is suited for various levels of abstraction. AB modelling is a more decentralized and individual-centric modelling perspective (AnyLogic, 2010a). In AB modelling agents (e.g. person, vehicle or product) are generated and given a certain behavioural pattern using individual parameters and state variables. These agents are then placed in an environment where they can make connections with other agents, change their state and interact with the environment. This modelling approach requires a high level of abstraction and a macro level of simulation.

AB is a relatively young perspective and there is no business-orientated conferences dedicated to it yet (Borshchev, 2007).

Process-centric (DE) - modelling was introduced by Geoffrey Gordon in 1960 and is suited for moderate level detail modelling. Process-centric simulation, as the name suggests, is concerned with processes and sequence of operations. This simulation view also takes into account how entities and resources are involved in processes. The RMTS is a dynamic system as it changes states over time. A useful function in AnyLogic® is that there is a specific process module specifically developed to cater for the transport of entities using a conveyor.

Conferences where DE is discussed include the following: Winter Simulation Conference and Informs (Borshchev, 2007). These conferences are more concerned with lower levels of abstraction and operation level uses.

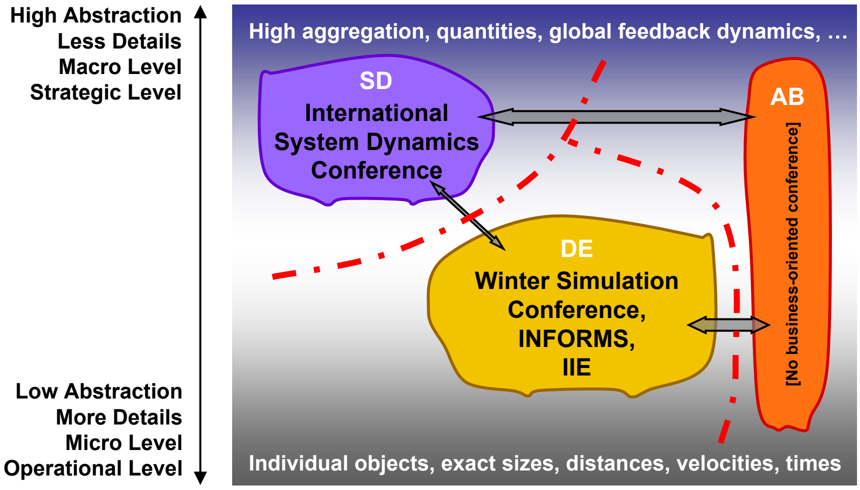


Figure 2.2: Abstraction levels and dedicated conferences for modelling perspectives (Source: Borshchev (2007)).

According to Carson (2005) one can define certain problems as DE models where the states change only at discrete points in accordance with time and not continuously as in SD models. An event is an instant occurrence that changes the model's state, and when an event occurs it can activate or trigger new activities or processes. This definition fits the RMTS better than the continuous aggregate approach because events in the RMTS occur at specific times. There is also a specific sequence of events that follow when a specific action is selected in the program.

However, as seen in Figure 2.1 the same system can be described by various modelling approaches. A process of the RMTS that can be modelled using a SD approach, for example, is the filling of the silos, because the filling process happens continuously as material falls into the silo. With effort one can model almost any system using any one of the modelling approaches, although certain modelling approaches are better suited than others. The main simulation perspective that will be used to model the RMTS will be the discrete event perspectives or more specifically the Process-centric perspective. However, to create a more accurate model one will need to incorporate more than one modelling approach.

Chapter 3

Model Building

3.1 System and simulation specification

When an attempt is made to represent a system as a computerised model, it has to be assumed that the system can be described in acceptable computer terms, i.e. variables. The manipulation of these variables will then express changes in the system that would occur in the real world (Pritsker, 1979). To represent the Raw Material Transport System (RMTS) in computer variables, the whole system has been simplified to an extent that it is suitable for the level of modelling required. This section aims to properly define and simplify the current system so that the model building phase can commence.

The current systems mainly consists of the storage facilities for raw materials, the different plants and the conveyor system. The conveyor system consists of various conveyors, change-over chutes and optionally a screen house through which the material has to reach in order to get to the different plants. Some of the main components are illustrated in Figure 3.1. To better understand processes in the system, the various operations of the RMTS are discussed using basic flow diagrams in the following subsections. The subsections discuss the current configuration of the system to supply the current furnaces, subsection 3.1.8 stipulates the changes that the current configuration will have to undergo in order to facilitate the new furnace, M14, at West Plant.

(a) Reclaimer

(b) Tippler

(c) Stacker

Figure 3.1: Main components of the RMTS

3.1.1 Transport via the tippler

Raw materials are delivered from the mines either via locomotives on the Transnet railway system or by contracted logistic companies via trucks. These vehicles drop their loads at the tippler. Material that falls into the tippler's hopper are directed to Conveyor (CV)1 and moves to CV2 which transports material to Transfer House (TH)1. From here it can either go to the stacker or directly to the plants via the screen house, as illustrated in Figure 3.2. Material delivered by rail is stacked in either in the stockyards and will rarely be used to supply the plants.

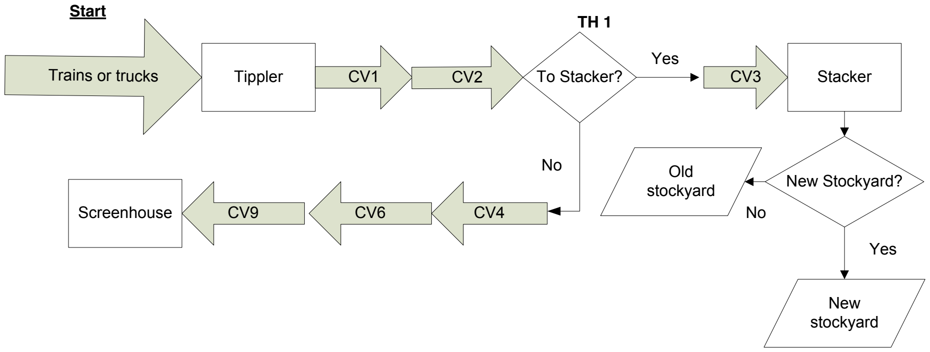


Figure 3.2: Schematic overview of material flow from tippler.

The direct path to the plants is used when material not available from the new stockyard needs to be supplied. This is mostly for remelt material and coal, because it generate unwanted amounts of fines if transported through the stacking and reclaiming process. An operator request a lorry to deliver the material needed in the tippler's hopper which will then be transported manually to the TH1. At the TH material will go via CV4 to CV6 and from CV6 falls on the last section of CV9, which will take the material into the screening house. From here material follows a new set of conveyors as depicted in Figure 3.5.

Material that needs to be stacked in the stockyards is transferred via TH1 to CV3 where the stacker can either stack it in the new stockyard or the old stockyard. Materials that are needed on a regular basis are stored in the new stockyard as they can easily be put back into the transport system via the reclaimer. Material in the old stockyard must be put back in the system by front-end loaders or trucks. This is orchestrated by operators and the conveyor system then needs to be run on manual.

To store material in either of the stock yards the stacker moves to a designated position along the stacker line and moves the end of the stacker to a predetermined spot in the chosen stockyard. Material then flows off the end of the stacker and forms a stockpile.

3.1.2 Transporting from the new stockyard

To retrieve material from the new stock yard the reclaimer moves to the desired position on the reclaimer line and rotates to create the desired angle at which to reclaim material. Figure 3.3 shows the path taken once material is reclaimed. Material is conveyed via CV7 and CV8 to TH4 where it can either go to North and South Plant without being screened or to the screen house via CV9. Material going to West Plant must always go through the screen house. Screening takes additional time to complete.

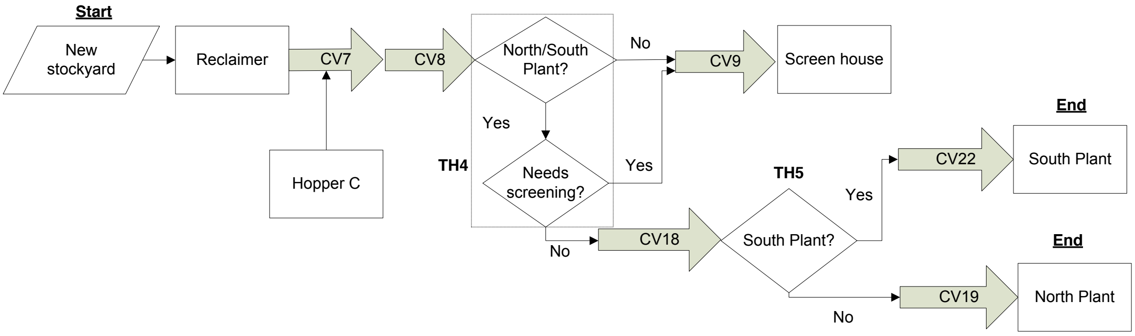


Figure 3.3: Schematic overview of transportation from the new stock yard.

At TH4 material can be chanelled directly on CV18 to TH5 where it can be directed to either South or North Plant via CV 22 and CV19 respectively. Inside North Plant, CV20 and CV21 distributes the material into the correct bunkers. Inside South Plant, CV23 does the same.

At the end of CV7 is hopper C which can be used as a second backup in case the tippler and hoppers A and B can not be used for whatever reason. Material needs to be loaded into hopper C by front-end loaders and the operator runs the system on manual to supply the different plants.

3.1.3 Transporting from the old stockyard

If material that is not stored in the new stock yard is needed by the plants, it either has to enter the conveyor system via the tippler or hoppers A,B or C. The supply of material from the old stockyard is done while the total system is on manual. Material stored in the old stock yard needs to be collected with front-end loaders and then, depending on the situation, be transported by trucks or by the front-end loaders themselves to the designated entry points. Usually material is fed through the tippler as the supply rate through the tippler is much faster than through the hoppers. Days on which the tippler is under maintenance or if there is another emergency, operators can instruct material to be loaded into hoppers A and B by the front-end loaders. These hoppers are directly over CV5 which transports material to CV6 as illustrated in Figure 3.4. The conveyors is laid out in such a way that CV6 drops the material only on to a small segment of CV9, which transports the material to the screen house.

On certain days maintenance occur on the hoppers and a section of the CVs, this prohibits the transport of material through either the tippler or hoppers A and B. Front-end loaders will then deliver material to a second backup hopper situated at the end of CV7, called hopper C. Material will then follow the path depicted in Figure 3.3.

3.1.4 Transporting from screen house

Transportation within the screen house is done via CV16. Inside the screen house there are transfer chutes to direct material onto CV10 for West Plant and CV17 for North and South plant. If screening is activated for material an additional screening process takes place.

