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Impact analysis of Capesize vessels on ArcelorMittal Ghent

A cost-based opportunity study concerning vessel logistics and steel site supply chain

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This document contains the redacted version of the thesis which is handed in to the graduation committee. Some parts have been redacted due to the fact that they contained company sensitive information of ArcelorMittal Ghent. Examples are source materials, prices and certain costs.

The tables that are redacted are labeled REDACTED in the title and can easily be found in the list of tables. One figure is redacted and removed but can still be found in the list of figures. Finally, sensitive numbers in the text have been replaced by X's. Chapter 4 and Chapter 8 are the main chapters that have been altered.

Content-wise this document is similar to the unredacted version. If for some reason, more information is required from the unredacted version, A. Van Hove can be contacted (see graduation committee).

Abstract

The enlargement of the lock complex of Terneuzen in 2023 will allow Capesize vessels up to 300 meters in length, to access the Ghent-Terneuzen canal and reach the quay of ArcelorMittal Ghent (AMG). The goal of this thesis is to estimate to what extent these vessels can be used, the impact that these vessels will have on the supply chain and the cost impact of the implementation of Capesize vessels.

The production of AMG is expected to be increased up to 5.5 million ton of steel for 2026. Therefore, it will require an estimated 12.9 million ton of raw materials (12% increase compared to 2019) which mainly consist of iron ore and coal. Up to 31% of this material can be shipped from source ports that are accessible by Capesize vessels. The draught restriction of 12.5 meters for the canal, limits the amount of bulk material that can be unloaded by the Capesize vessel to 105,000 DWT which is 60% of the maximum of 175,000 DWT. The remaining 70,000 tons of material can be unloaded externally and be transported to AMG by the use of inland barging vessels. The increased volume of Capesize vessels compared to the current Panamax vessels will lead to an increase in load size and a decrease in load frequency which will affect the downstream installations of AMG. Most of the current quay cranes will be unable to unload Capesize vessels due to the increased size of the ships. A proposed crane was introduced in the model to examine the ideal positioning to unload Capesize vessels and barges.

6 realistic scenarios for 2026 have been examined with varying levels of Capesize utilization. As a result of these scenarios vessel arrival lists for full year were simulated. Each of the vessel lists served as input data on a quay model with as results the downstream impact. The main output parameters were the waiting time for sea vessels, waiting time for barges and the amount of material that had to be stored on a temporary storage. In general, the implementation had a negative effect on all three of the output parameters resulting in additional quay costs.

The net effect of Capesize vessels on the total costs was positive thanks to the lower shipping price per ton of material. This benefit was partly compensated by the increased costs for barging that was caused by Capesize transport. The barging could be eliminated by sharing Capesize vessels with other sites resulting in a cost reduction of 1.65 euro per ton for iron ore and 5.29 euro for coal. When the material cannot be shared, the Capesize shipping price for Brazilian iron ore is 1.59-2.02 euro more favorable compared to the current transport by Panamax vessels, depending on the source port and external stock that is used.

The shipping costs for Capesize vessels should at least be 2.53 dollar per ton cheaper, to break-even with Panamax vessels. Under current circumstances the full-scale use of Capesize vessels can be feasible. However due the high volatility of the dry bulk market and bunker prices, it is impossible to guarantee this will be the case for 2026.

Table of Contents

Lists of figures, tables and acronyms

List of figures

List of tables

List of acronyms

A10GNT	Crane configuration with the A10 crane on the Ghent side of the quay
A10ZZ	Crane configuration with the A10 crane on the Zelzate side of the quay
AM Shipping	Shipping department of ArcelorMittal global
AM Sourcing	Sourcing department of ArcelorMittal global
AMA	ArcelorMittal Asturias, Spain
AMB	ArcelorMittal Bottrop, Germany
AMDK	ArcelorMittal Dunkirk, France
AMG	ArcelorMittal Ghent, Belgium
AMMIN	ArcelorMittal Mining
AMMIN-KRYC	ArcelorMittal Mining Kreyvik Ryk iron ore
AMMIN-NCWT	ArcelorMittal Mining Mount Wright iron ore concentrate
AMZKZ	ArcelorMittal Dąbrowa Górnicza, Sosnowiec and ZKZ, Poland
ARA range	Waters between Amsterdam, Rotterdam and Antwerp
BB	Board-board unloading
BTS	Buitentransport (Logistics department AMG)
DWT	Dead Weight Tonnage (maximum load of vessel)
EMO	Europees Massagoed Overslag (external stock Rotterdam)
FIFO	First in, first out
FR scheduling	Full random scheduling of arrivals
GHV	Raw Materials department of AMG
GNA	Gemeenschappelijk Nautische Authoriteit (Dutch waterway authority)
GT	Gross tonnage (hull volume of ship)
HFO	Heavy fuel oil
HLN	Belgium newspaper
IOC	Iron Ore Company Canada, partly owned by Rio Tinto
IO	Iron Ore
LKAB	Luossavaara-Kiirunavaara Aktiebolag (mining company, Sweden)
MGO	Marine Gas Oil
NSP	North Sea Ports (port authority Westerschelde area and Ghent)
OBA	Bulk terminal Amsterdam
OVET	Overslag Vlissingen en Terneuzen (external stock Flushing)
PCI	Pulverized Coal Injection
PDM	Brazil 2 (source port for iron ore in Northern Brazil)
PSRM	Planning Supply and Raw Material department of AMG
SSFT	Standardized Sinter Feed Brazil 1
VLOC	Very Large Ore Carrier
VLSFO	Very Low Sulphur Fuel Oil

1. Introduction

1.1 Introduction

Steel is unarguably the most used metal worldwide and it therefore requires raw materials supply on an enormous scale. Primary steel production is the largest driver for the mining industry accounting for almost half of the total revenue (World Economic Forum, 2015). ArcelorMittal is the world's largest steel producer with a total production of almost 90 million metric tons of steel per year in 2019. Besides the manufacturing of steel in 19 countries, the company has assets in infrastructure, transport and mining. The Belgium cluster is an important contributor with an annual production of 4.9 million tons of steel per year. The Belgium cluster consist of a primary steel plant in Ghent and downstream facilities in Ghent, Geel, Genk and Liege.

The main raw material that is used for the ferrous industry is iron ore which is an iron oxide. During the steel making process the iron component is extracted from the ore. This can only be done after a certain number of processes which are illustrated in figure 1. Iron ore is extracted at an underground or open pit iron ore mine. The material is usually extracted by a combination of drilling and blasting after which the rocks can be excavated and moved to a primary crusher. The material is further processed in a crushing and screening plant until it reaches a grain size fine enough to be fed to a mill. Milling is an energy consuming process to break down the iron ore till a fine mix of high concentrated iron ore which mostly is the end-product of the mine. This end-product will be transported over land by rail, road or conveyor to a nearby deep-water port where it can be loaded on ships.

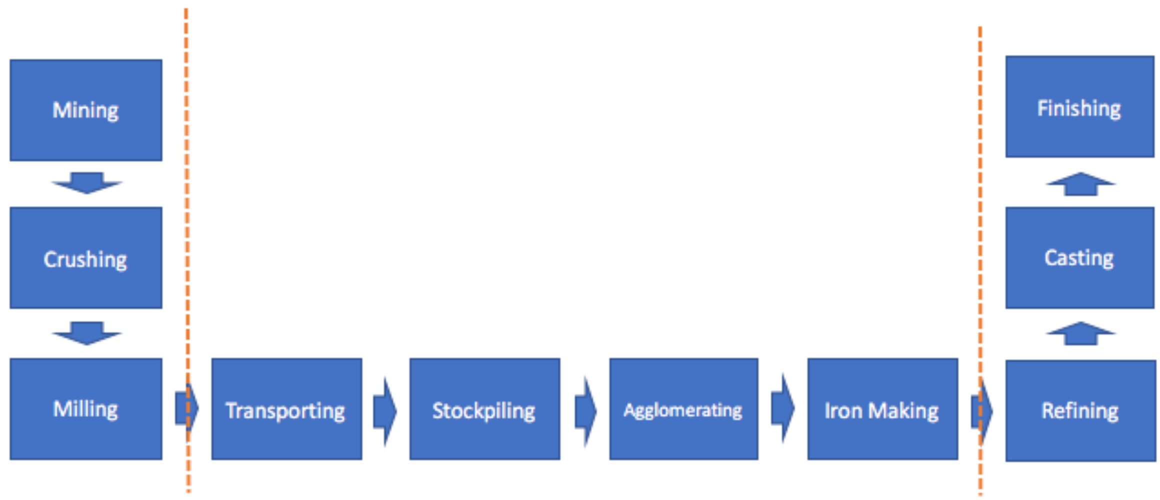

Figure 1: Different stages in steel production

Large dry bulk vessels transport the material from the source port to the steel companies that will further process the material and extract the iron component from the ore. The ships are unloaded by bulk cranes and by a network of conveyors the ore will be transported to the stockyards. The stockpiled iron ore can be used for the production of an iron ore agglomerate called sinter which is formed by partially melting the iron ore at a sinter plant. Another option is to agglomerate the iron ore already at the mine site into small balls called pellets and to transport this in a similar manner to the steel site as the iron ore fines. The iron ore agglomerates are fed to the blast furnace where the iron ore get reduced with carbon. The end product of the blast furnace is a molten substance called hot metal which consist mainly of pure iron.

The hot metal still contains some carbon and other unwanted contaminants which are removed during the refining process. In a basic oxygen furnace, oxygen is added to further purify the hot metal after which it can be called steel. The liquid steel is casted into slabs and transported to the milling facilities. During the milling process the slabs are rolled into a flat end-product called steel rolls. These rolls can be further processed or sold directly to customers.

This thesis will focus on the transportation of the raw materials and the upstream facilities of the steel site where the raw materials are transformed to hot metal. These processes can be divided geographically as shown in figure 2. The first part of the processes is within the transporting domain while the second part takes place at the upstream facilities of the steel site in Ghent.

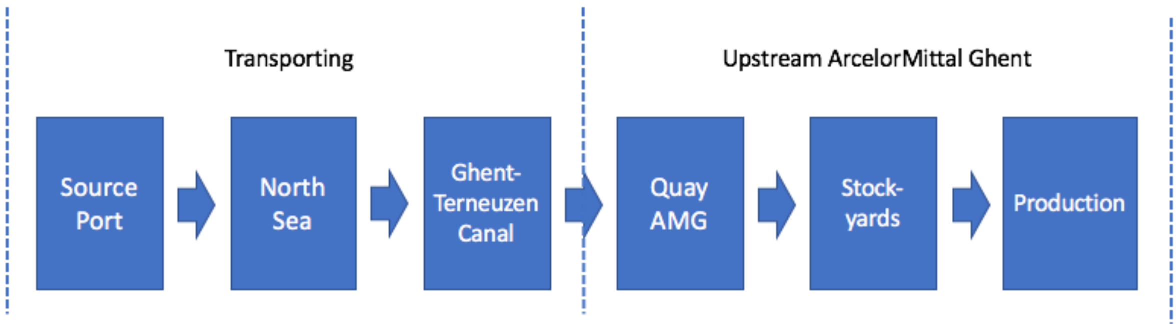

Figure 2: Geographical stages in hot metal supply chain

Besides iron ore, there are other materials required for the production of hot metal. Chapter 2 will elaborate on all of the used materials. Figure 3 shows the locations where the two main components, iron ore and coal, are extracted. As shown, the materials destined for ArcelorMittal Ghent (AMG) are imported from all over the world. The transport time for materials is ranging from several days within Europe, till almost 2 months if the material originates from Australia. Most materials are imported over long distance in large amounts and therefore the transport needs to be as efficient as possible. To increase this efficiency and to decrease the cost per ton, the material should be transported in large volumes. Currently, vessels up to 75.000 DWT (dead weight tonnage) called Panamax vessels, are the ships with the lowest cost per ton while still being able to reach the quay of AMG. Larger vessels called Capesize vessels are able to transport to the North Sea region but cannot reach the quay of AMG due to the width constraints of the Lock of Terneuzen which the vessels need to pass on the journey to Ghent.

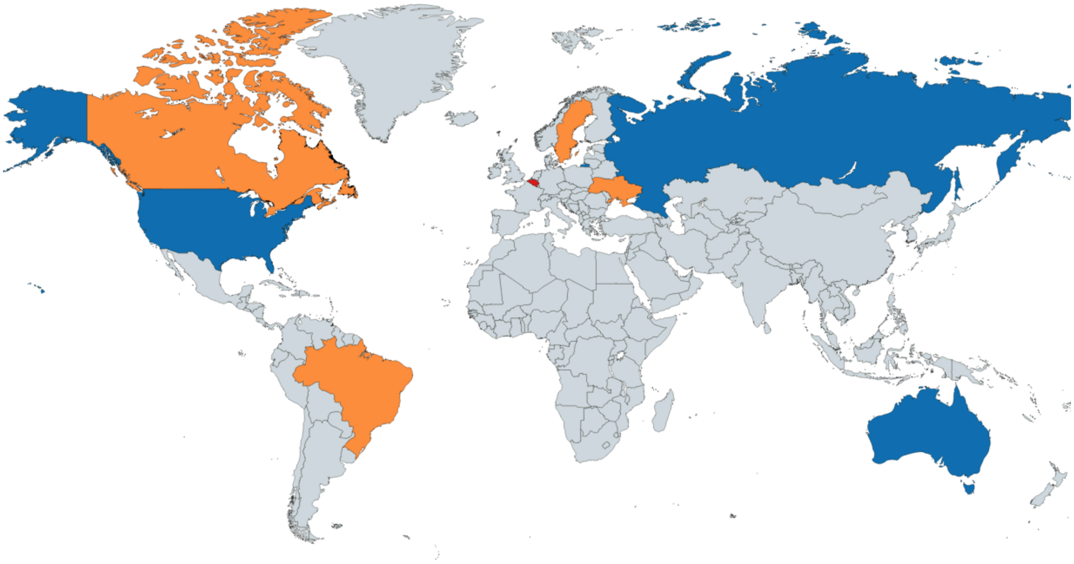

Figure 3: Main sources of raw materials for AMG (iron ore in orange and coal in blue)

After the vessel is loaded at the source part, it can start the voyage to the North Sea. Figure 4 shows the geographical position of the most important locations for the bulk transport of raw material to AMG in this region. The vessels arrive at an agreed anchorage point on the North Sea (also called the pilot point). Panamax vessels destined for Ghent have to wait at this point until they receive a port call from AMG and the involved authorities. Capesize vessels that cannot reach the quay of AMG are redirected to one of the two external bulk storages in Rotterdam (EMO) or Flushing (OVET). The material will be unloaded at the external stocks and transported to AMG by the use of smaller vessels called barges. To reach the steel site, the vessels and barges have to access the Ghent-Terneuzen canal which is sealed off by the Lock of Terneuzen. Panamax vessels are able to pass through this lock in width and length but are too heavily loaded to pass the depth restriction of the lock. Therefore, they need to be partially unloaded on barges near Terneuzen which is done by floating cranes of the OVET.

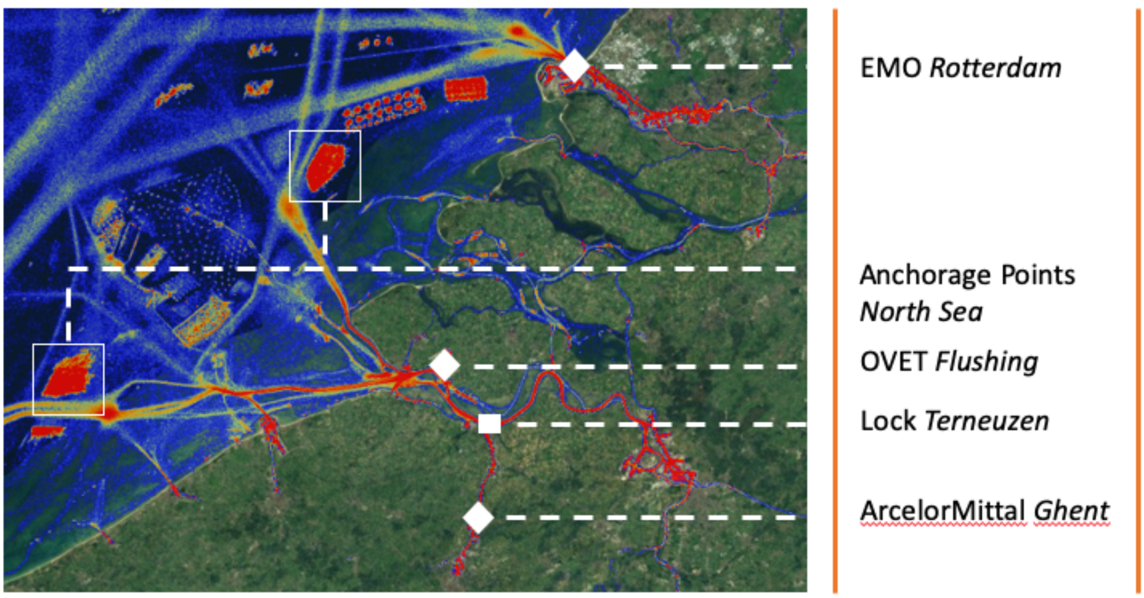

Figure 4: Main locations North Sea project on bulk vessel heat map

After all depth requirements have been met, the material can travel south through the Ghent-Terneuzen canal. The second part of processes stated in figure 2 is located on the site of AMG. Figure 5 shows a satellite image of ArcelorMittal Ghent with the most important locations for this thesis. The arriving barges and vessels are unloaded by quay cranes on a conveyor network that transports the material to the stockyards. There are separate stockyards for different types of coal and iron ore. When the material is required by the upstream production facilities it is reloaded onto the conveyor network and transported to the corresponding facilities. Chapter 2 gives a more detailed overview of these processes.

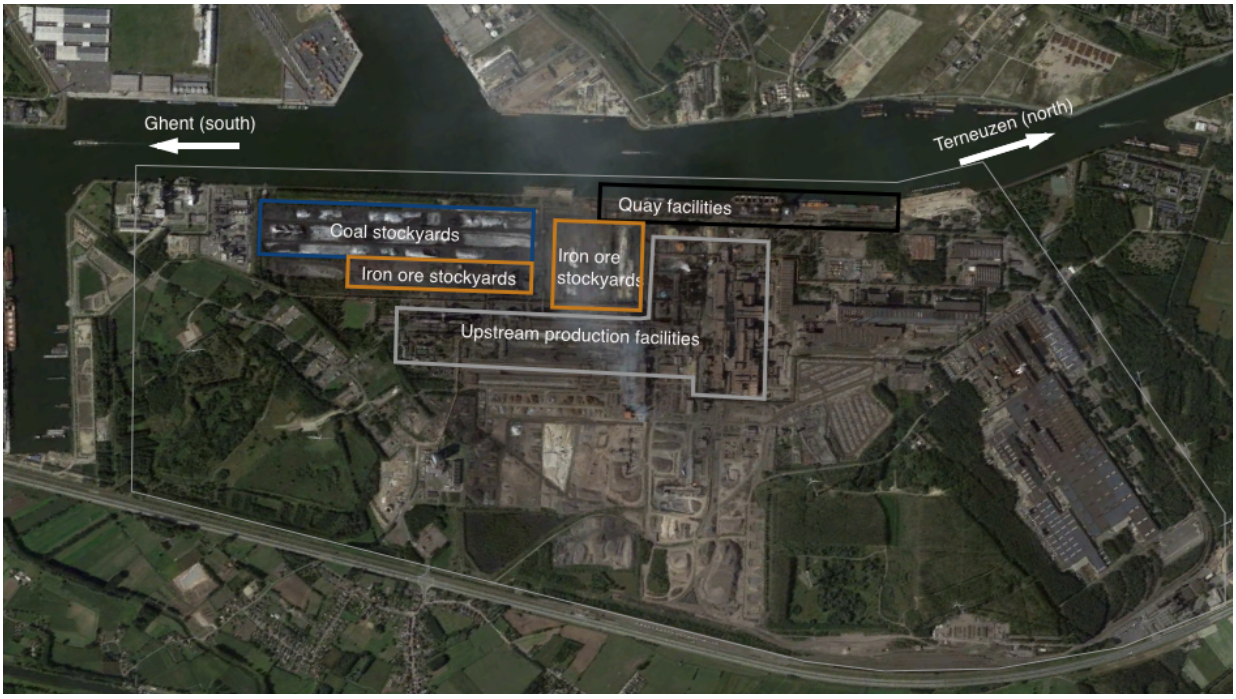

Figure 5: Main locations within AMG located alongside the Ghent-Terneuzen canal

With a general understanding of the current supply chain, the main subject of the thesis can be formulated. As stated earlier the efficiency of the transport by sea is directly linked to the quantities of material that can be transported with each journey. In 2023, the current Lock of Terneuzen is planned to be replaced by a larger lock called 'The New Lock'. With the implementation of this lock, Capesize vessels will be able to reach AMG. Furthermore, there will also be a production increase in 2026 which will increase the demand for raw materials. Both of these implementations will affect the frequency and quantity of the arrivals of vessels at the quay of AMG. This can have a significant effect on the earlier sketched supply chain of raw materials, ranging from the source ports located worldwide to the stockyards at the site of AMG. In this thesis this effect will be quantified by using an extensive analysis of the supply chain. The potential and limitations of the use of Capesize vessels will be examined and the effect of different scenarios of Capesize utilization will be analyzed.

1.2 Aim of thesis

The main goal of this thesis will be to give an impact estimation of the transportation of raw materials for ArcelorMittal Ghent in 2026. In this impact estimation, different degrees of Capesize utilization will be analyzed. The impact will be measured in the total costs of operations and the occupancy of the quay and downstream facilities. Combined, this will answer the main research question of this thesis: '*What will be the impact of the use of Capesize vessels on ArcelorMittal Ghent in 2026?*'

This main question does not stand on its own and requires results from different stages of the raw materials supply chain. Therefore, the following sub questions should be answered first.

1. *What will be the influence of a production increase till 5.5Mt steel per year, on the quay and production facilities of ArcelorMittal Ghent?*
2. *To what extent can Capesize vessels be used for transporting material to ArcelorMittal Ghent?*
3. *How will the arrivals of Capesize vessels influence the downstream supply chain of raw materials?*
4. *Which price differences between Panamax and Capesize vessels are necessary to make the use of Capesize vessels feasible?*
5. *What will be the influence of the addition and positioning of a new quay crane?*
6. *Which external stock will bring the most benefits for Capesize unloading?*

The answers to sub questions 1 and 2 will give insight in the current quay usage of AMG and how this is expected to change for the year 2026. The impact of a production increase will be examined and an estimate will be given, which raw materials will be used in the future. The initial possibilities and limitations for Capesize vessel will be discussed to estimate realistic scenarios in which Capesize vessels can be used.

When realistic Capesize scenarios are established, the impact of these changes will be examined. Sub question 3 will provide answers on how Capesize vessels will influence the waiting queue for ships and barges and how they will affect the functioning of cranes, conveyors and stockyards. The cost reduction of using Capesize vessels and the increased cost by the upstream and downstream effects will be analyzed in sub question 4. The remaining 2 sub questions are less focused on the main question but include two topics that can be of great influence on the Capesize situation. A newly proposed crane needs to be installed to unload vessels with a width of over 40 meters and the positioning in relation to the other cranes can influence the overall efficiency. Finally, the use of Capesize vessels requires an extra stop before these ships can reach the quay of AM Ghent. Each possibility has different (dis)advantages and eventually the questions has to be answered which of the options will have the most potential.

With all these 6 sub questions answered, the total impact on the quay of ArcelorMittal can be evaluated. This evaluation will be based on the limitations in capacity and the total benefit of the cost reduction.

1.3 Scope of thesis

The question whether or not to use Capesize vessels for AMG is comprehensive and therefore requires a clear scope of what should be included in this thesis and what not. The most logical way of doing this is by marking clear boundaries within the overall supply chain of the raw materials. The upstream supply chain is limited from the moment the material will be loaded on the vessel in the source port. The mining of the different materials itself will not be included and neither will be the logistics of material transport to the source ports. Downstream of the quay, the scope is limited by the upstream production facilities. These facilities require certain input rates of material from the stockpiles but besides that, they will not further influence this thesis. Within these two boundaries all processes are linked to each other and therefore the materials loaded in the source ports will have a direct effect on the capacities of the stockyards. It works the other way around as well that the outflow of the stockpiles should be matched by the inflow of material through the incoming vessels. Figure 6 shows the main processes that are included in the scope.

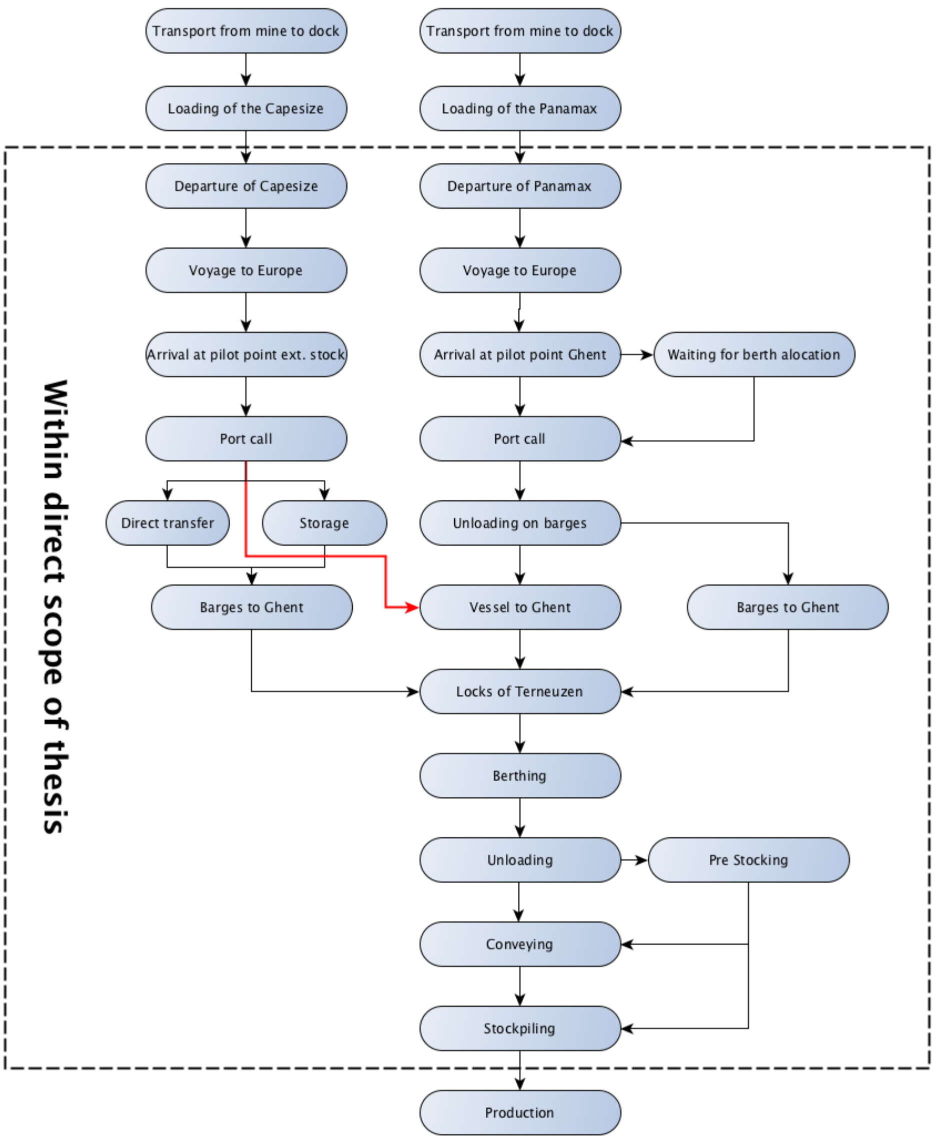

Figure 6: Scope of thesis with in red the extra Capesize opportunity

1.4 Outline thesis

The base of the study will be an introduction to the domains of shipping, bulk terminals and steel site supply chain. It will be partly based on literature but mainly on the current practice of the raw materials supply chain at AMG. Chapter 3, 4 and 5 are the three main pillars on which the research is built: the potential and limitations of Capesize vessels and an estimation of the estimated inflow of raw materials in 2026. By combining these chapters, multiple realistic scenarios can be given of the vessel and barge arrivals in 2026, each using a different amount of Capesize utilization. These scenarios will be translated into vessel arrival lists that will be the input for the next two chapters. In Chapter 7 existing modelling software will be used and altered to give an estimation of the impact of Capesize vessels on the on-site facilities of AMG such as the cranes, conveyors and stockyards. Chapter 8 will look at the cost impact of the Capesize vessels on the shipping price but also on the overall supply chain. The results of these impact studies will lead to the conclusions in which the sub questions and finally the research question will be answered. Figure 7 shows how the different chapters of this thesis relate to each other. At the beginning of each chapter a short summary is given of what will be discussed. Figure 2 will be used to give a clear indication which part of the supply chain is reviewed. At the end of most Chapters the main findings of the corresponding chapter will be summarized.