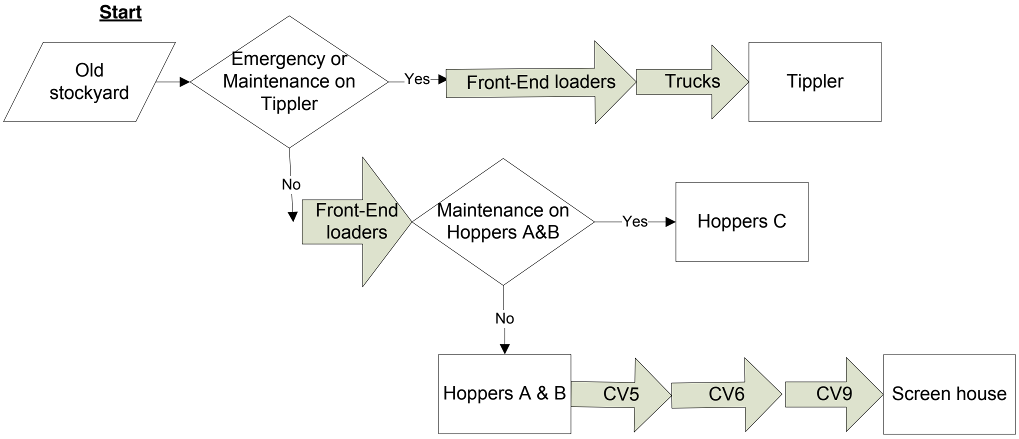


Figure 3.4: Schematic overview of transportation from the old stock yard.

Material that flows to West Plant goes via CV10, CV11 and CV12 into West Plant's raw material silos. Inside West Plant CV13 distributes the material into the correct silos. Between CV11 and CV12 there is a transfer chute that directs material to the M12 furnace silos and the proposed, but currently not available, M14 furnace silos.

The path to North and South Plant is via CV17 onto CV18. From CV18 the sequence is as previously discussed in Figure 3.3

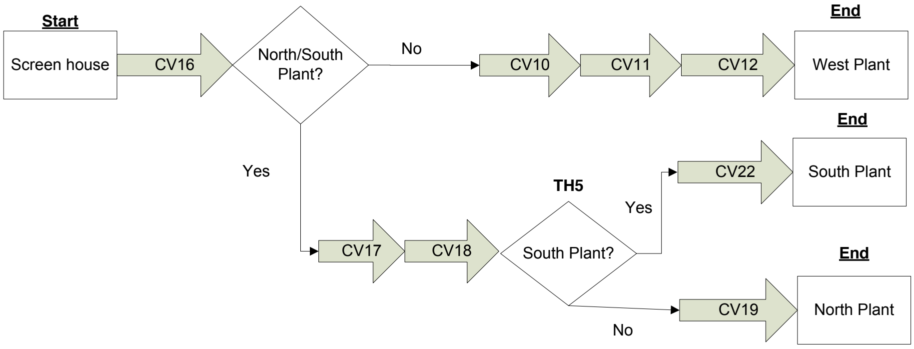


Figure 3.5: Schematic overview of transport from the screening house.

3.1.5 Raw material supply methodology

The supply of raw material is controlled by an operator and an automatic program. Operators decide on a material to be transported by enabling the silos at plants to receive material, then an automatic program is used to operate the conveyor system and reclaimer so that it transports the selected material to the various plants. However, operators are allowed to transport material manually when demand is crucial. This makes simulating this process very difficult as each operator varies in their operating technique, which depends on their level of skill and experience.

Although most material are supplied using the reclaimer, some material types are fed using the tippler. This is a manual process and the operator controls all the parts of the system. The material types that are currently supplied using the tippler can be seen in B.12

Operator logic

When the auto program is controlling the system, an operator only enables plant silos to be filled according to the level of raw material in each silo, the type of material in the silo and the current position of the reclaimer. Usually when an operator starts his shift he assesses the silo levels and then organises a sequence of materials to be loaded. He does not necessarily enable all the silos that will be filled during his shift at once, but reassesses the silo levels after each type of material has been filled. The operator decides which material to load into which silo according to the following steps:

1. Operator checks the silo levels of priority material at each plant. The priority materials are coal, coke and sinter. The degree of priority of each of these materials differs slightly from plant to plant. If the levels of these silos are below 30% the operator will enable these silos first.
2. Operator also checks the levels of other silos at each plant. If a silo is below 20% this will become a new priority silo. Operators sometimes call the specific plant and determine how long they will be able to hold out. This is taken into consideration before the operator makes his decision.
3. The operator then assesses the current position of the reclaimer at the new stock yard and uses his own discression and experience to decide in what sequence he must load the material identified in steps 1 and 2. The distance that the silo's materials selected in steps 1 and 2 are from each other and from the current position of the reclaimer, plays an important role in his decision as the speed at which the reclaimer moves is significantly slow.
4. Once the operator has decided on a material to load he selects a silo at a plant witch contains the selected material and enables the silo to be loaded. The operator usually enables all the silos containing the selected material at all the plants, although this depends on the current situation and the specific operator's modus operandi.
5. If there are no critical silo levels most operators just enable silos containing the material from the next stockpile closest to the reclaimer's current position at all the plants. Usually operators move from one end of the stockyard to the other feeding all the material to the different plants in sequence of their placement in the stockyard, changing this sequence only if certain material levels become critical.
6. If the reclaimer is out of service the operator can decide to use either the tippler or hoppers A, B or C to manually load material from the stockyards onto the conveyors. Loading using front-end loaders is considerably slower than using the reclaimer or tippler.

When the operator needs to supply materials that are not kept in the new stock yard he requests trucks to be filled with the material and brought to the tippler. The amount of material requested is an estimate of what the silo levels will be once the trucks arrive at the tippler. The operator usually times his request such a way that the trucks will arrive at the end of supplying all the plants from one stockpile. This is done so that no time is wasted from moving over from one procedure to the next. The timing of this operation depends greatly on the operators' skill and experience. Some operators use the time during manual feeding to move the reclaimer to the next stockpile that he wants to enable after the manual process. During the process of manual supply the operator follows the following steps:

1. As soon as the trucks arrive at the tippler they dump their loads into the tippler hopper. The operator waits for the last material to be transported by the conveyors and switch the whole system over to manual control.
2. The operator starts the conveyors that will be needed to supply a specific plant and moves the change-over chutes to direct material to the selected plant.
3. Material falls out of the bottom of the tippler's hopper by use of a vibrator feeder and is transported via the conveyors.
4. The operator checks the weight of material transported using various scales situated along the conveyors. When he has conveyed the correct amount to a certain plant's silo he stops certain conveyors, let the material clear the conveyors, move selected chutes and starts the conveyors again.

Automatic feeding of raw material

Once the operator has enabled certain silos to be loaded, the automatic control program on the Systems Controller and Data Acquisition (SCADA) will run a program and use the reclaimer to supply material to selected silos and plants. This program can be divided into two parts namely: Scanning and Supplying. The process follows the following sequence - the sequence is graphically represented in Figure 3.6:

1. The program starts by scanning. In the scanning process the program checks whether a silo containing the material from the next stockpile, relative to the reclaimer's current position in the stockyard, is enabled at any of the plants. It starts checking at West-, North- then South plant. If a suitable silo is found it continues to step 2. If no suitable silo is found the reclaimer scan the rest of the stockpile's materials and then restarts scanning from stockpile 1 until the end continuously or until an enabled silo containing material from a stockpile is found.
2. The reclaimer will then move to the stockpile containing the selected material in the new stock yard. The distances of each stockpile in the stockyard is preprogrammed into the system so that the program knows where to move the reclaimer.
3. The program firsts checks if any silos are enabled at West Plant, the other plants are checked later in the program sequence. If more than one silo of the selected material is enabled at West Plant the program will start filing in the silo closest to the current position of CV13. It also calculates the amount of material needed, in tons, to fill the silo to 90%. This is done by predetermined material density and silo volumes.
4. The program will then move all change-over chutes in the system such a way that the material will be diverted to West Plant. CV13 will also be moved to the correct position if needed.

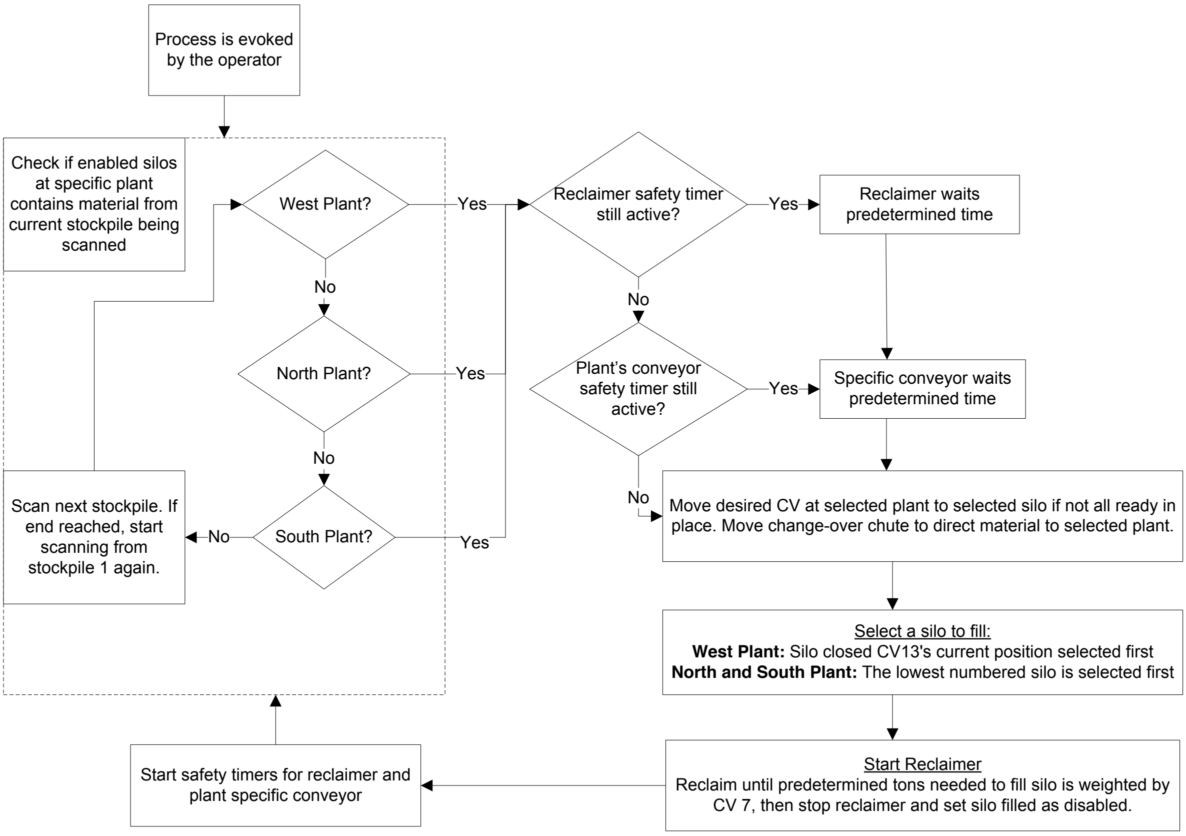


Figure 3.6: Schematic representation of the SCADA sequence for supply.

5. The reclaimer will then start to reclaim material onto CV7. The belt scale on CV7 weighs the material as it lands on the conveyor. The reclaimer will stop when the predetermined amount needed to fill the silo, calculated in step 3, has been measured by the belt scale. When the reclaimer stops reclaiming the silo that is being filled is disabled, so that it will not be assessed a second time and a set of timers are started. These timers are specifically calculated for the reclaimer's current position and the plant being supplied to ensure the material reaches the intended silo before the change-over chutes move or the reclaimer starts again.