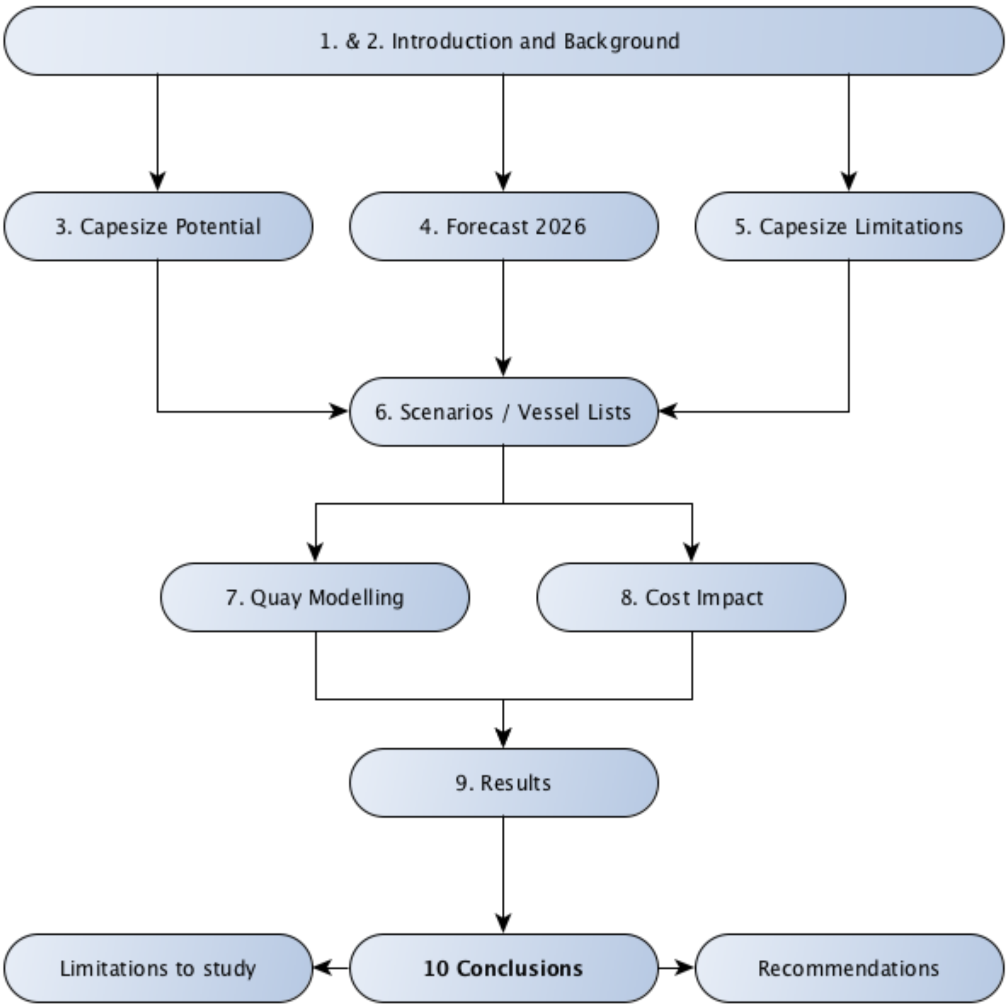

Figure 7: Outline of thesis

2. Background

This chapter is used to provide additional information which is required to start the research. It contains a combination of relevant literature and practical information concerning the raw material supply chain of ArcelorMittal Ghent. An introduction will be given in dry bulk vessels and dry bulk terminals in general, after which the supply chain of AMG, which was briefly discussed in Chapter 1, will be covered extensively. This includes all the internal and external stakeholders. Since this contains the complete process from raw material until hot metal, every step of the original figure 2 is included in this chapter. There will be no findings summarized at the end due to the fact that this chapter only contains background information.

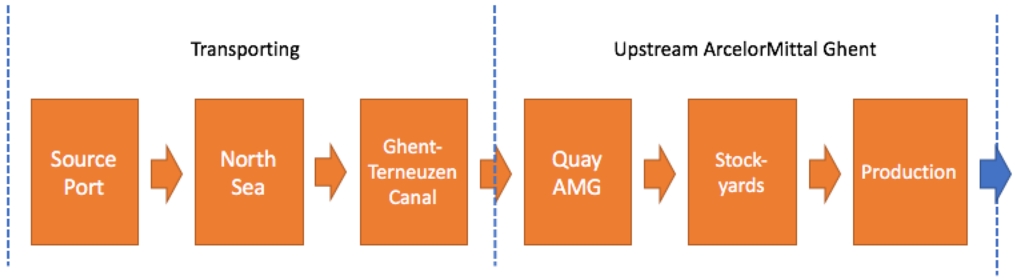

Figure 8: Steps in supply chain that are discussed in Chapter 2 (in orange)

2.1 Dry Bulk Vessel sizes

This subchapter introduces the different types of bulk carriers used for the transport of raw materials. Most international sea transport can be divided into 4 categories: container cargo, break-bulk cargo (general cargo neither in containers or bulk), bulk liquid cargo and dry bulk cargo. (Gerhardt, 1995). A steel mill, such as AMG, imports (raw) materials as dry bulk cargo while exporting materials as break-bulk cargo. This thesis fully focusses on the import of raw materials. The raw materials are imported in different quantities and therefore require different vessel sizes. Figure 9 shows the main classes in vessel sizes that are used for dry bulk transport with the corresponding vessel sizes that are used in this thesis. In 2014 there were an estimated 10.000 dry bulk carriers above 5.000 DWT (UNCTAD, 2015). Of these vessels 29% were indicated as Panamax vessels (55.000-80.000 DWT) and 19% as small Capesize vessels (80.000-200.000 DWT).

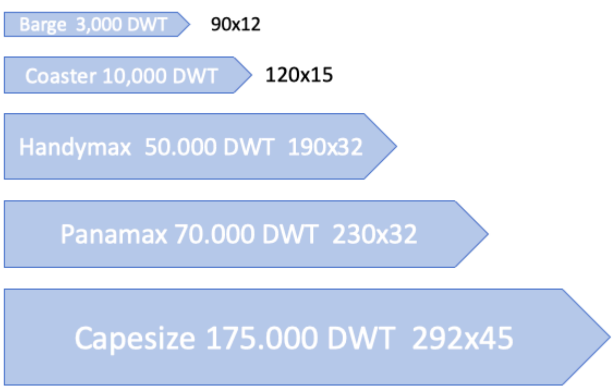

Figure 9: Dry bulk vessels with dimensions and maximum DWT

Subclasses can be made based on regional restrictions of certain waterways and locks. The most well-known are the Seawaymax vessels which derived their name from the fact that it is the maximum size vessel that can pass through the draught restriction of 8 meters and can access the Atlantic Ocean from the Great Lakes area. For this thesis it is important to take note of the subclasses for Capesize vessels which are shown in Table 1.

Subclass	Max DWT	Length	Beam	Draught	Region
Newcastlemax	200,000	300	50	18.5	Port of Newcastle, Australia
Dunkirkmax	175,000	292	45	18.2	East lock of Dunkirk, France
Mallacamax	300,000	330	60	20.5	Strait of Malacca, Malaysia
VLOC (Very Large Ore Carrier)	200,000 – 400,000	300 - 360	50 - 65	18.5 - 23	Largest vessels for certain ports in Australia, Brazil and China

Table 1 Subtypes of Capesize vessels

Furthermore, coasters (<15,000 DWT) are used to transport material along the coasts to different ports. These ships are not meant to cross oceans and therefore the transport is limited to small quantities of materials within Europe. Another commonly used vessel type is the barge. A barge is used for inland transport of materials over the water. Barges are usually pushed or pulled by a tugboat. Multiple barges can be moved by one tugboat until a certain amount. Motorized barges can also be used that are not in need of a tugboat. Bulk barges can range in difference sizes with a capacity of 2500 tons as common average for the Rotterdam area.

2.2 Bulk terminals

The PhD study at Delft University of Technology concerning simulation-integrated design of dry bulk terminals (Van Vianen 2015) gives a complete overview of the different aspects of export and import dry bulk terminals concerning coal and iron ore. Figure 10 shows the simplified difference between an import and an export terminal for raw materials. The suppliers of raw material for AMG (mining companies) are using export terminals to get the material from the mine and processing plant into the vessels that will ship it to import bulk terminals. ArcelorMittal Ghent can be considered a dry bulk import terminal for coal, iron ore and other materials. Van Vianen (2015) derived characteristics from existing dry bulk terminals (including steel sites such as Tata Steel IJmuiden and ArcelorMittal Dunkirk) and used this information to simulate design criteria for the sea side, stockyard and landside aspects for general bulk terminals. The characteristics and design criteria for the seaside part of terminals are useful for the Capesize problem statement.

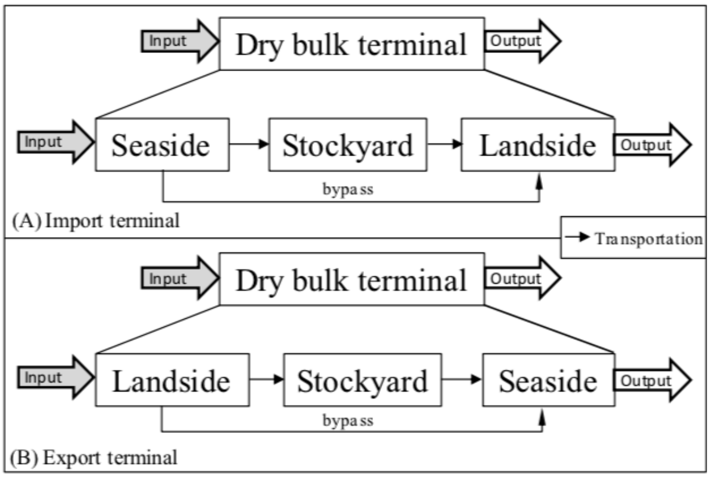

Figure 10: Difference import and export dry bulk terminal (Van Vianen)

An efficiency analysis of the bulk shipping market (Evans, 1994) listed important parameters that should be considered when evaluating the efficiency of certain ports for ship-owners as well as charterers. Two capacity studies (De Monie, 1987) (De Oliveira & Cariou, 2011) give insight in the performance of related terminals such as the port of Rotterdam (EMO), Flushing (OVET), Dunkirk (AMDK) and IJmuiden (Tata Steel). These efficiency analyses based on key performance indicators (KPI's) such as berth availability, waiting times and throughput give perspective how the port of AM Ghent is performing compared to similar bulk handling ports.

2.2.1 Waiting queue and demurrage

When sea vessels are delayed due to the fact they cannot be loaded at the source port or unloaded at the port of destination, ship-owners should be compensated for the lost profits that the vessel could have made (Tiberg, 1979). This waiting fee is called demurrage and is dependent on the waiting time of the vessel and an agreed demurrage rate which is differs with the vessel size and market conditions at the time. In general, there is a predefined demurrage rate agreed in the charter party (a contract between ship owner and charter which is further explained in 2.3.1). The charter party also states what the allowed timespan is for a vessel to arrive at the source and destination port and what the allowed loading and unloading time for a vessel is before the time will be counted as demurrage time.

For import bulk terminals, there can be multiple vessels destined for the quay that are accumulating demurrage by waiting on the anchorage point. This waiting queue of vessels can only be reduced by handling vessels on top of the queue on a higher rate than new vessels are joining the queue. This is all dependent on the berth availability of the quay which gives the amount of time that the berth is occupied by vessels. When a bulk terminal has a high percentage of berth use, it is unlikely that the waiting queue can be reduced, while a low berth occupancy reduces the amount of waiting time. Demurrage can be reduced without improving the berth availability. In general, the ships in waiting queue are processed on a first in first out principle (FIFO). By smart scheduling the total time of the waiting queue can be reduced by moving vessels up or down the queue based upon the quay availability and the demurrage rate. This issue is called the berth allocation problem which can be optimized by different metaheuristic methods (Atencio et al, 2019)

The relation between berth capacity and waiting times is given in several studies e.g. Wadhwa (1992), Radmilovic (1992) and Van Vianen (2015). The relation depends on certain parameters but in general an exponential relation can be found between berth capacity and the resulting waiting time. By using this historical relation in combination with the measured berth capacity and waiting time, a prognosis of the waiting time and demurrage can be given for different berth capacities.

Besides sea vessels, a waiting fee can also occur for the waiting times for barging vessels. The price for barging highly depends on the local supply and demand where the price for sea vessels are determined by the global market. Barge owners, often want to be compensated for the missed profits of the barges and therefore the waiting time is again multiplied by a certain, earlier agreed upon, waiting rate.

2.2.2 Cranes

Ship unloading machines can be divided into three different categories which are: on-board cranes, mobile quay cranes and rail mounted quay cranes. If a bulk vessel contains on-board cranes it is called a geared vessel. Especially ship sizes in the Handysize and Handymax category are geared while in general Panamax and Capesize vessels come ungeared and require quay cranes to be unloaded. Mobile cranes can be moved on rubber tires or a pontoon and are therefore more flexible in use than rail mounted cranes. Rail mounted cranes are unable to pass each other because they are mounted to the same rail. They do however, have a higher unload capacity than mobile cranes. Usually cranes use a grab as unload mechanism although in some cases continuous unloaders are used which are more expensive and inflexible for different types of material. Figure 11 shows a basic diagram of a quay crane that is used to unload material from barges. The material can be unloaded into a hopper (the bin in the middle of the figure) that evenly distributes the material on one of the quay conveyors or it can be unloaded on an intermediate stockpile at the far end of the crane.

The unloading capacity of a crane is dependent on the maximum capacity (in tonnage) of the crane itself, the volume of the grab and the period that it takes to make a full crane cycle (grabbing the material, moving to the unload spot, unloading, moving back to the vessel). Furthermore, the dimensions of the vessel and the hold do also influence the rate in which a vessel can be unloaded. Finally, the properties of the material have also an influence on the unloading capacity.

When the grab is not limited by the sides or the bottom of the hold, it can work on full capacity. This phase is called the free digging phase. When all free digging material is unloaded and the walls or the bottom of the holds are starting to form a problem, the next intermediate phase start. This phase is also known as the trimming phase and has a lower capacity. The last phase is the cleaning of the hold. Machinery and stevedores are moved down the bottom of the hold to clean it out and accumulate the material so it can be unloaded by the crane. In this phase the crane works on the minimum of its capacity. The three phases are shown in figure 12 with the work rate on the vertical axis.

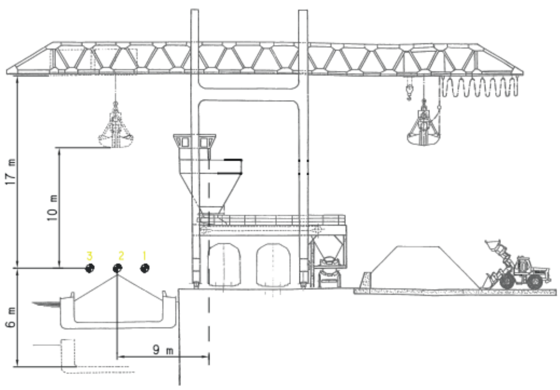

Figure 11: Overview of a standard quay crane (Bubaric, 2011)

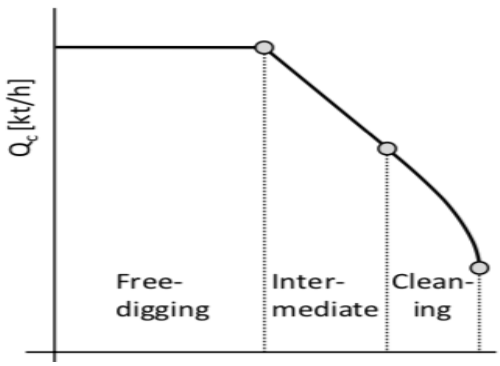

Figure 12: Digging phases for bulk unloading (Gerhardt, 1995)

Multiple cranes are able to work on one vessel as long as there are multiple holds of material and the dimensions of the vessel allow it. Three studies ((Bugaric et al., 2007), (Bugaric et al. ,2011), (Bugaric et al., 2012)) by the same first author were consulted for determination of different crane configurations. These studies show optimization methods to minimize the berthing time for arriving vessels by maximizing the total crane use on a continuous berth with 3 different cranes.