6. The program will then start scanning again. If there are one or more silos to fill at West Plant the reclaimer will have to wait for the predetermined safety time before it can start reclaiming again. The program will then move CV13 to the selected silo and start the reclaimer as soon as the timers have stopped. Some of the operators reset the timers or start the reclaimer on manual before the timers have stop, this is allowed as the the timers have redundancy built into them in order to ensure that no spillages or contamination occurs while on full auto.

7. After supplying West Plant the program will again scan for any enabled silos containing the material from the current stockpile. If there are no enabled silos at West Plant, the program starts with step 1 again and assesses the silos at North Plant. If their is more than one silo to fill at North Plant, it will start to fill the lowest numbered silo first.

8. If the silos at North Plant are filled, the program starts with step 2 again and assesses the material at South plant. Again, it will start to fill the lowest numbered silo of the selected silos first.
9. After all these steps are carried out the program will assess whether the material in the next stockpile is enabled at a plant, thus starting with step 1 again.

3.1.6 Demand of materials from plants

Each plant needs different materials at different rates in order to ensure optimal furnace operation. The plants create different manganese alloys and therefore have different recipes for materials to be loaded into their furnaces. The default recipes, frequency of use and silo content for each plant used in the simulation can be viewed in Appendix B.

3.1.7 Maintenance

The RMTS needs regular maintenance in order for the system to function properly and to prevent breakdowns. Maintenance on different parts of the system is done usually for 8 hours a day, Monday to Friday. During maintenance certain system components can not be used and alternative or back-up systems needs to be used as substitute components by the operator. The default maintenance schedule used in the simulation dictating the different parts serviced on the specific days and substitute components, can be viewed in table B.13.

3.1.8 Proposed furnace M14

M14 will be a replica of M12, the furnace currently in use at West Plant, and will operate in the same way. The demand, maintenance and silo content will be similar to that of M12. To accommodate M14 in the system little changes need to be made to the current components of the RMTS when M14 is implemented. The automatic program will be reprogrammed to also scan for enabled silos at M14, while operators will now have an extra furnace to monitor and supply. Hardware changes include a directional controller for CV12 to move material to either M14 or M12. The supply methodology will resume in relatively the same way as before with only an extra step for supplying M14.

3.2 Model formulation and construction

In this section the use of the simulation software to build a suitable model will be discussed briefly. The various assumptions and simplifications from the real world to the model will also be highlighted so that the extent to which the real world is represented in the model can be known. Most of the logic is hard coded but certain parameters can be changed. The default values of the parameters can be viewed in the Appendices. This section also very briefly discusses how AnyLogic was used to create the model, the main features of the system and the main approaches used to model each of them.

3.2.1 Main simulation components

Simulation Parameters

In order to make the simulation more user-friendly and flexible a parameters page was developed in the front-end of the model where the specific parameters of each plant or process can be viewed and changed before the simulation is run. This allows the model user to adjust the operating scenarios and evaluate changes in the model output. The parameters that can be changed include:

- Material specifications that can be changed are: reclaiming rate and density. There are 45 material types hard coded, which represent the materials most commonly used at Metalloys.
- Conveyor speeds and lengths of the 23 conveyors.
- For each plant the following can be changed: the silo content and level, the average number of rounds used during a day and the amount of each material used in each round.
- Stockpile layout, specifying material type at each stockpile and the start and end point of each stockpile location. The current reclaimer position can be specified.
- Material that can be supplied using the tippler, specifying material type, frequency of supply and rate of supply.
- Checkboxes to select whether the simulation should be run using an automatic operator and automatic feed. These can be changed at any time during the simulation run.

Operator Logic

The operator logic consists of three main parts namely: critical analysis of silo levels, enabling the correct silos and supply using the tippler or hoppers. Because the operator logic resembles characteristics found in the Agent Based (AB) perspective it was decided to use state charts to represent the different states that the operator can be in.

The logic of enabling the correct silos at all the plants was done in conjunction with the critical analysis of the silo levels. The logic first determines if the average silo level per plant for each material type is below a certain threshold. This threshold can be changed in the model parameters page but is defaulted to 20%. If the logic finds a material type at a specific plant that has an average per silo below the threshold it will enable only this material at the specific plant. At North Plant M10 and M11 are taken as seperate plants because each furnace uses their own set of raw material silos and they are unable to use each others' silos. As soon as the silos have been enabled the reclaimer logic takes over to supply the critical material at the selected plant. The scanning of plants as well as critical silo scanning will not occur at plants where the conveyors used to supply that plant is under maintenance.

The tippler supply logic affects the reclaimer and other operator logic. Event generators generate an event to start the supply of material from the tippler by using a triangular distribution. When the event occurs the reclaimer and operator logic enters a dormant stage, waiting until the conveyors are empty and the tippler supply has finished before continuing. During the tippler supply event the logic enables and disables relevant silos at each plant containing the material that was scheduled to be supplied. The logic also controls the conveyors' speeds dynamically by starting and stopping them in specific sequences to prevent spillages and contamination. When the tippler is being maintained the tippler supply logic requests a front-end loader to deliver material to the correct hopper, either A & B or, when maintenance is being done on A and B, hopper C.

The operator logic does not however take into consideration the material types when doing the critical analysis as a normal operator might. In addition it is impossible to simulate the correspondence between the operators from different plants and the transport operator. It is also assumed in the model that operators can make decisions instantly. The operator logic in the model dictates a generalization of all the operators' modus operandi as not all operators run the process exactly the same.

Reclaimer Logic

The reclaimer logic has three main states: idle, active and moving. The logic stays in state idle until the automatic feed parameter is activated by selecting the appropriate checkbox at either the parameters page or the overview page during the simulation run. It can also move from the idle state to the moving state by selecting the move button from the reclaimer page during the simulation run.

The active state of the reclaimer consists of scanning, reclaiming and waiting states and works more or less the same way as described in Section 3.1.5

Conveyor System

The conveyor system can adequately be represented by Process-centric objects as it can best be viewed from a Discrete Event (DE) perspective. In AnyLogic there are specific objects in its Enterprise Library to accurately represent conveyors. The conveyor system is modelled using these objects and are controlled dynamically by other logic found in the model.

Silos

The silo attributes are modelled by variables to represent tons needed, silo level and material type. These are graphically displayed at each plants' page with the silo level visually illustrated by means of a bar chart.

Plant Demand

Plant demand can be modelled purely using a DE approach. The demand is controlled by a set of events for each plant, using the average rounds per day parameter as the input for the generation of the events. These events check if a silo is in use by the plant at that specific moment and then removes a certain amount of that material, according to the recipe parameters, from that silo. The silo level in percentage and the tons needed of that silo are then adjusted. To stop these events from using silos that are empty another event for each plant checks whether the silos currently in use are empty. If this the case it will assign a new silo with the same material to be used by that plant. If it can not find another silo to be used the stock-out time is recorded.

Maintenance

As maintenance of components dictates the parts of the system that are available for utilization, a state chart controlling the availability of components were created. The maintenance state chart logic moves to a specific state of maintenance on the appropriate day and time and controls the system components that are being maintained on that specific day. It stays in this maintenance state until the desired time for maintenance on that day has run out. The logic will then return to the idle state. The system components that are maintained on the specific days are hard coded but the start time and duration of maintenance on the specific days can be specified before the simulation run on the parameters page.

M14

It is assumed that M14 will be a direct replica of M12 found at West Plant. These furnaces will share the same operating procedures, demand and silo configuration.

3.2.2 Model assumptions

In order to model the RMTS efficiently certain assumptions have been made. Most of these assumptions have been made in order to facilitate better model building without too much complication. A summary of the assumptions or simplifications including the reasons for each, can be viewed in the table 3.1.

Table 3.1: Assumptions and simplifications

Number	**Assumption**	**Reason**
1	Manpower and equipment is available at all times, except during routine maintenance.	This greatly simplifies the model and will represent the system working at its full potential during normal operations.
2	Raw material are always available at the stockyards; stacking and supply to the stockyard will not be modelled.	Stockpile levels will not be modelled as it assumed that the bottlenecks are not the at the stockyards.
3	Only arrivals by trucks to the tippler will be modelled.	This is because trains only bring material that will be stacked in the stockyards and only in emergencies will the material be used to fill up the silos.
4	Silo material assignment will remain fixed throughout each simulation run.	The silo material assignments can be changed before each model run in the parameters page by the model user but not during a simulation run. This prevents confusion for the model user as well as mishaps during a simulation run.
5	M14 furnace will have exactly the same parameters as M12.	This is done as it is impossible to forecast the behaviour of M14.
6	The inner workings of each plant will not be modelled.	The inner workings of each plant is irrelevant as the silo levels are only affected by the amount of material taken during a round.
7	The average modus operandi of each operator can be simulated using the given operator logic.	Because each operator differs in his or her operating techniques, the general standard operating procedures were used.
8	The time it takes an operator to request a truck to supply material through the tippler as well as the loading time of the trucks, will not be modelled.	This is because these activities can be done during the normal operations of the plant and does not need to be modelled if the operator manages his time well.

Chapter 4

Model testing

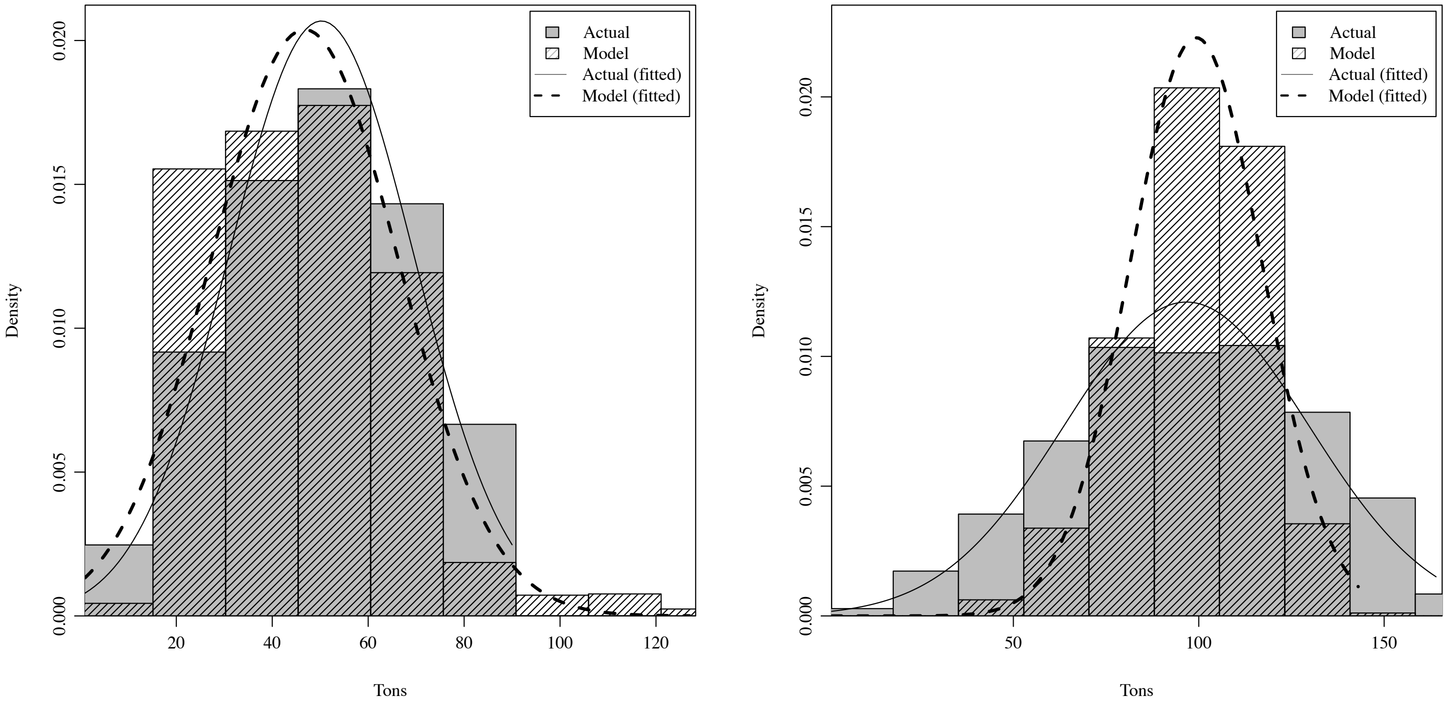
4.1 Verification

To ensuring that the model is an accurate representation of the real world system, the basic model workings were verified by operators at the Raw Material Transport System (RMTS) control room. This is done by using various animations in the model front-end to illustrate the model logic. The base time period used for model experimentation was the time period 3 to 24 June 2010. This time period was chosen as it is the longest stable period regarding plant recipes and silo content. All the model parameters were calibrated to reflect the true system parameters of the base period. The values hereof were calculated from plant operations data collected during the base period. All the inputs, specifications and process flows were verified by the instrumentation and raw materials foreman.

4.2 Validation

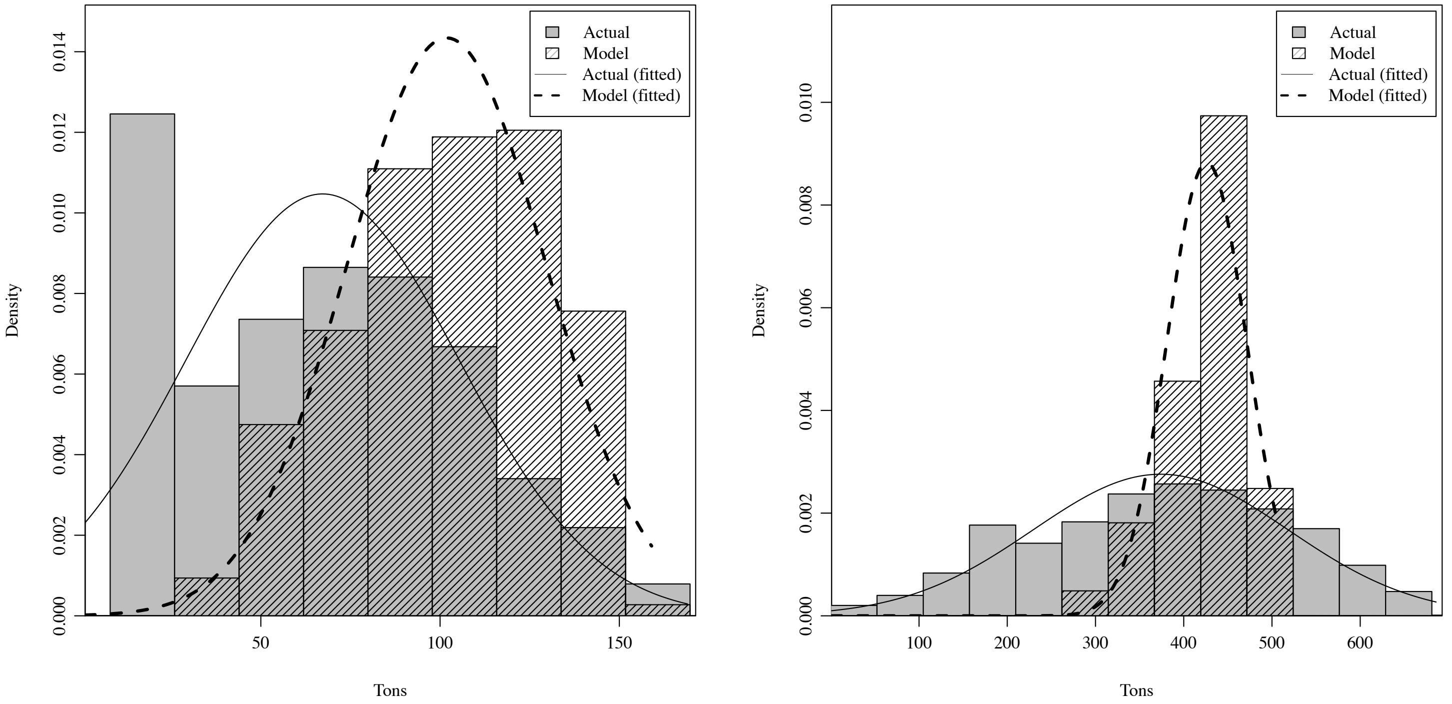
To test the validity of the model, the model outputs where compared to the actual output of the system for the base period. The output to be measured against the actual data is the tons available of each material type for each plant. This is a more aggregate way of analyzing the data as compared to the analysis of the individual silo levels, as the silo levels are prone to huge fluctuations. These fluctuations greatly depend on both the specific plant's operator and the operator working at the RMTS. Measuring the material available at each plant is also a more effective way of analyzing the productivity of the RMTS, as a silo might run empty because of a plant's operating procedure to use all the material in a silo. An empty silo will reflect negatively on a silo-level based analysis but not necessarily on a total material available analysis. It is also impossible to accurately model all the different operators at all the different plants' modus operandi to accurately reflect their particular method of using silos. Some plants split a recipe of a material over more than one silo containing the same material to decrease batch loading time. Validating the model output at the aggregate level of tons material available also helps to compare disparate elements of the model to the real world, because material available captures all of the following elements: material drawdown, plant and furnace utilization and RMTS productivity. For all testing and analysis the model was run five times to ensure that a more reliable average of statistical measures where determined.

The model time starts on 3 June 2010 at 06h00 with the exact parameters that was recorded by operators at that time, and continues to run until 24 June 2010 at 06h00. The model records material levels in each silo at 10 minute intervals. These readings are then transformed into tons available for each material per plant. The actual systems



(a) North Plant M10 Chinese Coke

(b) North Plant M11 Coal Khutala



(c) West Plant M12 Remelt FeMn

(d) South Plant M1L

Figure 4.1: Histograms of material availability at different plants actual data versus model Data

was monitored in the same way during the base period using Aspen. The model output and actual output were then plotted against one another as a histogram to illustrate the distribution of material available against their probability density. After the analysis of various distributions it was found that a normal distribution proved a sufficient fit for the data sets, as it can be used for all the data sets. Other distributions, like Weibull and Beta, proved a better fit for some data sets but was an inappropriate fit for others. The normal distribution was fitted over each data set to give a more definitive view of the distribution of material available. In Figure 4.1 four graphs of the the 30 histograms drawn up to analyze the model output illustrate different scenarios of the validation analysis.

The statistical parameters of the outputs used during the validation process include average, standard deviation and Mean Average Deviation (MAD). Distribution have the potential to have a wide spread so it was decided to use both the standard deviation and MAD to evaluate the spread of the output. MAD is often used as a base measure of forecast accuracy. It is the sum of the absolute value of error or deviation from an expected value, in this case the mean, divided by the number of data points (Bridgefield Group, 2010). To compare the model output to the actual output the difference in statistical parameters had to be measured. Because of erratic results, some outputs over-predicting and some under-predicting, the absolute value of the difference between the statistical parameters for each output was taken. If only the differences were taken the average of these differences would give a false indication as the positive and negative numbers will bring the average difference closer to zero.

Since the parameter' units are in tons and do not give a clear indication of what is acceptable, as the different materials are required differently at each plant, the difference in parameters was then divided by the maximum amount of tons available during the base period of each material type at each plant. The differences in percentages of the averages and MAD can be seen in Table C.1

Figure 4.1a is a perfect example of a model output that is close to reality with the average tons available differeing by 3,5 tons or 2,75% when compared to the maximum tons available. The standard deviation and MAD of both outputs were also very close in value.

On the other hand, Figure 4.1b illustrates how North Plant M11's coal supply has an average tons available difference of 1.81% when compared to the maximum tons available. However, the standard deviation and MAD are lower than the actual output by almost 10% indicating a narrower spread. This is also true for Figure 4.1d although its average differes somewhat more from the actual data.

Some model outputs could not represent the actual data as accurately as the previous graphs. Figure 4.1c shows that although the model output for remelt FeMn at West Plant had a standard deviation and MAD close to the actual data the average was much higher. This is due to the fact that sometimes operators are instructed to fill silos only to 50% with remelt material such as FeMn briquettes to prevent the material crushing itself in the silos. The same result was seen with the analysis of SiMn slag and Remelt MnPick at South Plant where the difference in average was almost 28%. As can be seen in Figure 4.1c, there was a time in the base period when the material was unavailable at West Plant. During these times plants might change their recipe in order to accomodate the situation. This was not built into the model as it will considerably increase the complexity of the model.

In summary the model appears to yield an average difference in average material available of 13,3%, which can be interpreted as a validity of 86,7%. The standard deviation and MAD differed by 8,2% and 6,9% respectively, indicating that the spreads differed from the the actual data. Most of the differences with standard deviation and MAD were negative indicating a narrower spread than in reality.

The fact that the model output is more situated around the mean than in real life can have various reasons. One can also assume a null hypothesis stating that any differences between the experiment and control variables are attributable to chance (University of St Andrews, 2010). Although considering that the model has very few stochastic processes and the length of model run-time is more than sufficient for these processes to average out, it is unlikely that the null hypothesis can be accepted without question. To unquestionably accept it will be to overlook assignable causes to the variation in the outputs. A possible reason why the material availability does not always go below the average can be due to the fact that the model makes operating decisions instantly and will mathematically determine the material and plant that needs to be supplied in critical situations. In reality not all operators have the skill or the time to constantly and correctly evaluate the system needs. On the other hand, operators have the ability to change settings and control the system manually, allowing them to fill a set of silos at a plant with more than what the system is programmed to do, as they have interactive control over the system and can monitor the process. This will increase the material availability to far above the average availability and can be a cause of the increased spread in the actual data.

In conclusion it is believed that the model is a relatively good representation of the actual system. Experimental model outputs have to be taken as relative to the current model outputs and not as a forecasted output of the real system. The relationship between current model and experimental model can be applied on the real world current versus changed system.