2.2.3 Stockyards

Material that is unloaded by the quay cranes, can be dropped on an intermediate stock (also called pre-stock) or on quay conveyors. The intermediate stock will require extra material handling and transportation by trucks to the stockyards. The use of a quay conveyor is a quick and efficient way of transporting the material further downstream. By a combination of conveyors and distribution point the material can end up at the destined stockyards where it can be stockpiled. This can be done by stackers or stacker-reclaimers. Stackers can only be used to unload material on the stockpiles while stacker-reclaimers can also be used to load material so it can be used for the landside operations. Depending on the use of the materials, stackers can homogenize the stockyard by spreading it out layer for layer over a large area. When reclaiming the material from a perpendicular direction the material will contain different layers. For certain purposes, materials should not be homogenized to maintain the unique properties while for other purposes it is from large importance that the material gets properly blended. Homogenization is important for sintering plants and coking batteries, while being from less importance for power generating plants (Zador, 1991). Stockyards are in general planned on beforehand depending on the amount of incoming material and the material requirements for the landside operations. It is common to have a certain amount of safety stock to cover for landside operations if the incoming material is delayed or cancelled.

2.3 Supply chain from raw materials till hot metal

To be able to draw conclusion about the use of Capesize vessels it is important to have a complete overview of the supply chain that goes from mine to metal. Figure 13 shows the main materials that are required for the production of hot metal in blast furnaces. The raw materials are extracted from mine sites worldwide where they are processed mainly in the form of crushing, milling and screening. The main ingredient for steel production, iron ore, can be required in the form of lumps, fines or pellets. After the material is processed it will be transported to nearby ports where the material will be loaded on dry bulk vessels. From this moment it will fall within the scope of the thesis which concerns the shipping and stockpiling of the material. In this subchapter more information will be provided of the upstream situation from the source till the quay of AMG and the downstream situation from quay till the stockyards. The material on the stockyards will be used for the process of primary steelmaking at the blast furnace. The material first needs to be processed on site to make it fit for the blast furnace. Coking coal will be transformed to cokes in the coke batteries while flame coals and anthracite will be crushed and milled so they can be used in the blast furnace as pulverized coal injection (PCI) and in the sinter factory in the form of breeze. All other materials will be blended on the bedding which functions as source for the sinter factory. Sinter will be used as main ingredient for the blast furnaces, together with imported pellets and cokes. The main product of the blast furnace is hot metal, which will be further reduced and refined on the site for steelmaking. To give a better overview of the transport and the stockpiling phase, a short summary of the current upstream and downstream practices will be given in the following subchapters.

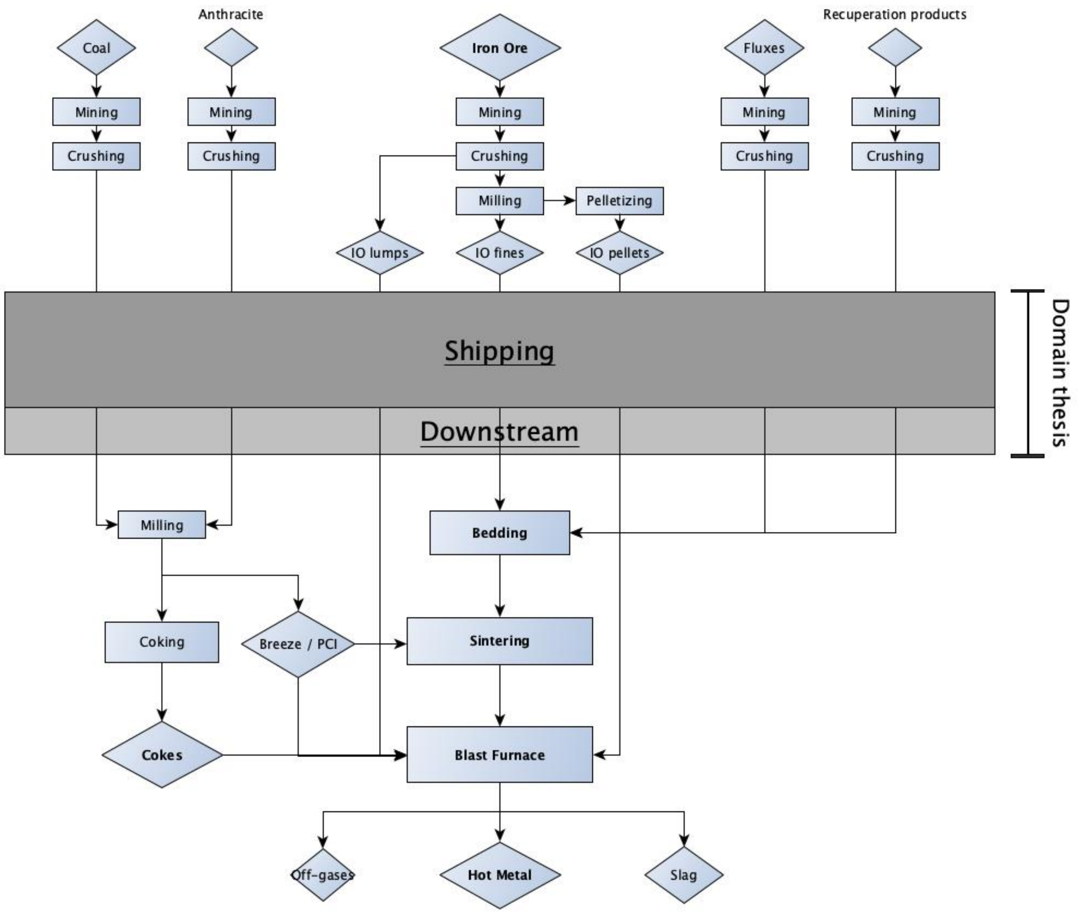

Figure 13: Overview of the downstream supply chain for hot metal

2.3.1 Upstream supply chain ArcelorMittal Ghent

The steel production of ArcelorMittal Ghent requires certain types and amounts of raw materials. Each production department communicates their needs to the Planning & Supply Raw Material department (PSRM). This department combines the information and gives an overview of the current materials on the stockyards and the required raw materials. It communicates the requirements with ArcelorMittal Sourcing which is responsible for the combined purchasing of raw materials for all European sites of ArcelorMittal. AM Sourcing tries to supply each steel site with the required materials for fair prices. However, not all materials can always be supplied or be supplied on the ideal arrival time. When AM Sourcing purchases the material and agrees with the source about the volumes, the loading conditions and the time, AM Shipping gets involved.

ArcelorMittal Shipping is the global department that arranges the shipping of the material from the source ports to the steel sites. It uses the knowledge about international bulk transport to arranges shipping under favourable conditions for low prices per ton. The agreements that AM Shipping make with the shipowners are getting stipulated in a charter party, which is a maritime contract between a shipowner and a charterer for the hire of a ship and the carriage of material. This charter party can be either a voyage charter or a time charter. Voyage charters are for a single trip and it contains the fixed price that should be paid. Furthermore, agreements are made of the allowed time before demurrage has to be paid, the price for the bunker usage and the conditions to which the ship is subjected to in the destination port. Time charters are used when the ship is rented for a certain amount of time (several months / years). They have a certain day rate which covers the general expenses for crew and vessel. This is excluding the costs for bunkers which should be paid by the charterer in the given time span. Furthermore, others expenses such as port costs are also expected to be paid by the charterer.

After the vessel is loaded, it will start the voyage to the agreed anchorage point (also called the pilot point). Two pilot points are located on the North Sea for vessels that are approaching the Westerschelde (see Figure 14). Upon arrival the ship will send a notion of readiness to the involved shipping agency. Vessels destined for AMG report to Vertom which is the responsible shipping agency. Vertom arranges the communication between all parties involved in the process from the moment the vessels arrive at the pilot point until the vessel arrives at the quay of AMG. The main party involved would be the port authority which is North Sea Ports (NSP) for the area in which Flushing, Terneuzen and Ghent are located. Panamax vessels have to wait at the anchorage point depending on the waiting queue until they can be berthed at AMG and in the meantime, they will accumulate waiting time. When the ship is called it will be steered by a pilot to one of the unloading points at the Westerschelde which are the Put van Terneuzen or Everingen. At these unloading points a part of the material will be unloaded on barges until the vessel will meet the draught requirements for the Ghent Terneuzen canal. The unloading of the material is provided by floating cranes that are provided by the OVET. The OVET is a dry bulk terminal located in Flushing and Terneuzen who arranges unloading throughout the ARA range (the waters between Amsterdam, Rotterdam and Antwerp). After the unloading the vessel will be guided by tug boats through the lock and along the Ghent Terneuzen canal until the vessel will arrive at the quay of AMG.

Figure 14 displays a heat map of bulk vessels in the North Sea area at the coast of Belgium. The main routes for ships are shown and the red colour displays heavy traffic. It shows the location of the external stock of the EMO in Rotterdam and the OVET in Flushing and the steel site of AM in Dunkirk and Ghent. The red blocks that are displayed are anchorage points for vessels destined for nearby ports such as Rotterdam, Flushing, Ghent or Antwerp.

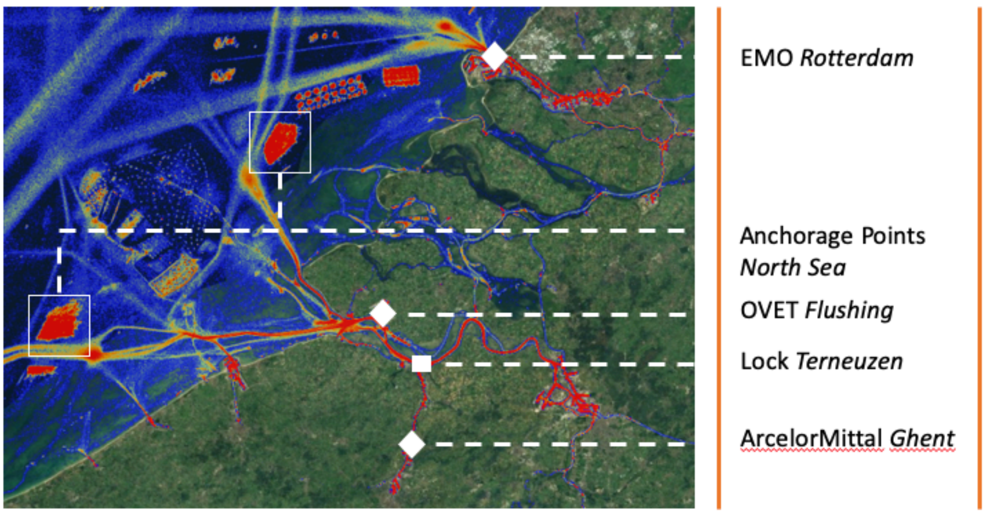

Figure 14: Main locations North Sea project on bulk vessel heat map

Capesize vessels are currently used for the transport of material from large source ports to the EMO external stock in Rotterdam. These materials are mainly Australian coals and on rare occasion Brazilian iron ore. The responsible agencies arrange the arrival at the EMO where the material will be partly unloaded board-board (BB) on barges but also unloaded on the storage. Material located on the storage can be loaded on barges later on and transported to AMG. The barging of material is arranged by a third party to which AMG have to pay a fixed price per ton. The communication between the EMO, the barging company and AMG is arranged by the Transport and Logistics department (BTR) of AMG. Just like the vessels, the barges are passing through the lock complex of Terneuzen to reach the quay of AMG where they will be unloaded.

2.3.2 Downstream supply chain ArcelorMittal Ghent

When the material arrives at the site of AMG it can be unloaded by one of the quay cranes. Sea vessels can directly be berthed since they would only be called from the pilot point if there is a berthing spot available at the quay. Barges on the other hand might have to wait before the quay until there are cranes available to unload them. Currently there are 5 quay cranes located at the site of Ghent of which 4 are operational. Figure 15 shows the location of each of the quay cranes. The relative location of the cranes of each other is always the same since they are all mounted on the same track. The absolute position however varies depending on the incoming vessels. The unload capacity of each crane is highly dependent on the vessel type, grab size and material. Approximations of the unload capacity for iron ore fines are shown in table 2.

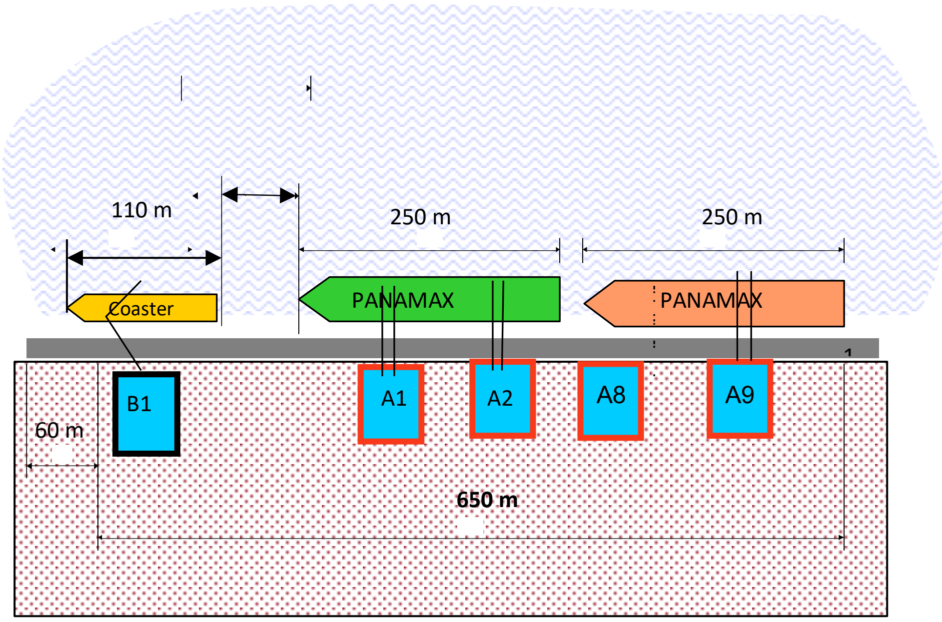

Figure 15: Quay lay-out of AMG (provided by GHV)

Crane	B1	A1	A2	A8	A9
Capacity	600 ton/h	-	700 ton/h	1000 ton/h	1200 ton/h
Beam length	20 meters	22 meters	22 meters	33 meters	40 meters

Table 2: Estimated capacity and beam length of the quay cranes

The B1 crane is the most southern crane located on the Ghent side of quay. This crane can only be used to unload small vessels such as coasters and barges. The next cranes are the A1 and A2 cranes which are dating from the 1970's. The A1 is currently being dismantled while the A2 is still operational. These cranes can unload barges as well as vessels although the beam length is too limited to fully unload some of the Panamax vessels. The A8 is a relatively new crane (2016) that can unload large amounts of material from sea vessels. It can be used on barges as well although the large grab makes working on small vessels more difficult. The newest A9 crane was installed in 2019 and has the highest capacity and largest grabs. This makes it the most efficient cranes to unload sea vessels, but unable to work on barges and coasters.

The management of the quay is done by the Raw Material department (GHV) who work together with an external stevedoring company (Euroports). GHV arranges the scheduling of the vessels and cranes while the stevedoring company is responsible for the unloading itself. During the unloading process priority is given for sea vessels over barges. Different cranes can work together on the same sea vessel as long as they are located next to each other and working on different holds of the ship. The maximum unload capacity of the quay is estimated on 250,000 tons per week for sea vessels, 210,000 for barges and 300,000 for a combination of barges and vessels. The largest cranes unload the material on the quay conveyors C21 and C1 that transport the materials to the downstream installation. The B1 crane has the ability to also unload on the F22 quay conveyor. This is especially helpful for the unloading of small vessels containing materials like fluxes and cokes. This reduces the usage of the other 2 quay conveyors that should be mainly used for large quantities of iron ore, pellets and coal. If no quay conveyor is available, or the material cannot be transported further downstream, there is the possibility to unload the material on an intermediate stockpile called the pre-stock. Later on, this material can be loaded by the cranes on the quay conveyor or the material can be loaded on trucks by front loaders and transported to the stockyards.

The quay conveyors transport the material to a network of conveyors that lead to the stockyards which are located throughout the site of AMG. If the incoming material is directly required by one of the production facilities, the material will not be deposited on the stockyards. This process is called direct transfer which is happening occasionally (3-5% of the total material). Each conveyor can only be used by one type of material at the same time. This material occupies the complete track which consist of a quay conveyor, different downstream conveyors and a stacker-reclaimer at the stockyard. The stacker-reclaimers of AMG are used for loading and unloading of material on the stockyards. The material can be directly be used for production when the stacker-reclaimer passes the material straight from the inflow conveyor to the outflow conveyor. The stockyards of AMG are separated in difference groups such as coals, iron ores and pellets. On a stockyard different subtypes of these materials can be stored although the stockpiles on this stockyard cannot be mixed. Multiple stockpiles on one stockyard decrease the maximum capacity of the stockyard. The outflow of the stockyard depends on the demand of raw materials that is required for the production of the blast furnace, the cokes factory and the sinter factory. The material for the sinter factory is premixed and blended on the bedding. Figure 16 shows the different stockyards and conveyors that are used in the downstream supply chain of AMG. The stockyards can be divided into iron ore stockyards (ertsenparken in Dutch), coal stockyards (kolenparken in Dutch) and remaining stockyards for calcite, fluxes and sinter. The green labels show the type of material (KOL for coal, ERT for iron ore, PEL for pellets, KAL for calcite, OLI for olivine) and the used track of conveyors and stacker-reclaimers (U5, U25, C7, C11, C31, C41 D35, D44, E2, F10).

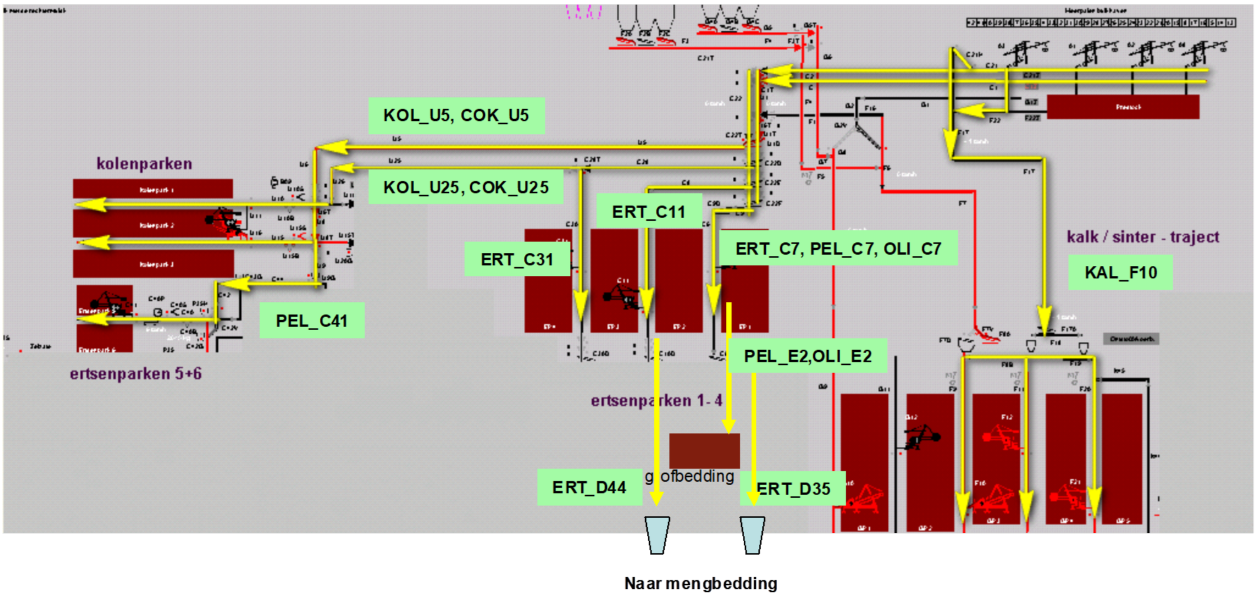

Figure 16: Overview of downstream installations AMG (provided by GHV)

The overall capacity of the downstream supply chain is depending on the overall equipment efficiency of the used machinery. The time use of the cranes, conveyors and stacker-reclaimers can be separated in different categories. The equipment is unavailable during breakdown and maintenance which can be planned or unplanned. Furthermore, each piece of equipment can be unreachable if connecting parts of the downstream track are unavailable. The remaining time that the machinery is available can be divided in productive time and idle time. When there is limited idle time available, there is no room to scale up the capacity if needed.

3. Capesize Potential

This chapter will show what the potential of Capesize vessels can be for AM Ghent. The opportunity of the new lock of Terneuzen is investigated with the known dimensions. These dimensions will be compared with the Capesize vessels that ArcelorMittal is using worldwide to transport their material. Secondly the depth constraint of the Ghent-Terneuzen canal will be examined, to see until what extent the vessels have to be unloaded before it passes through the lock. Different potential external bulk storages are compared to see where the unloading and barging of material can take place. An initial estimation will be made of the current shipping price with Panamax vessels and the potential situation with Capesize vessels. The decrease in shipping costs will be compared with the increasing barging costs for Capesize vessels in an initial estimation. Altogether this chapter will give an overview if there is a potential for Capesize vessels. In the remainder of the thesis further limitations will be examined and exact costs will be defined.

In terms of supply chain, this chapter will include the costs of the journey from the source port until the quay of AMG. This includes the travel time over open sea, the anchorage at pilot point, the partial unloading of the vessel and the passage of vessels and barges through the lock of Terneuzen.

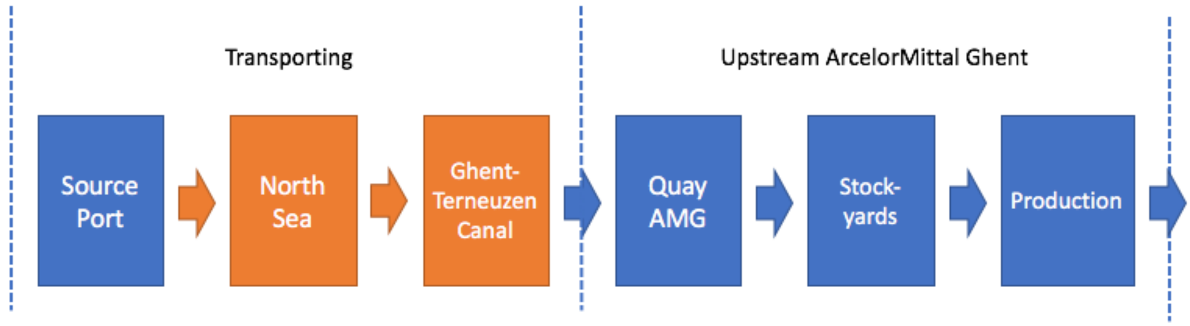

Figure 17: Steps in supply chain that are discussed in Chapter 3 (in orange)

3.1 Opportunity

3.1.1 New lock Terneuzen

The Terneuzen lock complex connects the Ghent-Terneuzen canal to the Western Scheldt river. This canal and the Western Scheldt are the waterways that connects the port of Ghent to the North Sea and therefore the Atlantic Ocean. The Ghent Terneuzen Canal is also part of the Rotterdam-Paris inland waterway route. The main inland waterways are displayed in figure 18. By the use of these routes, goods can be transported by barges rather than trucks. Transport by water is cheaper and more efficient than transport by truck although it requires specific infrastructure and is more time intensive.

Figure 18: Inland waterways near New Lock (source: De Nieuwe Sluis)

The Terneuzen lock complex currently consists out of three locks: the Middensluis (Middle Lock built in 1910), the Oostsluis (Eastern Lock built in 1968) and the Westsluis (West Lock built in 1968). In the near future, the Middensluis will be superseded by the Nieuwe Sluis (New Lock planned for 2023). A new lock is being built to accommodate an increase in traffic. In 2017 a total of 65,000 vessels passed through the lock complex of which 83% were inland vessels and 14% sea vessels. In 2040 the total number is expected to increase to 96.000 vessels a year (Nieuwe Sluis Terneuzen, 2018).

Besides handling more vessels, the Nieuwe Sluis will also be able to handle larger vessels than the Westsluis, which is currently the lock through which sea vessels pass. The dimensions of the Westsluis and the Nieuwe Sluis are shown below in table 3. An overview of the new lock complex is given in figure 19 with the old lock complex on the background. The Western Lock will stay unchanged and remain in use during the construction process. The New Lock will be located on the same place as the Middle Lock, while the Eastern lock will be slightly relocated to create more room.

	Westsluis (West Lock, 1968)	Nieuwe Sluis (New Lock, 2023)
Length	290 meters	427 meters
Width	40 meters	55 meters
Depth	13 meters	16.44 meters

Table 3: Dimensions old and new lock

With the new lock, the access to the Ghent Terneuzen channel will not be restricted by ship sizes ranging from barges till Panamax vessels. The Port of Ghent will be the second port (after the Port of Antwerp) in Belgium that can be accessible for Capesize vessels. The new lock of Terneuzen was scheduled to be finished at the end of 2022 but the opening date has been postponed until spring 2023 (*HLN,* 01-09-2020).

The construction costs for the new lock of Terneuzen are estimated on a total of 934 million euros of which 48 million euros is sponsored by European Union funds. The Dutch government contributes for 190 million euros while the Flemish government pays for the remaining 696 million euros. The Flemish region and especially the region Ghent is also the main beneficiary of the opportunities that the new lock provides.

Figure 19: Lay-out new lock complex Terneuzen (source: De Nieuwe Sluis)

3.1.2 Capesize dimensions

The new dimensions of the largest lock in Terneuzen will increase to 427 meters in length and 55 meters in width. This allows most Capesize vessels to pass through the lock and enter the Ghent-Terneuzen Canal. All Capesize vessels are ranging from 100,000 DWT – 400,000 DWT (see Chapter 2). However, ArcelorMittal only uses Capesize vessels in the Dunkirkmax subclass for the transportation of raw materials to their European steel mills. The maximum capacity of these vessels usually lies between the 170,000-180,000 DWT. A list of 50 vessel arrivals over the past 3 year was obtained from the EMO (see Appendix A). This list contains 10 ore carriers and 40 coal carriers which were all arranged by AM Shipping for different European steel mills. The basic parameters of these ships and the standard deviations are shown in table 4.

Furthermore, standard information was obtained from two reference ships (see Appendix B for the complete overview of the ships). As Table 5 shows, the basic parameters of these reference ships fall well within the margins of the standard deviation. Therefore, it can be concluded that these reference ships are representative for the expected cape arrivals and their hydrostatic particulars table can be used for draught estimations. Also, other characteristics of these ships, such as the number of holds, hold dimensions and cross-sections, are used in this thesis as representative information for the expected cape arrivals.

All Capesize vessels are gearless carriers which means they do not contain any cranes themselves. The ships depend on shore-based equipment for loading and unloading and can therefore only be used at ports with specific infrastructure. The main bunker that is used is HFO (heavy fuel oil) which is a common fuel type for ships this size.

	DWT	**Max Draught**	**Length**	**Breadth**	**Year**
Average	178,400	18.1518 m	291.12 m	45 m	2010
Standard Deviation	5,532	0.1862 m	2.0163 m	0 m	3
% Deviation	3%	1%	1%	0%	

Table 4: Dimension arrival list Capesize vessels

Reference ships:	**DWT**	**Max Draught**	**Length**	**Breadth**	**Year**
KATE	176,405	18.27 m	292 m	45 m	2011
SAVINA	176,382	18.27 m	292 m	45 m	2011

Gross Tonnage	**Net Tonnage**	**Fuel Oil**	**Speed**	**Displacement Summer**	**Cargo Holds**	**Hold capacity**
91,374	57,770	4,700 m^3	15 knots	202,712	9	194179 m^3

Table 5: Standard information reference ships

Gross tonnage: volume of the complete vessel
Net tonnage: volume of the cargo space
Displacement: maximum displacement of water when maximally loaded during summer draught

3.2 Basic constraints

3.2.1 Draught Limitation

The new lock in Terneuzen will give the opportunity for Capesize vessels (Dunkirkmax, see chapter 2.1) to access the Ghent-Terneuzen canal in terms of width and length. However, the maximum draught of these ships (18.27 meters) remains a problem for the lock which has a water depth of 16.44 meters. The canal itself has a limitation of 12.5 meters draught and therefore the ships need to lose almost 6 meters in draught before they can reach AMG, which can be reached by lowering the amount dead weight tonnage that the ships are carrying.

By using the hydrostatic particulars table in the previous subchapter, it can be estimated how much DWT the vessels need to be unloaded to reach the desired draught levels. These tables are based on Archimedes' law that states that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces. In practice this means that the hull volume of the submerged part of the ship, multiplied by the density of the water should be equal to the weight of the ship. The difference in salinity between the open sea of the (un)loading port, the Westerschelde and the Ghent-Terneuzen Canal causes the ship to increase its draught. Since AMG is located on a fresh water canal, the vessel will have a larger draught than on open sea.