4.3 Repeatability and variance testing

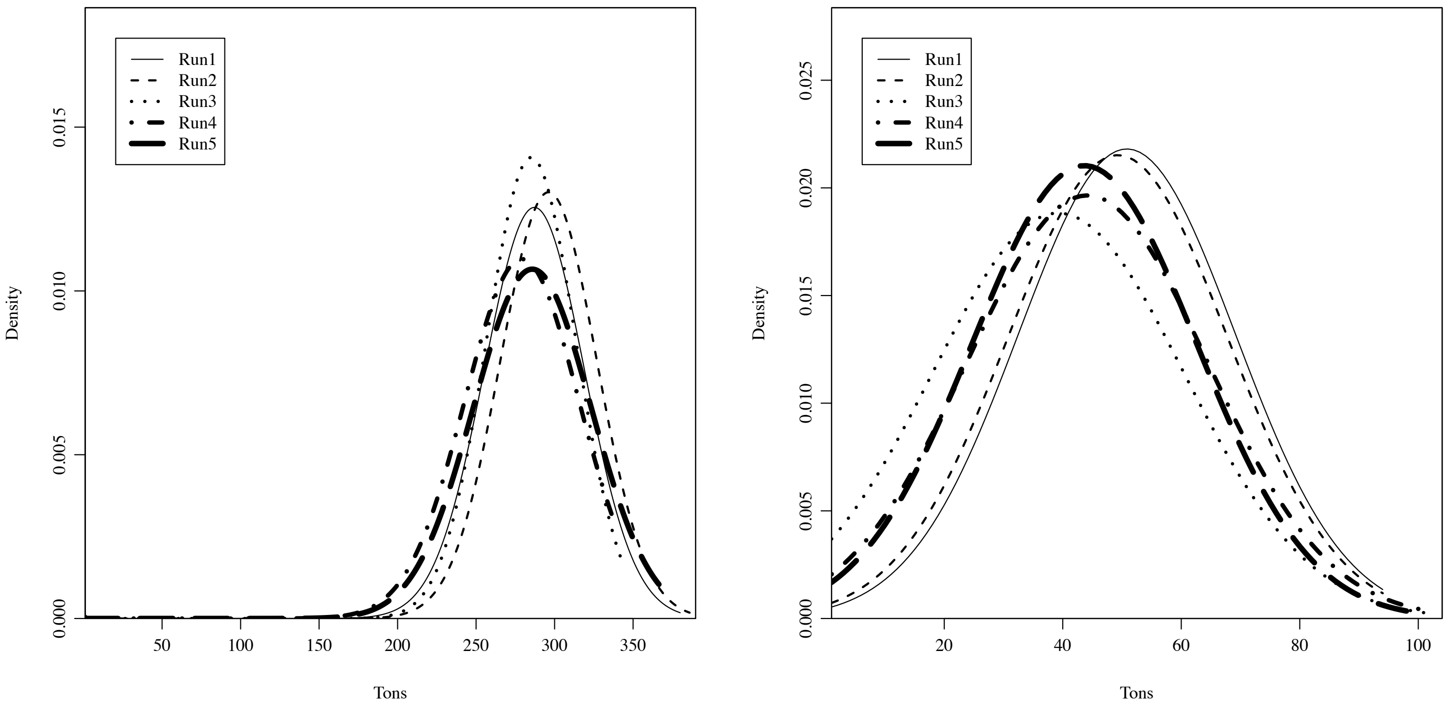
To ensure that the output of the simulation is repeatable, variance testing was done on the model outputs. A sample of five simulation runs for four different materials are taken and a normal distribution is fit onto each data set. The distributions for each run are plotted against each other to determine the repeatability of the model.

Figure 4.2 contains the comparison graphs of the four materials which clearly indicate that the results of the model-runs are relatively repeatable. Figure 4.2b indicates a difference in the expected value but a relatively equal spread for each run. Figure 4.2a indicates almost the same expected values but with lower probability densities. Figures 4.2c and 4.2d indicate little variance between the five runs.

In conclusion the model can be regarded as having a repeatable outcome with little variance. If however, the outputs are exactly the same it will show that it is a deterministic model which does not take the stochastic nature of operating the RMTS into account.

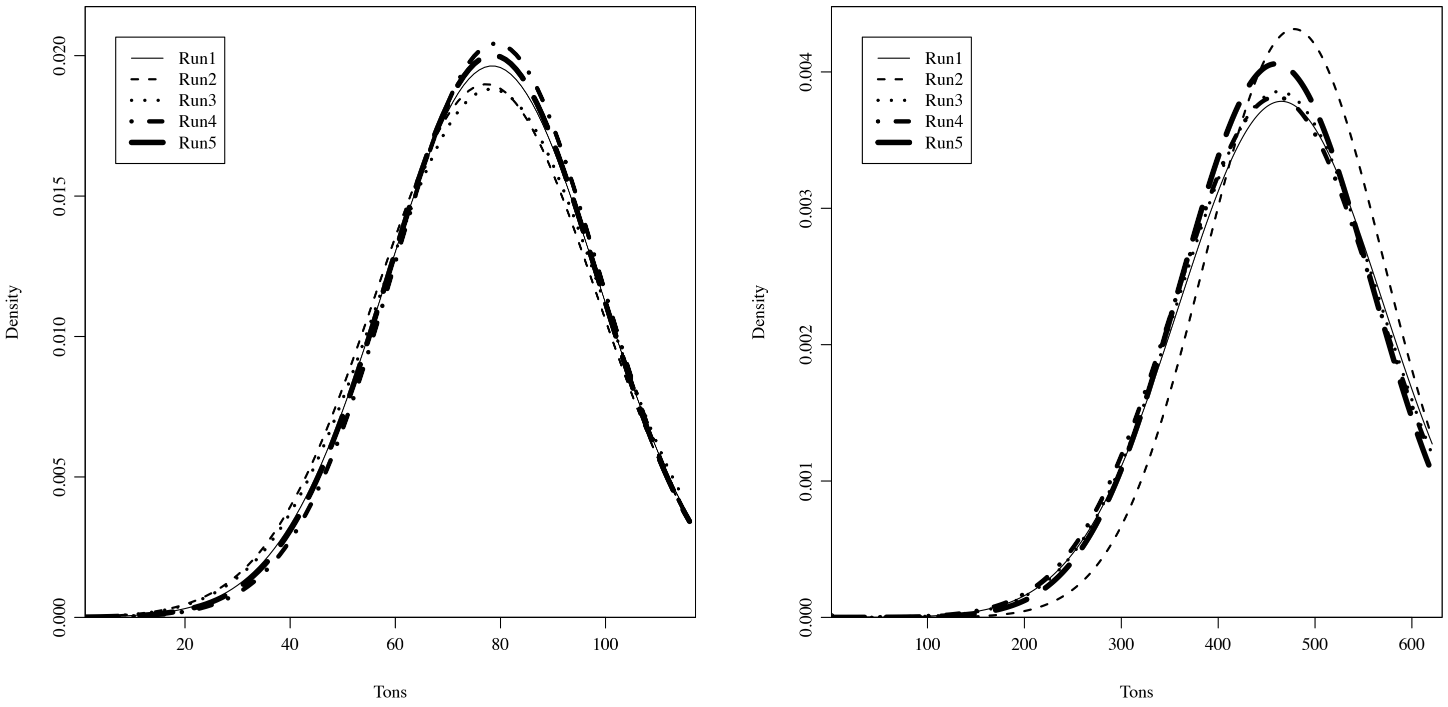
4.4 Experimentation and analysis

During this phase the effects that the new demand from M14 will have on the RMTS is determined by evaluating the distribution of the material available at each plant and comparing it to the model output of the current scenario. The secondary objective, to test whether or not the proposed stockpile layout will have an influence on the results, is also tested. In this section the results are given and discussed and in Chapter 5 the conclusions are drawn. For all testing and analysis the model was run five times to ensure that a correct average was determined for statistical analysis.



(a) North Plant M10 NHO

(b) North Plant M11 Coke Chinese



(c) West Plant M12 Coal Khutala

(d) South Plant SiMn slag

Figure 4.2: Distributions comparison for different runs

4.4.1 M14 Scenario

Material distribution

To analyse the distribution of material during the M14 scenario simulation run, it was decided not to use the absolute difference in the statistical values. Most of the differences in statistical parameter values between the M14 scenario and the current scenario were negative, as expected, with few showing a positive increase. If the absolute difference in values was taken, the average difference will not reflect a true average as a slight increase in parameters will be counted with the rest of the parameters that decreased.

The new demand on the system caused the material distribution average of all the plants to lower by an average of 13,7%. The MAD increased by an average of 6,2%, resluting in a lower than expected value and wider spread of material availability at most plants. Figure 4.3 illustrates four of the graphs drawn during the M14 scenario analysis phase. The differences in the averages and MAD can be viewed in Table C.2

Figure 4.3a is an example of a material output that did not exhibit any extreme variation in relation to the current output. The coal at North Plant M10 had a lower average, down by 8,9%, and an increase in the spread by 2,2%, but still no probability of stockouts.

On the other hand, Figure 4.3b and Figure 4.3d illustrate how North Plant M11's W1L and South Plants Sam Quartz supply had a decrease in average tons available of 25% and 35% respectively. The MAD also increased and stockouts occured for both materials at these plants.

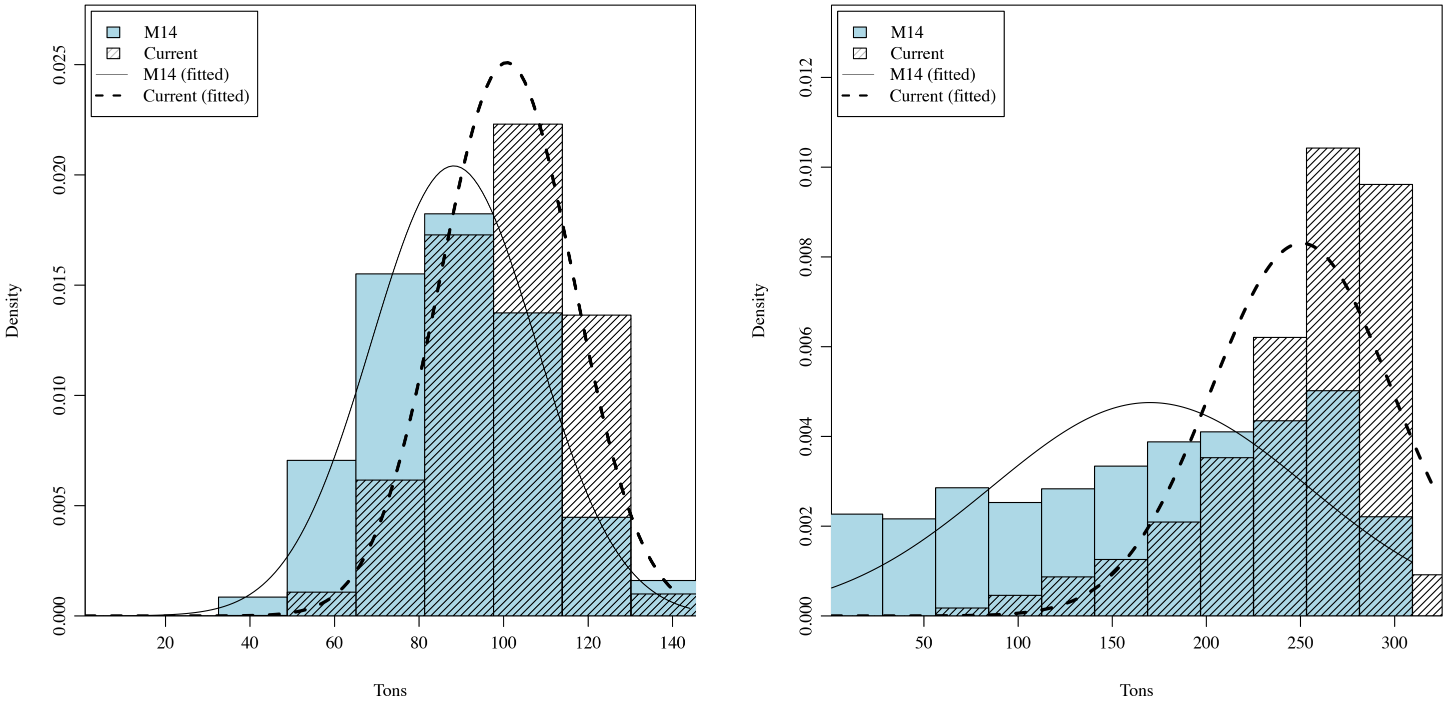
It is interesting to note that material supplied by the tippler showed much less variance when compared to the current scenario. As illustrated in Figure 4.3c the average of Remelt FeMn at West Plant changed by less than a percent. This could be due to the fact that in the model the decision to load a truck and supply material through the tippler is done instantly and in advance. However, in the reality this might not be the case as not all operators have the skill or time. The availability of trucks or front-end loaders might also be a problem in reality and could increase the probability that these materials' availability will be lower than in the current situation.

Stockout analysis

During the M14 scenario analysis the stockouts at the various plants were recorded. The time, material and duration of each stockout were calculated. What is interesting is the fact that stockouts increased considerably with nine out of the original 30 outputs showing stockouts during the model run time, and almost all of the M14 scenario' outputs showing stockouts. Most materials only had one or two stockouts during the model time period with the average stockout time being three hours. The material that showed a significant stockout probability were:

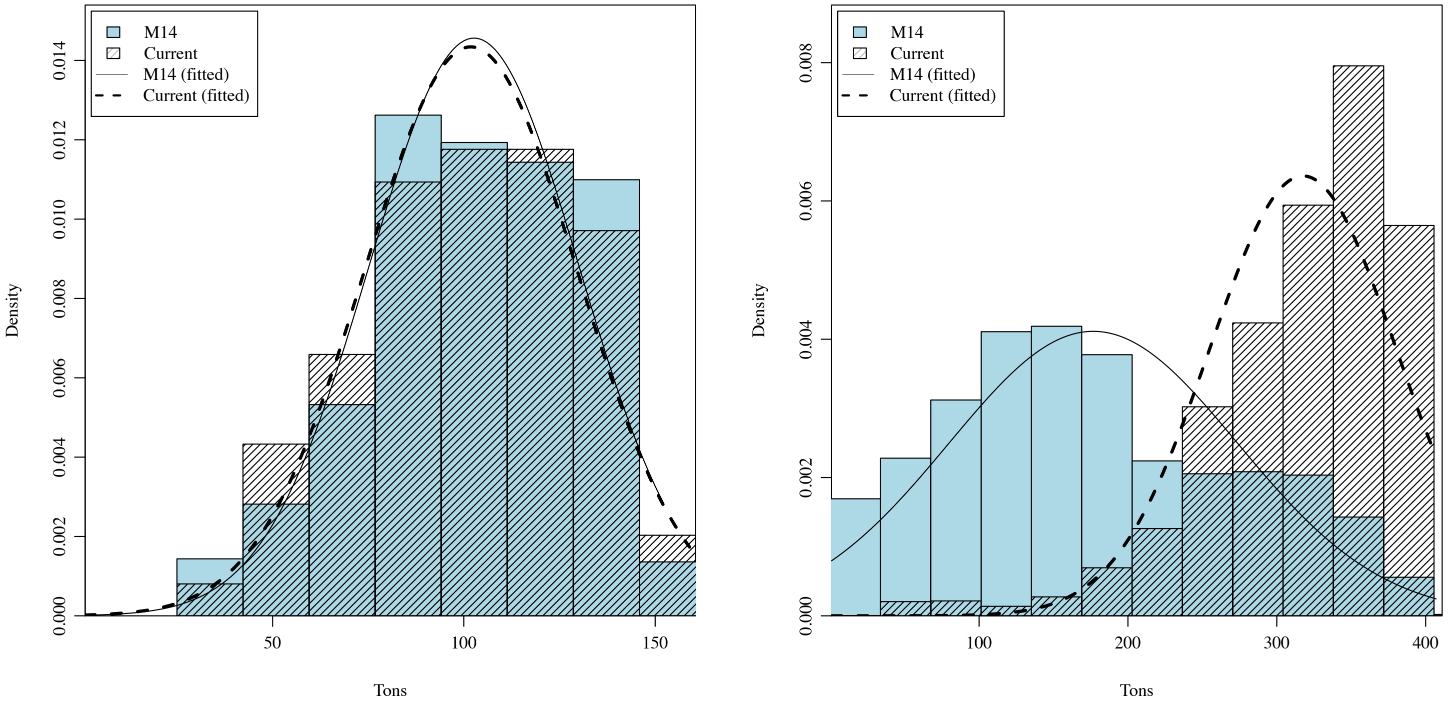
- Samquartz - Stockouts at North Plant M10, West Plant M14 and South Plant
- Coke Chinese Nuts - Stockouts at South Plant, West Plant M12 and M14
- MMS - West Plant M12 and M14

This gives a rough indication as to which materials need to be monitored more closely by operators if M14 should be implemented without changes to the RMTS.



(a) North Plant M10 Coal Khutala

(b) North Plant M11 W1L



(c) West Plant M12 Remelt FeMn

(d) South Plant Sam Quartz

Figure 4.3: Histograms of material availability at different plants current scenario model data versus M14 scenario model Data

4.4.2 Proposed modifications

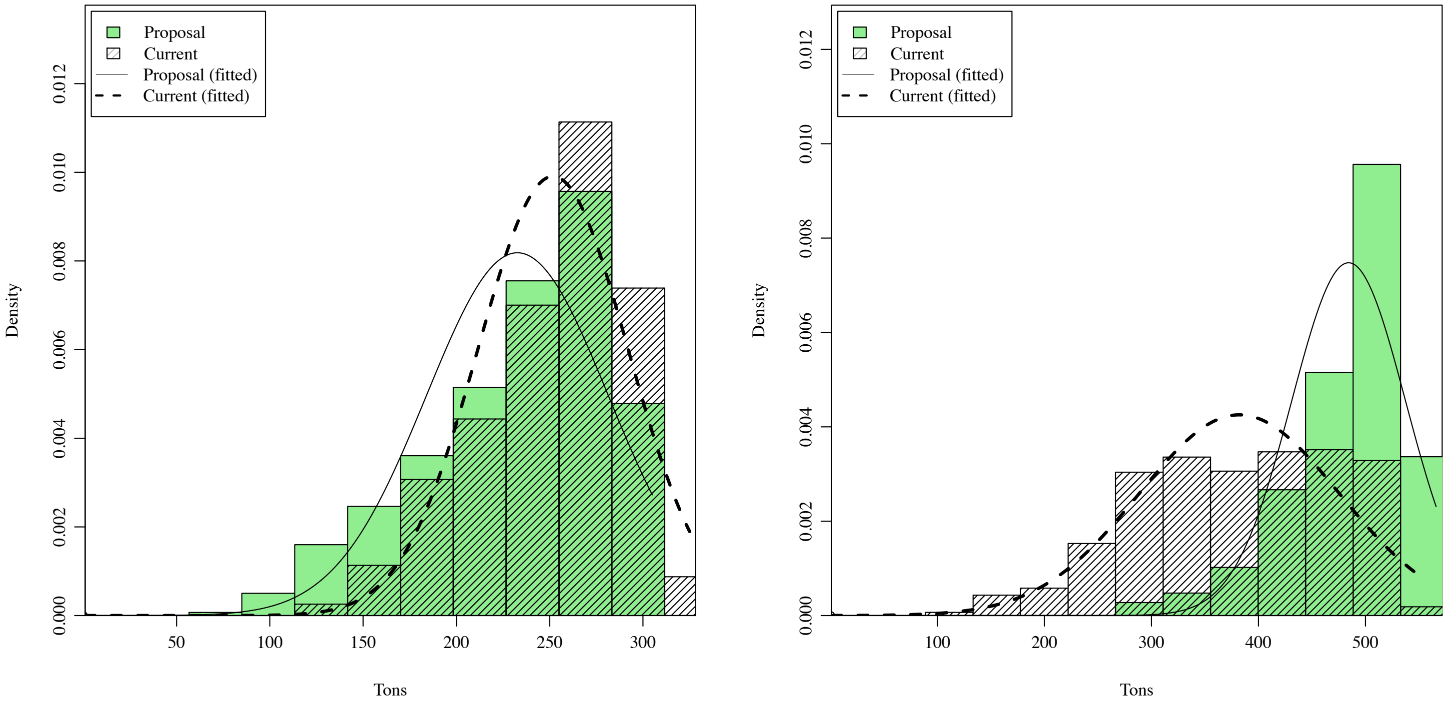
The proposed change to be assessed is a different stockyard layout that may enhance the supply and improve efficiency and/or effectiveness of the RMTS. This change was suggested by Materials Management Department (MMD) personnel based on previous studies. During the study analysis of the raw material usage of the different plants it was suggested to change the stockyard layout so that the materials are stored according to their usage rate, with the materials used the most stored in the front. The new stock yard layout can be viewed in Table B.10. In the new proposed layout SiMn slag is stored in the stockyard and no longer supplied using the tippler.

To fully analyse the effect that the new layout of stockpiles in the stockyard might have on the system, the proposal was tested on the current and M14 scenario. This is in order to understand the effect that changes in stockpile locations have on material availability. This might prove useful for future work on improvement studies. Figure 4.4 illustrates four of the graphs drawn during the proposal scenario analysis, two from the current scenario with and without the proposal, and two from the M14 scenario with and without the porposal. As can be viewed in these four graphs the proposed layout had mixed results on the system. For the current scenario the proposed changes had the effect of lowering the average material availability by 1,1% and increasing the MAD by 0,18%. For the M14 scenario it lowered the average by 2,2% but also lowered the MAD by 0,94%. The differences in the averages and MAD can be viewed in Table C.4