Figure 20 shows the average draught for a fully loaded Capesize vessel with a trendline on the 175.000 DWT for the decrease in draught by unloading. By following this trendline till a draught of 12.5 meters, the remaining weight of the vessel can be found before it can pass the canal. A vessel with an initial weight of 170,000-180,000 DWT will be able to access the canal when it is unloaded till 100,000-110,000 DWT depending on the hull shape and the water conditions. For the remainder of the thesis an average of 105,000 DWT is taken as the maximum amount of weight that a Capesize vessel can carry while still being able to reach the quay of AMG.

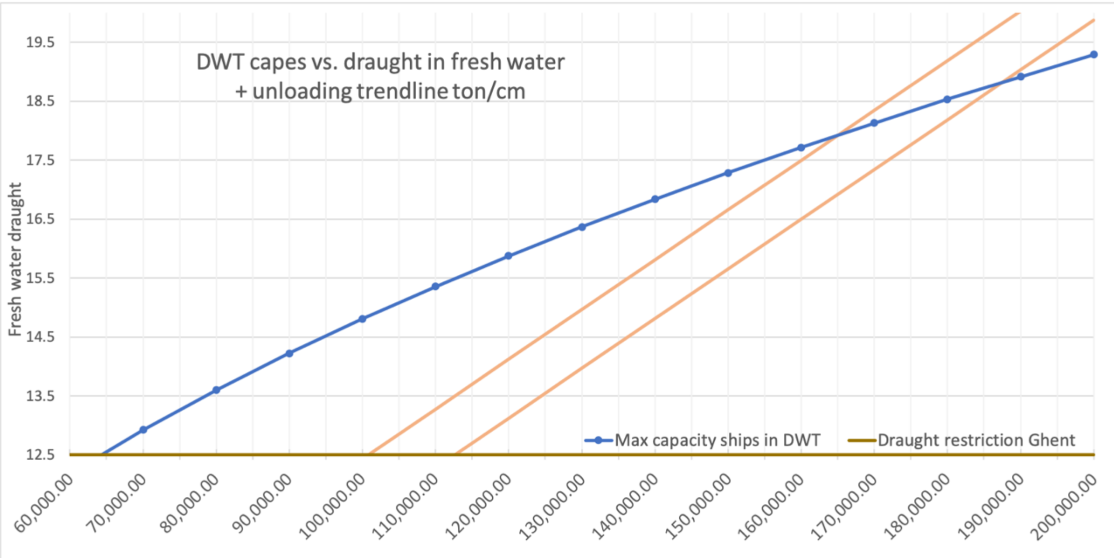

Figure 20: Draught vs DWT vessels

3.2.2 External Unloading

To reach the 105,000 DWT, a fully loaded Capesize vessel needs to be unloaded by 70,000 tons at an external location. Unloading of vessels this size cannot be done on open water which is currently happening for Panamax vessels on the Westerschelde. This is due to a draught limitation at the destined unload spots and safety concerns. Therefore, there are 2 remaining options.

1. Only partial loading of the ship in the source port so it will meet the draught limitation at the Ghent-Terneuzen Canal.
2. Unloading the material at a sea port that is able to berth loaded Capesize vessels with a deep draught.

Option 1 would not be feasible since the costs of the Capesize vessel need to be covered by the cargo and therefore, the costs per ton of material will increase drastically. Eliminating the price benefit that Capesize vessels have per ton compared to Panamax vessels.

For option 2 there are only a limited amount of ports available that meet the draught constraints and have the equipment to unload Capesize vessels. The ports are listed below with the pros and cons for each external bulk stock. Other options such as Dunkirk-West, AMDK (ArcelorMittal Dunkirk), OBA (Bulk Terminal Amsterdam) and other steel sites and external stocks have been evaluated and were concluded to be unfit.

AMA (ArcelorMittal Asturias), located in Gijon, Spain

- \+ Sister company, no third-party costs
- \+ Deep sea port with suitable unloading facilities
- \- Relatively far away

EMO (Europees Massagoed Bedrijf), located in Rotterdam, the Netherlands

- \+ Deep sea port with suitable unloading facilities
- \+ Nearby (within barging distance) AM Ghent

OVET (Overslag Vlissingen en Terneuzen), located in Flushing, the Netherlands

- \+ Very nearby (within the same port district)
- \- Draught limitations of 16.7 meters (90% of a full cape)
- \- Smaller unloading cranes

After the ship is partially unloaded at the external location, it can continue to the locks of Terneuzen and berth at the quay of AMG. The unloaded material can be used by AMG or by another steel site that is interested. Initially it is assumed that sharing is only possible with AMA. For the EMO and the OVET the unloaded material has to be transported to the quay of AMG by the use of barges. This requires increased material handling. When the material is unloaded directly from the vessel on the barge (board-board unloading), this extra handling is limited to unloading. When the material is stored on the external stock it requires unloading, conveying, storage, conveying and loading. The extra material handling and barging will come with extra costs compared to transport by sea vessels and to be feasible these costs need to be at least matched by the benefits of using Capesize vessels.

3.3 Capesize benefits

The main benefit of using Capesize vessels is the cost reduction per ton of material. Thanks to the economy of scale the material can be transported on a more efficient way which leads to a decrease per ton of material in fuel consumption, manpower and port movements. Also, it lowers the carbon footprint of transport by sea which is already the mode of transport with the lowest amount of CO_2 emissions per ton of material. Material transported by Capesize vessels have a carbon intensity of 1.7523 grams of CO_2 per ton-km compared to 2.6601 for Panamax vessels (Chang, 2013). For a trip from Brazil 1 (Brazil) to Belgium this equals more than 10 kg of CO_2 reduction per ton of material. Although emissions are from growing importance nowadays, the main driver for the use of Capesize vessels remains the reduction in costs.

To compare the potential benefit of Capesize transport it should be compared to the current way of bulk transport which is by Panamax vessel. To make a representative comparison the price per ton of material should be compared for the same source and destination. In this case the voyage between Brazil 1 (Brazil) and Rotterdam (the Netherlands). The reason to choose this specific route is because there is sufficient price data available and because Brazil 1 is the port that ships SSFT (Standardized Sinter Feed Brazil 1) which is one of the main components that AMG is using to create the sinter bedding. Figure 21 shows the price evolution of the spot rates (price per ton) for both vessel types over the past 11 years. The prices for both vessel types are shown to be highly volatile ranging from 5 dollars to 30 dollars per ton for Panamax vessels and 3 dollars to 25 dollars for Capesize vessels. From 2009-2014 the prices were at a record high while the spot rates were significantly lower in the last 5 years. It should be noted that these figures do not include recent times when the shipping prices were highly volatile due to the influence of the corona virus. Since the arrival of Capesize vessels is a long-term project, the effects of the virus are assumed to be cancelled out by 2026.

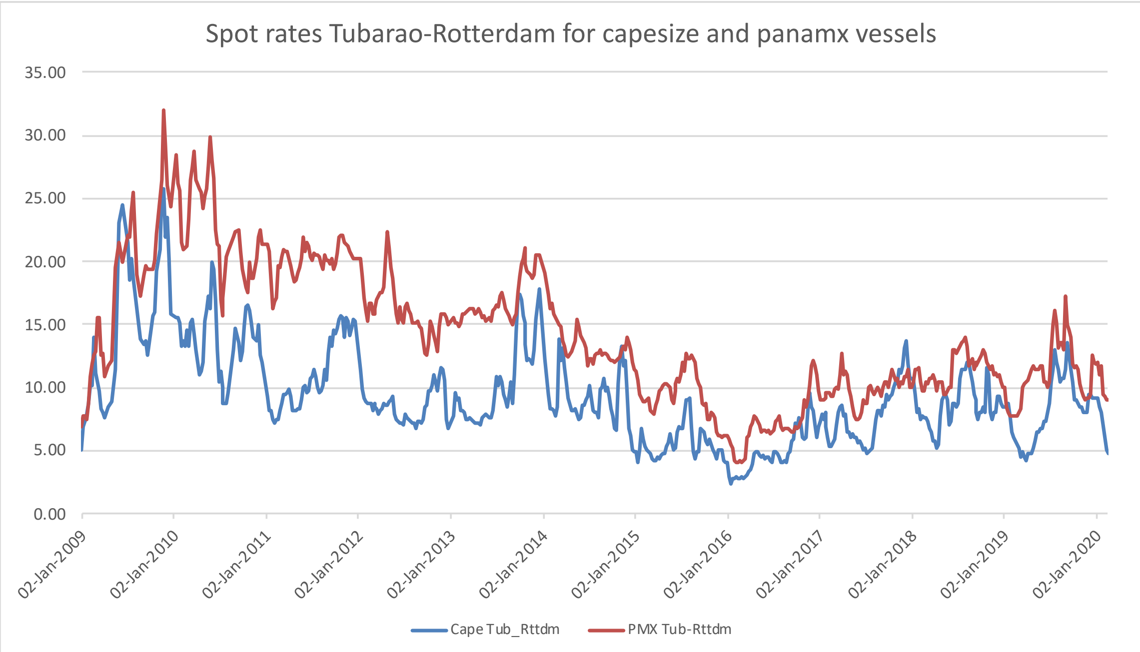

Figure 21: Price evolution spot rates over the past 11 years

It would be of interest to examine the difference in spot rates between Panamax and Capesize vessels over the last 3 years (from the beginning of 2017 till the beginning of 2020) which is shown in figure 22. The average difference over this period was 2.83 dollars per ton, but also in this case the difference between the two vessel types is highly volatile. Capesize vessels use significant less fuel per ton than Panamax ships and therefore the price difference is expected to be higher in times of high bunker fuel prices. Furthermore, there are far less Capesize vessels available worldwide than Panamax vessels. Therefore, the price is far more influenced by the supply and demand of the market. Even till such an extent that there are certain periods that Panamax vessels are cheaper per ton than Capesize vessel even though this type of shipping is less efficient.

For initial calculations the average difference of 2.83 dollars is taken in consideration. However, in Chapter 8 the cost scenarios will take price changes in consideration and the break-even price between Panamax and Capesize vessels will be calculated. The decision to ship the material by Capesize or Panamax is made by a joint coalition of AMG, AM Sourcing and AM Shipping depending on the market circumstances.

It should be noted that spot rates are a combination of shipping rates for multiple ships, for the same route in a week. Their main use is to give an indication what price to expect. The exact price for this journey might differ due to specific port and lock costs, long term price negotiations and vessel specifics. AM Shipping does not hire vessels on a voyage charter but on a time charter. However, the contract between AM Sourcing, AM shipping and AMG do have aspects of as well voyage charters, as of time charters. For the initial cost estimation, spot rates will be sufficient, but for the in-depth estimation (Chapter 8) other factors such as time charter rate and fuel use should be included as well.

The load factor of the ship is included in the initial estimation since it will heavily influence the price per ton. Most costs for transportation are absolute and not calculated per ton of material while the spot rates are prices per ton for fully loaded ships. It should be noted that the prices for Panamax vessels are based on a 70,000 DWT vessel and for Capesize on a 160,000 DWT vessel. In the case study of AMG Panamax vessels of 75,000 and Capesize vessels of 175,000 are assumed. This means that the load factor of the vessels is above 100% which reduces the spot rates, the extra costs for using slightly larger vessels are unknown and therefore the spot rates provided, are considered to be valid for the calculations.

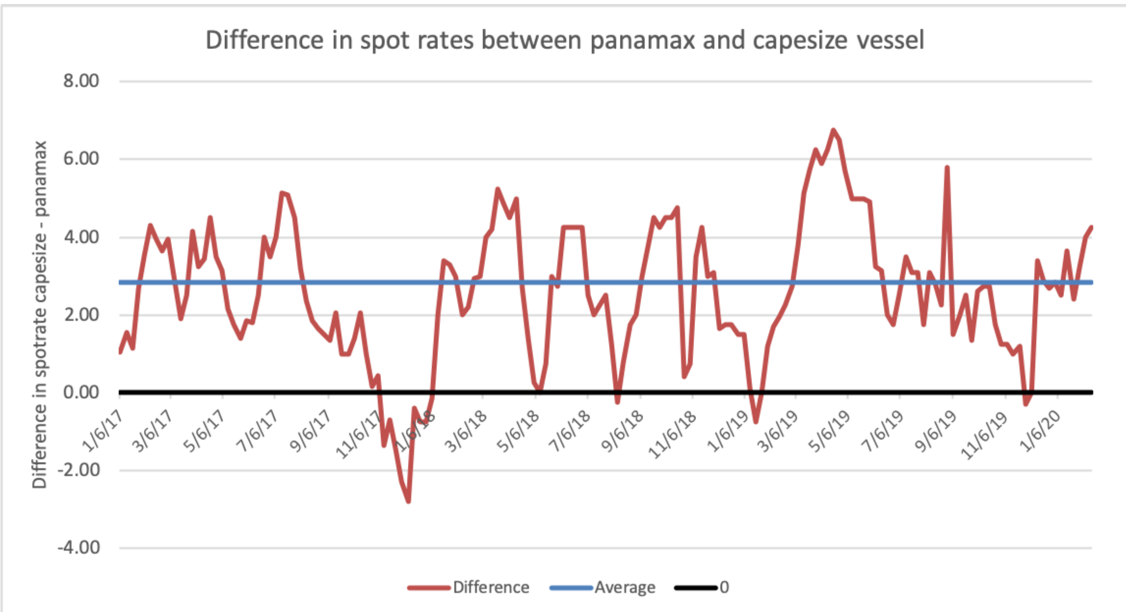

Figure 22 Difference in spot rates Capesize-Panamax (2017-2020)

3.4 Cost comparison

By knowing the basic constraints and main price differences between Panamax and Capesize vessels, the average potential of using Capesize type ships can be estimated. This can be done by taking the amount of barging into consideration and comparing it with the current practice of using Panamax vessels or external stocking. This will only be an initial estimation to determine if the use of Capesize vessels might lead to a cost reduction, if there is potential the exact costs will be determined in Chapter 8.

While the shipping price is reduced by the lower spot rates, there is also an increase in costs by the use of 2 ports for one freight. A multi-stop journey is not uncommon in international shipping but it means that the ship has to pay port fees at two different places while it will also will be in use longer, to transport the remaining material from destination A to destination B. ArcelorMittal Sourcing provided base numbers for northwest Europe to make an initial estimation of these extra costs. A multi-stop for coal transport is estimated to increase the price of the total shipment with an expected 1.5 dollar per ton for each extra stop while an extra stop for an iron ore shipment adds 1.2 dollar to the price per ton.

Figure 23 shows the expected transportation costs for importing ore for the current base scenarios and the potential cape scenarios. These scenarios are as follows:

> B1: Panamax arrivals which are partly (until 62.000 DWT) unloaded on barges so the ship meets the draught restrictions of the Ghent-Terneuzen Canal.
> S1: Capesize arrivals that are partly unloaded at the EMO (until 105.000 DWT) on barges and on shore so the ship meets the draught restrictions of the canal.
> S2: Capesize arrivals that are partly unloaded at the OVET (until 105.000 DWT) on barges and on shore so the ship meets the draught restrictions of the canal.
> S3: Capesize arrivals that are partly unloaded at AMA (until 105.000 DWT) on shore ship continues to AMG

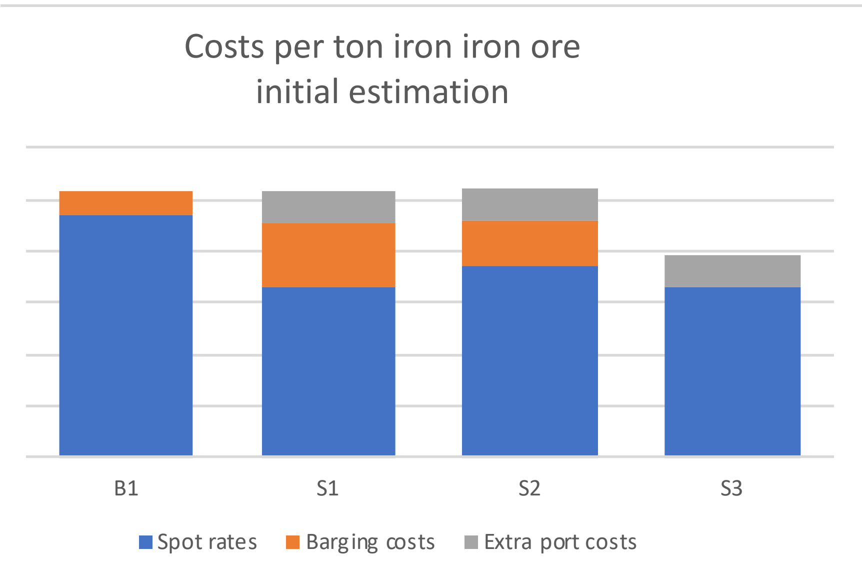

Figure 23: REDACTED Initial estimation costs per ton iron ore

As the figure shows, the cape scenarios have a lower total amount of spot rates than Panamax shipping. S2 has a higher amount of spot rate costs since the ship can only be loaded up till 90% which increases the price per ton by 11%. Base scenario 1 requires barging for all the material form the Capesize which is costlier than S1 (40% of the vessel) and S2 (32% of the vessel). Panamax vessels would only have to unload 18% of the material to reach the draught limit but the unloading on sea is more expensive. By only using base numbers, it can be concluded that the differences are small for iron ore and therefore a better estimation of the costs should be made.

Figure 24 shows the expected transportation costs for importing coal for the current base scenarios and the potential cape scenarios. These scenarios are as follows:

> B1: Importing coal by via the EMO, from which all material will be shipped to AMG by barges
> S1: Capesize arrivals that are partly unloaded at the EMO (until 105.000 DWT) on barges and on shore so the ship meets the draught restrictions of the canal.
> S2: Capesize arrivals that are partly unloaded at the OVET (until 105.000 DWT) on barges and on shore so the ship meets the draught restrictions of the canal.

In this figure there is no difference in spot rates because there is currently no material imported from Australia by the use of Panamax vessels. The long journey (over three weeks) makes this infeasible. Therefore, the only price difference will be between the barging costs and the extra costs. B1 has the highest barging costs for 100% barged material while S1 only requires 40% barging. S2 requires again only 32% of barging but will have an increase spot rate.

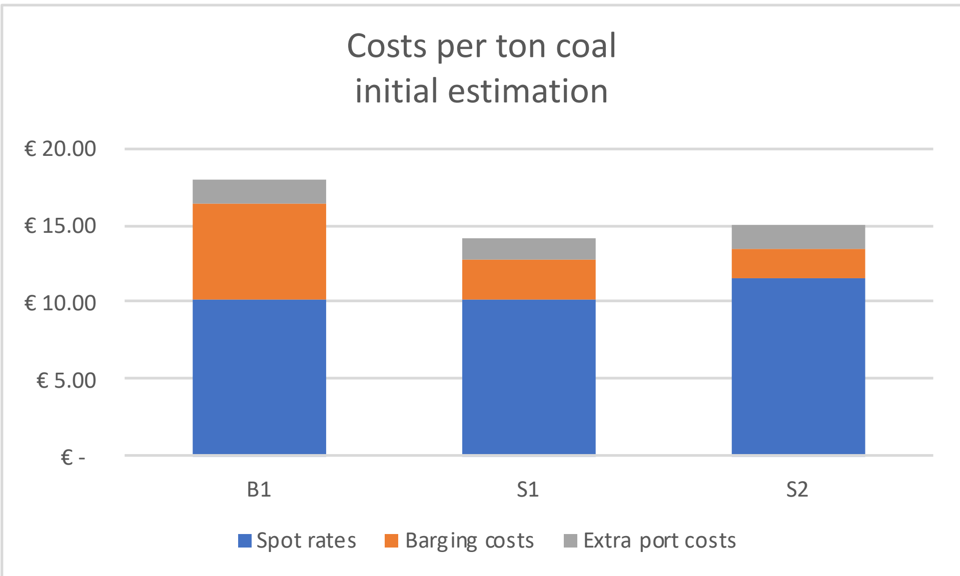

Figure 24: Initial estimation price per ton coal

Considering the basic constraints and main price differences it can be concluded that Capesize vessels might lead to a cost reduction in total shipping price. However, this is only an initial estimation for fully loaded ships with an average spot rate. Besides the basic constraints, there are other limitations to the use of these vessels in terms of source ports, availability and contracts. Also, the use of Capesize vessels might lead to issues further down the supply chain which can make the operation costlier than the decrease in transportation price. The following chapters will go deeper into these issues while Chapter 8 will give a more accurate estimation of the total benefits of Capesize vessels for AMG.

3.5 Main findings Chapter 3

The main findings of this chapter can be summarized in the following bullet points:

- The increased dimensions of the New Lock of Terneuzen are 427 x 55 meters.
- This allows Capesize vessels of the Dunkirkmax class (175.000 DWT) to reach AMG.
- The depth of Ghent-Terneuzen canal will remain unchanged leading to a draught restriction of 12.5 meters for all vessels.
- Capesize vessels have to be unloaded until 105.000 DWT before passage through the Lock of Terneuzen while Panamax vessels should be unloaded until 62.000 DWT.
- Unloading can be done in Rotterdam (EMO), Flushing (OVET) or in Spain (Asturias).
- The remaining 70.000 tons for Capesize vessels (40% of the total) should be transported by barges, compared to 13.000 ton when using Panamax vessels.
- The costs per ton for Capesize vessels are on average 2.83 dollars per ton less expensive than the costs per ton for Panamax vessels.
- In the initial estimation the barge usage costs and extra handling costs are estimated to be similar to the price decrease for iron ore.
- Australian coal is currently already transported to Europe by Capesize vessels and fully arriving on barges from the EMO, if Capesize vessels are able to reach AMG this will automatically lead to a fast cost reduction.

4. Forecast 2026

The main goal of this chapter is to make a forecast of the material and volumes that will be used in 2026. First the current demands of the production facilities within AMG will be examined. This will be based on data of the past three years for quay arrivals, external stock arrivals and barging. The tonnages and sources of the current material mix will be used to make an estimation for 2026 when a planned production increase to 5.5Mt of steel (12% increase in raw material) is taken into consideration. Furthermore, there will be some changes in the material mix of 2026 compared to the material mix of 2019. Special attention will go to sources that are (partially) owned by ArcelorMittal Mining and large mining companies. With an expectation of 2026 in place, source ports can be examined for Capesize vessel compatibility. Finally, the maximum impact of Capesize vessels on the arrivals can be estimated by making used of the tonnages from suitable ports.

For this chapter only the first and final stage of the supply chain are of importance. The production departments within AMG choose the amount and type of materials that should be procured and therefore determine the locations of the source mines and source ports. The type of vessel and quantities per shipment are depending on the location and restrictions of the source port. The type of arrivals (vessels or barges) on the quay of AMG are also briefly discussed in this chapter but this part of the supply chain will not be the main focus.

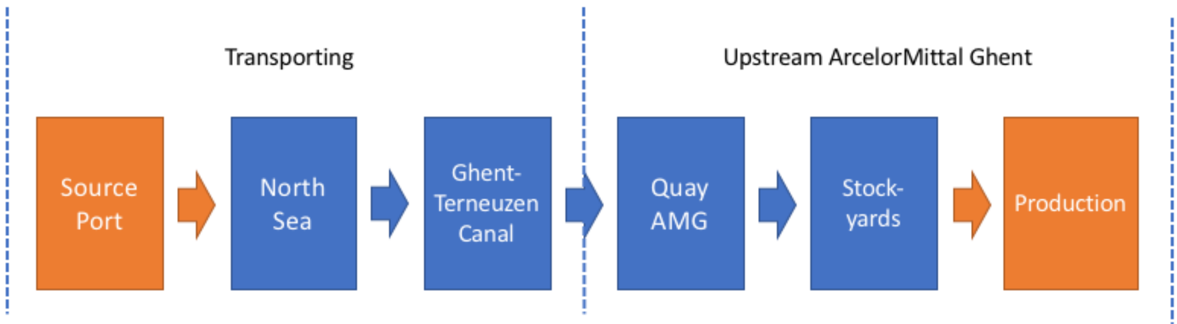

Figure 25: Steps in supply chain that are discussed in Chapter 4 (in orange)

4.1 Material use 2019

Chapter 2.3 discussed the raw materials supply chain for the production of steel. Table 6 gives a short summary of this chapter and shows which raw materials are unloaded at the quay of AM Ghent and what the general use is for these materials in the steelmaking process.

Material type	Material subtype	General use
Iron ore	Fines	Main feed for the sinter bedding
Iron ore	Lumps	Direct feed to the blast furnace (uncommon)
Iron ore	Pellets	Imported and directly used in the blast furnace
Coal	Coking coal	Feed for the coking batteries to create cokes
Coal	PCI coal	Pulverized and injected in the tubes of blast furnace
Coal	Anthracite	Grinded and use as breeze for the sinter plant
Coal	Cokes	Imported and directly used in the blast furnace

Fluxes	Calcite	Increasing basicity in blast furnace, used in the sinter bedding and in the blast furnace itself
Fluxes	Dolomite	Increasing basicity and magnesium content in blast furnace, used in the sinter bedding
Fluxes	Olivine	Increasing magnesium content in blast furnace, used in the sinter bedding

Table 6: Raw materials used at AMG

The raw materials used for the production of hot metal are imported from multiple countries worldwide. The distance over which these materials have to be imported depends on the abundancy of the materials and the price. Scarce, high value products such as low silica iron ore and high energetic coking coal are imported from countries such as Brazil and Australia even though the transport costs are significant. Lower value products such as olivine, PCI coals and lower grade iron ores can be extracted within Europe or nearby regions such as the Western Asia or Northern Africa. Limestone and dolomite are mainly imported from nearby quarries within Belgium. Table 7 and 8 provides the source of the raw materials and port from which they are shipped and in which quantities.

There is a difference between the amount of materials that is estimated to be imported and the actual amount. The column 'Budget 2019' gives the estimation that has been made at the end of 2018. The real amount can differ because of limited availability, cheaper alternatives or a decrease in the production of hot metal. In the case of 2019 there are significant differences due to the European steel crisis, the unavailability of the mining company Vale to provide certain materials and the availability to import more pellets from AM Mining instead from third party mining companies.

AM Mining is among the world's largest of iron ore by producing 73.7 million tons of iron by its mines and strategic contracts (Barbosa et al,2016). The company also produced 6.3 million tons of coking coal and PCI coal in 2016. 62% of total iron ore and 15% of the coal that is required by all ArcelorMittal steel sites, is provided by AM Mining.

AM Ghent imported XX.X% of the total iron ore (fines, lumps and pellets) from mines listed under AM Mining. XX.X% of the material came from the large iron ore companies Vale (SSFT and Carajas) and Rio Tinto (IOC pellets). Furthermore, LKAB provided a large part of the used blast furnace pellets.

Name	**Company and material / mine**	**Port**	**Budget 2019 (ton)**	**Real 2019 (ton)**
IO fines 1	-	-	0	0
IO fines 2	-	-	1,120,000	621,000
IO fines 3	-	-	0	235,000
IO fines 4	-	-	1,350,000	1,411,000
IO fines 5	-	-	0	73,000
IO fines 6	-	-	1,600,000	1,411,000
IO fines 7	-	-	160,000	0
IO fines 8	-	-	0	82,000

IO fines 9	-	-	219,000	225,000
IO lumps 1	-	-	0	16,000
IO lumps 2	-	-	0	0
IO pellets 1	-	-	335,000	786,000
IO pellets 2	-	-	0	68,000
IO pellets 3	-	-	0	705,000
IO pellets 4	-	-	1,350,000	0
IO pellets 5	-	-	0	50,000
IO pellets 6	-	-	1,220,000	977,000

	Iron ore (ton)	**IO pellets (ton)**	**Total (ton)**
Budget 2019	**4,449,000**	**2,905,000**	**7,354,000**
Real 2019	**4,074,000**	**2,586,000**	**6,660,000**

Table 7: REDACTED Imported types of iron ore 2019

Contrary to iron ore, the total amount of coal that was shipped to AMG was higher than budgeted in the first place. The main reason for this was the import of premade cokes from AMB in Germany (ArcelorMittal Bottrop). This site has a high coke battery capacity and can therefore produce more cokes than it is using for steel making. At AMG there is not much room for a capacity increase for cokes.

Table 8 shows that AMG is highly dependent on the mining company BHP for the coking coal and PCI coal supply. XX.X% of these materials are imported from BHP mines located in Australia. Each Australian coal type arrives in Europe per Capesize vessels and the material gets distributed from the EMO in Rotterdam where barges with material will go to AMB and AMG while the vessel itself can continue the journey to AMDK and/or AM ZKZ (Dąbrowa Górnicza, Sosnowiec and ZKZ in Poland). The anthracite is supplied by many different suppliers in small amounts and relatively small vessels such as Handysize ships and coasters (see chapter 2).

Name	**Company and material / mine**	**Port**	**Budget 2019 (ton)**	**Real 2019 (ton)**
Coking coal 1	-	-	500,000	94,000
Coking coal 2	-	-	67,000	379,000
Coking coal 3	-	-	200,000	189,000
Coking coal 4	-	-	300,000	298,000
Coking coal 5	-	-	0	19,000
Coking coal 6	-	-	333,000	306,000
Coking coal 7	-	-	167,000	109,000
Coking coal 8	-	-	0	55,000
PCI coal 1	-	-	800,000	419,000
PCI coal 2	-	-	190,000	458,000
PCI coal 3	-	-	0	19,000
PCI coal 4	-	-	0	41,000

PCI coal 5	-	-	0	35,000
PCI coal 6	-	-	360,000	279,000
PCI coal 7	-	-	0	33,000
PCI coal 8	-	-	0	60,000
Anthracite 1	-	-	0	10,000
Anthracite 2	-	-	0	8,000
Anthracite 3	-	-	20,000	58,000
Anthracite 4	-	-	0	16,000
Anthracite 5	-	-	0	10,000
Anthracite 6	-	-	0	32,000
Anthracite 7	-	-	100,000	82,000
Cokes 1	-	-	0	267,000

	Coking coal (ton)	PCI (ton)	Anthracite (ton)	Cokes (ton)	Total (ton)
Budget 2019	1,567,000	1,350,000	120,000	0	3,037,000
Real 2019	1,449,000	1,344,000	216,000	267,000	3,276,000

Table 8: REDACTED Imported types of coal 2019

The remaining materials that are not listed in the two previous tables are calcite, dolomite, olivine and scrap metal. Calcite arrives from 3 different suppliers (2 in Belgium, 1 in Spain) by coasters, barges and trucks. Dolomite arrives from a Belgian source while the olivine comes from Norway and Spain. Finally, a limited amount of scrap metal can be used in the iron making process. However, the amounts depend on the price and the availability and can heavily differ in quantity and source.