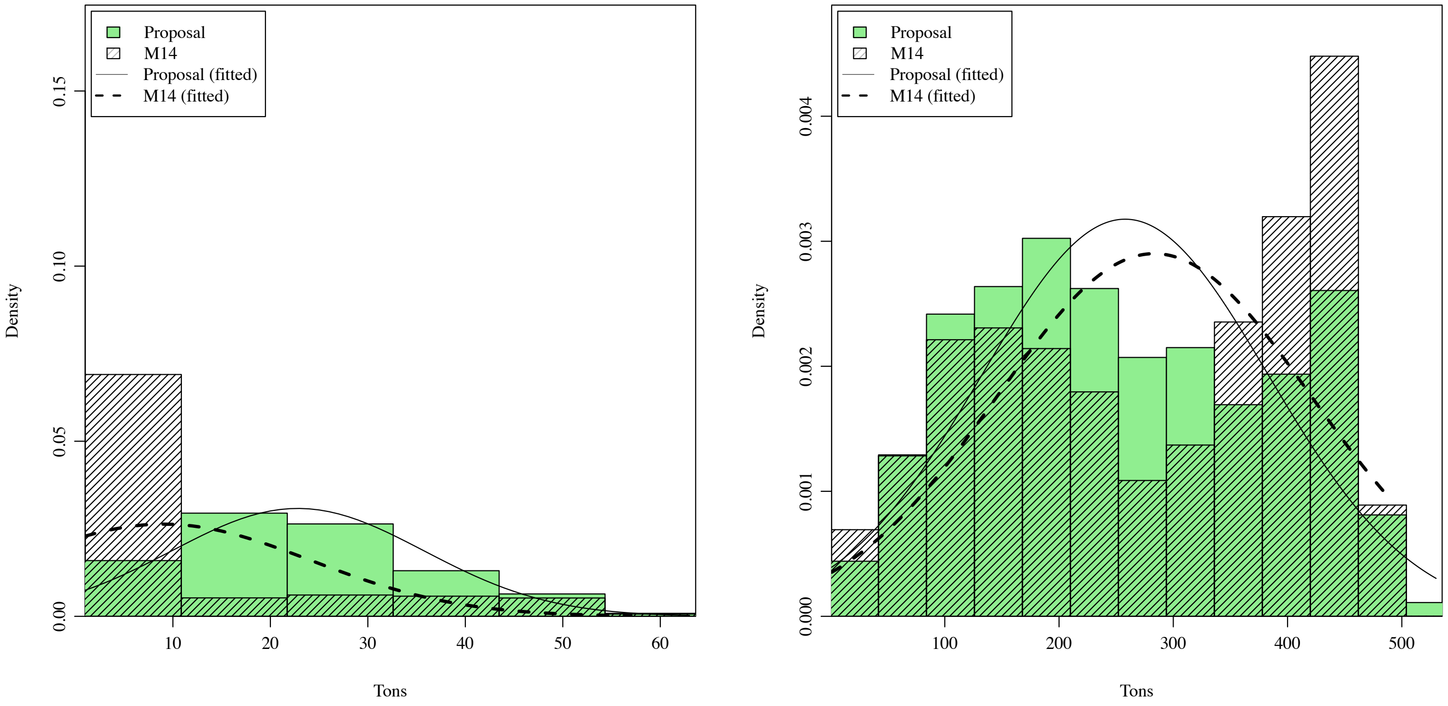
Analysis of the proposed changes in the current scenario showed interesting results for North and South Plant. Figure 4.4a illustrates how NHO at North Plant, a material in the second stockpile of the proposed layout, had a lower average and a wider spread. This indicates that moving it from the current scenario position of 385m to the proposed 222m decreased the availability. SiMn slag at South Plant on the other hand showed a significant increase in availability with the average increasing by 18,5% and the spread lowering as indicated by a difference in the MAD by 6,9%. Interestingly enough the SiMn slag availability at South Plant lowered during the M14 scenario analysis by 6,4%, this illustrates the unpredictability of outcomes if the layout is changed.

Figure 4.4c and Figure 4.4d illustrates how results were also unpredictable for other materials during the M14 scenario analysis. Chinese Coke availability at M14 increased by 12,8% eventhough it has been moved in the stockpile from a position of 484m to 506m. M1L availability decreased at South Plant eventhough it was moved a few meters to the front of the stockyard.

The problem with trying to increase RMTS efficiency by changing the stockyard layout is that time can never really be saved by putting material more frequently used closer to the start of the stockyard, as sooner or later the reclaimer will have to move to the end to supply the less used material. Because the reclaimer moves significantly slow, the time it takes to move to the less used material might nullify the time saved during the short movements of supplying the more frequently used materials. The stockyard layout also has little effect because operators usually start from one end of the stockyard and move al the way to the other end and back, supplying plants with the material from every stockpile along the way. However, material that is usually supplied by the tippler that is now stored in the stockyard showed a significant increase in availability.



(a) North Plant M10 NHO, current scenario (b) South Plant Slag SiMn, current scenario



(c) West Plant M14 Chinese Coke, M14 scenario (d) South Plant M1L, M14 scenario

Figure 4.4: Histograms of material availability with proposed change of stockyard layout

Chapter 5

Conclusions and recommendations

5.1 M14 implications

When taking into consideration the stochastic nature of certain processes and human operators that control the RMTS as well as the assumptions made, the model of the current scenario can be regarded as a relatively valid model. The model runs with less variation in decision making and more according to standard operating procedures than the system in the real world. This however does not render the model useless. The statistical parameters analyzed from the M14 scenario model can be used, not as accurate predictions, but as being relative to the current scenario model. These relative outcomes of the M14 scenario can now be inferred to estimate effects on the RMTS should M14 be built.

It clearly indicates that average material availability will drop by an average of 13,5% while the spread of the distribution will increase by an average of 5,8%. Through finer analysis it was also deduced that certain materials, especially Samquartz, Coke and MMS, might be in short supply as stockouts were recorded. This implies that the risk of a decrease in production as well as unwarrented breakdowns due to system overloading will increase during the M14 scenario.

5.2 Proposed modification

To enhance the supply and improve efficiency and/or effectiveness of the RMTS by altering the stockyard layout, appears to be a trial and error process. One can not seem to accurately predict the outcome of material availability time being gained and lost by reclaimer movement along the stockyard. The next problem with this idea is that materials are changed regularly in the stockyard as some materials are not available anymore. The replacement material then have to be stored in the stockyard in a new location to wait for the old material to be finished, thus making it very difficult to keep the same type of material in the same location.

The proposed modification showed an overall negative impact on both scenarios with mixed outcomes across the board. It can be argued that this layout might be a good layout to try and maintain because of the principle, but as seen from the analysis it does not increase the efficiency of the RMTS.

5.3 Recommendations

The M14 project represents a huge investment to BHP Billiton and if production of this future furnace as well as the current furnaces were to be hampered by frequent shortages of raw material supply, it could greatly affect profits. It is therefore recommended to search for alternative supply methods, test other modifications or alter the RMTS to allow for shorter or faster traveling.

Suggestions for future work to be done on the RMTS include:

- Hopper scheduling to allow supply to West Plant while other pants are being fed.
- Alternative supply methods to hoppers as these have a very slow supply rate, perhaps introduction of another tippler.
- Scheduling of tippler supply so that trucks can be loaded on time.
- Studies on the RMTS to determine components that can be improved or changed to allow faster supply.

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Appendix A

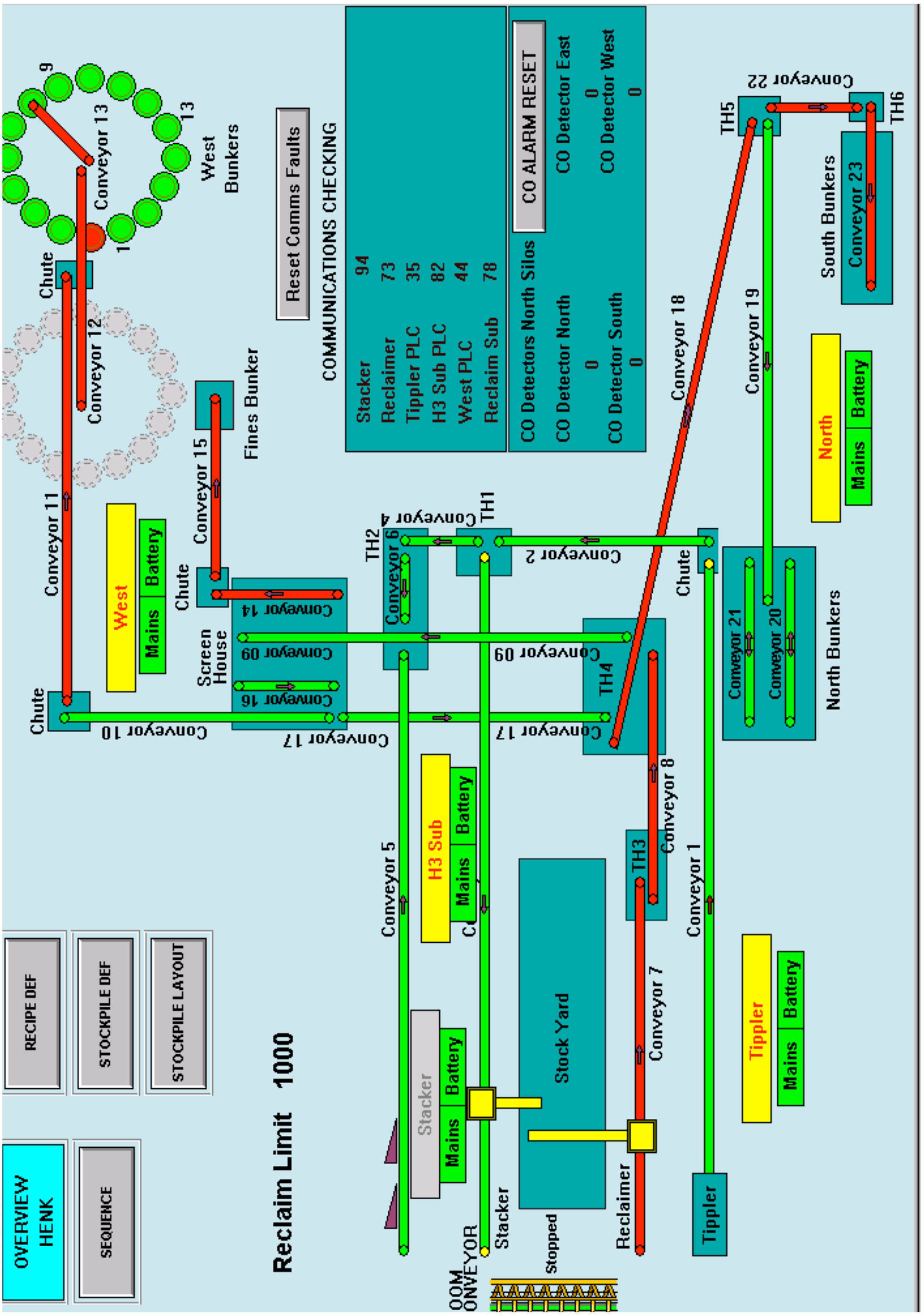
Layout of RMTS

Figure A.1 shows the Raw Material Transport System (RMTS) as seen by the operators in the control room from the systems controller and data acquisition (Systems Controller and Data Acquisition (SCADA)) system. This also represents the actual layout of the conveyors and their relative distances.

Raw material is dropped into the tippler, bottom left corner of Figure A.1. The raw material is then transported via conveyors 1,2 and 3 to the stacker line where a stacker creates piles of raw materials in either the new stock yard or old stock yard. On the left of the Figure one can see the new stock yard where all the different raw materials are stored until needed by the various plants. The old stock yard is not indicated on the figure but is situated on the stacker line and conveyor 5.

When raw material is needed the reclaimer line collects the raw material with a special machine, called a reclaimer, and transports the raw material via a complex system of conveyors either directly to the different plants, or via a screening process that removes fines and ensures the right size of raw materials. The finer detail of this transport system has been discussed ins section 3.1

At the top of Figure A.1 the grey circles indicate the proposed set of raw material silos for M14. The green circles indicate the raw material silos of M12. M14 will be a direct replicate of M12 and will receive raw materials using the same set of conveyors as M12.



Stacker 94
Reclaimer 73
Tippler PLC 35
H3 Sub PLC 82
West PLC 44
Reclaim Sub 78

CO Detectors North Silos
CO Detector North 0
CO Detector South 0
CO Detector East 0
CO Detector West 0

Figure A.1: SCADA view of RMTS

Appendix B

Simulation parameters

In this section the default parameter values for the simulation are specified. The values where calculated from plant operations data during the time period 3 to 24 June 2010. This time period was chosen as it is the longest stable time period regarding plant recipes and silo content.

Table B.1: Average rounds of raw material per day for each plant

Plant	**Average**	**Standard Deviation**
North M10	211	18
North M11	238	10
South	611	70
West	242	16

Table B.2: North Plant silo content M10

Silo	**Material**	**Level (%)**	**Volume (m^3)**
1	Coal Khutala	61	60
2	Remelt Brique FeMn	32	60
3	MMS	76	140
4	Coal Khutala	74	140
5	Remelt IronOre	99	60
6	Quartz Samquartz	5	55
7	W1L	61	140
8	NHO	64	140
9	MMS	63	140
10	Coke ChineseNuts	41	140

Table B.3: North Plant silo content M11

Silo	**Material**	**Level (%)**	**Volume (m^3)**
1	Coal Khutala	78	60
2	Remelt Brique FeMn	36	60
3	MMS	65	140
4	Coal Khutala	59	140
5	Remelt Brique FeMn	83	60
6	Quartz Samquartz	67	55
7	W1L	85	140
8	NHO	54	140
9	MMS	61	140
10	Coke ChineseNuts	75	140

Table B.4: North Plant M10 and M11 recipe

Material	**M10 Amount kg**	**M11 Amount kg**
Remelt Brique FeMn	70	0
MMS	1505	1155
Coal Khutala	624	583
Quartz Samquartz	180	216
W1L	385	840
NHO	875	350
Coke ChineseNuts	339	317

Table B.5: South Plant silo content

Silo	**Material**	**Level (%)**	**Volume (m^3)**
1	Coal Khutala	76	200
2	NHO	72	200
3	M1L	85	140
4	W1L	58	140
5	Coke ChineseNuts	64	120
6	Remelt Brique SiMn	61	100
7	Quartz Samquartz	25	160
8	SlagSiMn	32	160
9	Coal Khutala	89	200
10	Coal Khutala	92	200
11	M1L	72	140
12	Reelt Brique MNPICK	67	140
13	Remelt Pellets	26	140
14	W4L	76	100
15	Quartz Samquartz	26	160
16	SlagSiMn	71	160

Table B.6: South Plant recipe

Material	**Amount kg**
M1L	500
SlagSiMn	360
Remelt Brique SiMn	50
Coal Khutala	370?
Remelt Brique MNPICK	50
Quartz Samquartz	364
W1L	150
NHO	200
Coke ChineseNuts	41
W4L	150
Remelt Pellets	0

Table B.7: West Plant silo content

Silo	**Material**	**Level (%)**	**Volume (m^3)**
1	NHO	49	70
2	W1L	56	70
3	W1L	80	70
4	NHO	32	70
5	MMS	2	70
6	MMS	14	70
7	MMS	86	70
8	M1LMix	30	70
9	Remelt IronOre	44	70
10	Quartz Samquartz	74	70
11	Coal Khutala	59	70
12	Coke ChineseNuts	62	70
13	Coal Khutala	58	70
14	Quartz Samquartz	29	70
15	Coke ChineseNuts	12	70
16	Remelt Brique FeMn	32	70

Table B.8: West Plant recipe

Material	**Amount kg**
NHO	525
W1L	525
MMS	2380
Quartz Samquartz	217
Coal Khutala	612
Coke ChineseNuts	326
Remelt Brique FeMn	250

Table B.9: Current stockyard layout

Stockpile	**Material**	**Start**	**End**
1	None	0	12
2	MMS	12	90
3	MSS	105	174
4	W4L	180	230
5	W1L	236	276
6	M1L	282	328
7	Quartz Samquartz	334	381
8	NHO	385	438
9	MHS	444	478
10	Coke ChineseNuts	484	585

Table B.10: Proposed stockyard layout

Stockpile	**Material**	**Start**	**End**
1	MMS	6	216
2	NHO	222	342
3	M1L	348	413
4	Samquartz	419	461
5	Slag Simn	467	500
6	Coke ChineseNuts	506	536
7	W1L	542	573
8	W4L	579	588

Table B.11: Safety timers per plant

Plant	**Normal**	**Screening**
West	220	175
South	520	280
North	540	340

Table B.12: Material fed by Tippler

Material	**Frequency (/24hr)**	**Tippler Supply Rate**	**Hopper Supply Rate**
Coal Khutala	3	400	170
SlagSiMn	1	900	170
Remelt Brique FeMn	1	900	170
Remelt Brique MNPICK	1	900	170
Remelt Brique SiMn	1	900	170

Table B.13: Maintenance schedule June 2010

Day	**Areas affected**	**System components**	**Duration**	**Substitute Components**
Monday	Reclaimer	Reclaimer, CV7, 8	8 Hours	Tippler
Tuesday	Tippler	Tippler, CV 1–4	8 Hours	Hoppers A&B
Wednesday	West Plant, Tippler	CV4, 6, 9, 10–17, Hoppers A&B	8 Hours	Hopper C
Thursday	North & South Plant	CV 18–23	8 Hours	N/A

Appendix C

Model results

Table C.1: Actual vs model output

	Material	**Difference in average**	**Difference in Mean Average Deviation (MAD)**
North Plant M10	Remelt FeMn	23,4%	2,9%
	MMS	14,4%	0,4%
	Coal Khutala	37,2%	19,2%
	Samquartz	4,8%	5,2%
	W1L	1,6%	11,8%
	NHO	7,4%	5,7%
	Coke Chinese Notes	2,8%	0,3%
North Plant M11	MMS	11%	2,7%
	Coal Khutala	1,8%	9%
	Samquartz	7%	4,7%
	W1L	14,4%	8,3%
	NHO	7,8%	9%
	Coke Chinese Nuts	4,6%	0,3%
South Plant	M1L	10,4%	16,5%
	Slag SiMn	26,5%	1,6%
	Remelt SiMn	17,1%	10,6%
	Coal Khutala	11,2%	11,9%
	Remelt MnPick	28,1%	12,7%
	Samquartz	12,5%	6,1%
	W1L	8,1%	3,5%
	NHO	8,7%	1,7%
	Coke Chines Nuts	17,5%	2,1%
	W4L	14,4%	4,2%
West Plant M12	NHO	17,1%	9,3%
	W1L	20,2%	11,9%
	MMS	9,5%	2,8%
	Samquartz	6,6%	10,3%
	Coal Khutala	22,2%	5,1%
	Coke Chinese Notes	8,37%	2,2%
	Remelt FeMn	21,8%	5,6%
	Average	13.3%	6.91%

Table C.2: Current vs M14 Model Output

	Material	**Difference in average**	**Difference in MAD**
North Plant M10	Remelt FeMn	-2,5%	-0,7%
	MMS	-17%	0,7%
	Coal Khutala	-8,9%	-2,2%
	Samquartz	-19,9%	9,3%
	W1L	-23,4%	14,9%
	NHO	-23%	10,8%
	Coke Chinese Notes	-8,9%	1,3%
North Plant M11	MMS	-19,8%	-1,5%
	Coal Khutala	-2,1%	0,7%
	Samquartz	-14,1%	8%
	W1L	-25%	10,7%
	NHO	-22%	15,1%
	Coke Chinese Nuts	-4,7%	2,1%
South Plant	M1L	-28,3%	17,4%
	Slag SiMn	-0,7%	0,3%
	Remelt SiMn	0,4%	-0,1%
	Coal Khutala	-4,4%	1%
	Remelt MnPick	1,7%	-0,2%
	Samquartz	-34,8%	7,8%
	W1L	-24,3%	10,6%
	NHO	-24,1%	11,5%
	Coke Chines Nuts	-6,75%	3,2%
	W4L	-15,9%	9,8%
West Plant M12	NHO	-21,1%	13,5%
	W1L	-21,5%	13,4%
	MMS	-9,6%	-1,3%
	Samquartz	-13,2%	14,7%
	Coal Khutala	-4,4%	2,6%
	Coke Chinese Notes	-7,8%	-1,8%
	Remelt FeMn	0,5%	-0,4%
	Average	-13,52%	5,84%

Table C.3: Current scenario proposed modification analysis

	Material	Difference in average	Difference in MAD
North Plant M10	Remelt FeMn	0,7%	-2,8%
	MMS	-3,3%	1,5%
	Coal Khutala	-7,2%	1,7%
	Samquartz	-3,5%	1,4%
	W1L	-1%	0,2%
	NHO	-5,9%	2,2%
	Coke Chinese Notes	3,1%	-1,1%
North Plant M11	MMS	-3,8%	-1%
	Coal Khutala	-6,2%	0,6%
	Samquartz	-6,3%	0,2%
	W1L	-4,7%	0,6%
	NHO	-3,8%	2,9%
	Coke Chinese Nuts	5,7%	-2%
South Plant	M1L	-8%	2,4%
	Slag SiMn	18,5%	-7%
	Remelt SiMn	-0,01%	0,4%
	Coal Khutala	0,8%	1,2%
	Remelt MnPick	0,4%	0,5%
	Samquartz	-8,2%	1,6%
	W1L	-1,6%	-1%
	NHO	-5,2%	3,2%
	Coke Chines Nuts	9,9%	-2,7%
	W4L	-10,7%	2,8%
West Plant M12	NHO	-3,2%	0,8%
	W1L	-3,3%	2,3%
	MMS	2,8%	0,1%
	Samquartz	3,5%	0,3%
	Coal Khutala	1,5%	0,7%
	Coke Chinese Notes	2,9%	-3%
	Remelt FeMn	3,1%	1,3%
	Average	-1,1%	0,18%

Table C.4: Current scenario proposed modification analysis

	Material	**Difference in average**	**Difference in MAD**
North Plant M10	Remelt FeMn	4,2%	-2,2%
	MMS	-6,5%	-1,1%
	Coal Khutala	0,4%	-0,1%
	Samquartz	0,3%	-,4%
	W1L	-1,7%	-0,4%
	NHO	-1,4%	-0,8%
	Coke Chinese Notes	-0,5%	-0,3%
North Plant M11	MMS	-4,8%	-2,6%
	Coal Khutala	-6,5%	0,3%
	Samquartz	-0,6%	-1,6%
	W1L	3,1%	-3,2%
	NHO	-4,9%	-0,9%
	Coke Chinese Nuts	2,8%	-1,7%
South Plant	M1L	-5,1%	3,2%
	Slag SiMn	-6,5%	8,1%
	Remelt SiMn	0,1%	0,2%
	Coal Khutala	0,4%	0,3%
	Remelt MnPick	-0,6%	-0,1%
	Samquartz	-5,7%	-5,4%
	W1L	-2,5%	0,1%
	NHO	-1,8%	0%
	Coke Chines Nuts	2,9%	-0,9%
	W4L	-8,1%	-0,8%
West Plant M12	NHO	-3,8%	-0,1%
	W1L	-5,2%	2%
	MMS	-8,9%	-0,4%
	Samquartz	-4%	-2,2%
	Coal Khutala	1%	-0,2%
	Coke Chinese Notes	3,5%	2,3%
	Remelt FeMn	1,7%	-0,5%
West Plant M14	NHO	-10,4%	-1,9%
	W1L	-6,1%	-2,8%
	MMS	-17,2%	-8,3%
	Samquartz	-2,8%	-4,4%
	Coal Khutala	-0,5%	-0,1%
	Coke Chinese Notes	12,8%	-1,4%
	Remelt FeMn	-1,1%	0%
	Average	-2,2%	-0,9%