4.2 Arrival data

With the inflow of material known, the way of transportation can be further examined. The arrivals at the quay of AMG can be separated into three different categories. The first and main category is the arrival of sea vessels at the quay. This accounts for almost 70% of the total material inflow. Secondly there is the material that originally came from the Panamax vessels that arrived at AMG. However, this part of the material had to be unloaded at the Put van Terneuzen or Everingen so the ship could meet the draught restrictions of 12.5 meters. The material is unloaded from the ships by floating cranes and loaded onto barges. This type of board-board (BB) loading accounts for an average 16% of the total amount of material on the vessels. The barges will pass the lock of Terneuzen alongside the vessel and will be unloaded at the quay. The third type of arrivals is the material that is originated from the EMO external bulk storage in Rotterdam. This material does mainly come from Capesize vessels that are (yet) unable to reach AMG. The material is directly unloaded on barges or stored on the external stock first, afterwards the material will be transported on barges to AMG. The last category will be all other types of material inflow. This include, dolomite and cokes. The total material inflow for each category is shown in table 9.

	Vessels	BB Panamax	EMO	Other	**Total**
Volume 2018 (tons)	7,680,000	1,290,000	1,580,000	700,000	11,200,000
Volume 2019 (tons)	7,270,000	1,370,000	1,230,000	700,000	11,060,000

Table 9: Material inflow per category

4.1.1 Vessel Arrivals

Throughout the year numerous sea vessels arrive at AMG with different materials and capacities. Figure 26 shows all vessel arrivals at the pilot over the past three year displayed by time, tonnage and the material type that is transported. The figure shows that the highest number of vessels that arrive are within the Panamax range. The volume share of these vessels is over 75% of the total volume that arrive by vessels.

Figure 26 showed the original DWT of the sea vessels destined for AMG. However, the Panamax vessels do not deliver all the material to the quay of AMG. Due to the draught restriction of the Ghent-Terneuzen Canal some material needs to be unloaded on barges. Figure 27 shows the same vessels as figure 26 with and adjusted draught. It shows that most vessels are unloaded till 60,000-65,000 DWT to meet the draught restrictions. The outliers with around 70,000 DWT can be explained by the fact that these vessels are not regular Panamax vessels but Post-Panamax vessels. These ships have increased dimensions and will therefore have a higher maximum capacity and more buoyancy.

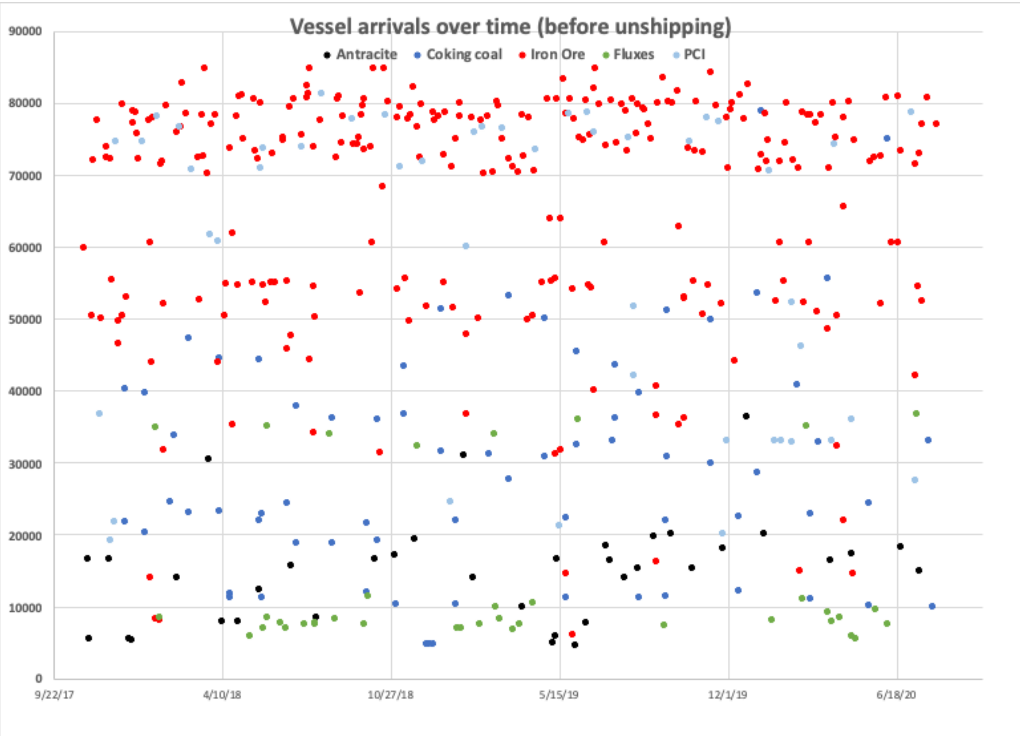

Figure 26: Sea vessel arrivals at pilot point over the last three years by tonnage and material type

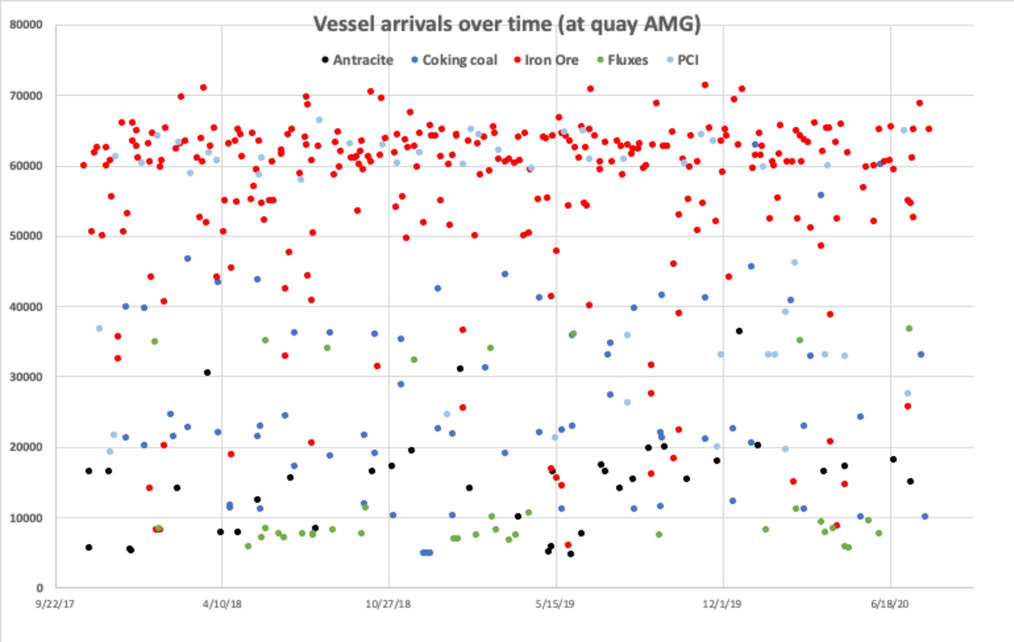

Figure 27: Sea vessel arrivals at quay AMG over the last three years by tonnage and material type

4.1.2 Barge arrivals

Barge arrivals include categories 2, 3 and 4 that were stated earlier in this chapter. The main material that is unloaded BB from Panamax vessels is iron ore from Brazil and Canada and Russian PCI coal. On average 12,000-14,000 ton of material per Panamax is loaded on and transported by barges. The materials derived from the EMO are mainly different types of Australian coal that is shipped by Capesize vessels. These vessels do not unload a full ship at the EMO since the same ships are used to supply other sites of ArcelorMittal. An average of 40,000 ton is unloaded from the ship and destined for AMG. The last category barges that arrive are mainly fluxes such as dolomite and chalk. These fluxes originate from nearby quarries and are transported over the inland waterways to AMG. Also imported cokes from AMB fall within this category. The quantities for these materials are one barge / small vessel at the time that arrive with a high frequency.

In general, sea vessels have priority over barges during the unloading of the material. Therefore, the arrival and unloading of barges should be carefully planned. The BB unloading of Panamax vessels cannot be planned on beforehand because it depends on the arrival time of the ship. This can lead to a situation where barges and ships have to be unloaded simultaneously which can be done thanks to the different cranes. This situation has the advantage that the quay conveyor is already handling the same type of material and therefore the material can use the same track.

Barges that are derived from the EMO can be partly scheduled on beforehand. When the vessel arrives at the EMO there is the choice to load the unloaded material directly onto barges without storing it. This is the preferred option since it does not require storage space and reloading the material on the conveyors. However, this is not always an option since there should be barges available and there should be room at AMG for the barges to be unloaded. The other option would be to store the material at the EMO for a certain amount of time. This comes with a cost but it does provide more flexibility in quay scheduling and barge arrivals. Table 10 provided the basic information about how much material is stored and for how long for the past 2.5 years. There is a cost reducing trend to unload at least 50% of the material BB at the EMO and for the future it is planned to maintain these percentages.

EMO	**Volume (tons)**	**BB unloading**	**Storage**	**Average days on storage**
2018	X,XXX,XXX	XX%	XX%	XX
2019	X,XXX,XXX	XX%	XX%	XX
2020*	X,XXX,XXX	XX%	XX%	XX

Table 10: REDACTED BB unloading and storage at the EMO

4.3 Material use 2026

The goal of this subchapter is to make an estimation of the raw materials that are imported in 2026. This year was chosen for the reason that it will incorporate the opportunity of cape arrivals and consider the scheduled production increase to 5.5Mt steel. In 2019 a total of 4.9Mt hot metal was produced and therefore an increase of 12.2% of raw materials is required to reach this amount.

The amount of 5.5Mt steel is estimated as a long-term goal for the site in Ghent. The increase is a project that considers the upscaling of production facilities. In September 2020 blast furnace B was refurbished for the first time in decades. The refurbishing of blast furnaces is required once every 20-25 years to guarantee an efficient operation and to maintain a high throughput of material. By 2026 blast furnace A is scheduled to be refurbished as well. The increase of 12.2% is set as baseline for all the required blast furnace materials which are pellets, sinter, PCI coal and cokes. However, there is not much room for a capacity increase at the cokes facilities of AMG. Therefore, the total amount of cokes for the blast furnace, need to be increase by importing premade cokes from external parties.

Besides an increase in the total amount of material, the material mix will change as well. This is due to the availability of certain materials and preferences for certain suppliers. A general trend is that AM Sourcing is trying to decrease the dependency on large mining companies and to increase the share of AM Mining in the material mix. These large mining companies are Vale and Rio Tinto for different types of iron ore and BHP Billiton for different coals. Table 11 shows the dependency of these companies and the share of AM mining in the material mix for 2019 and the estimated numbers for 2026.

	2019 (t)	**2019 (%)**	**2026 (t)**	**2026 (%)**
Coal BHP Billiton	**X,XXX,XXX**	**XX.X%**	**X,XXX,XXX**	**XX.X%**
Iron Ore Vale + Rio Tinto	**X,XXX,XXX**	**XX.X%**	**X,XXX,XXX**	**XX.X%**
Iron Ore AM Mining	**X,XXX,XXX**	**XX.X%**	**X,XXX,XXX**	**XX.X%**

Table 11 REDACTED Share of large mining companies in material mix AMG

A detailed overview of the estimated material mix is given in table 12. The most notable materials that are entering the mix for iron ore are IO fines 1b, IO fines 4 and IO fines 5. The IO fines 1b is a new sinter mix that compensates for the decrease in the use of IO fines 1 and

IO fines 4. This material will be shipped from the same ports that Vale is currently using that are Capesize accessible. IO Fines 5 and IO pellets 1 increase the share of own material within the total material mix. The coal mix is estimated to be better spread over different suppliers, where it is very depending on Coking coal 2 in 2019. Figure 28 projects the main source ports for 2026 on the world map combined with the tonnages. Coals are marked black while iron ore is marked in red.

Name	Material	Port (cape ports in bold)	Tonnage
IO fines 1b	**Iron ore**	**-**	**750,000**
IO fines 2	**Iron ore**	**-**	**750,000**
IO fines 4	**Iron ore**	**-**	**1,550,000**
IO fines 5	Iron ore	-	310,000
IO fines 6	**Iron ore**	**-**	**1,600,000**
IO fines 7	Iron ore	-	160,000
IO fines 9	Iron ore	-	440,000
IO pellets 1	**Iron ore (pellets)**	**-**	**1,700,000**
IO pellets 6	Iron ore (pellets)	-	1,300,000
Coking coal 1	**Coking coal**	**-**	**300,000**
Coking coal 3	Coking coal	-	200,000
Coking coal 4	**Coking coal**	**-**	**300,000**
Coking coal 9	**Coking coal**	**-**	**300,000**
Coking coal 6	Coking coal	-	333,000
Coking coal 7	Coking coal	-	167,000
PCI coal 1	Pulverized coal injection	-	800,000
PCI coal 2	Pulverized coal injection	-	200,000
PCI coal 4	Pulverized coal injection	-	200,000
PCI coal 5	Pulverized coal injection	-	200,000
Anthracite 3	Anthracite	-	50,000
Anthracite 7	Anthracite	-	185,000
Cokes 1	Cokes	-	220,000
Flux 1	Flux	-	300,000
Flux 2	Flux	-	650,000
Flux 3	Flux	-	80,000

Table 12: REDACTED Forecasted material mix in 2026

Figure 28: REDACTED AND REMOVED Locations and tonnages of main source ports of iron ore (red) and coal (black) in 2026

4.4 Arrivals 2026

By knowing the total amount of each material, a first indication can be given of the proposed arrivals in 2026. This is highly depending on the number of capes that are used and therefore two situations are worked out, both for an increase production of 12%. The first situation is by using no Capesize ships at all while the second situation maximizes the utilization of Capesize vessels. Both situations will have the same arrivals from source ports that are not able to dock Capesize vessels. The capacity of the ships for each material are assumed to be similar to the numbers of 2019.A maximum Capesize utilization will ship all material by Capesize vessels from the ports that are marked bold in table 12. Considering the basic constraints stated in Chapter 3.2, the increased barging that comes with Capesize vessels should be included as well.

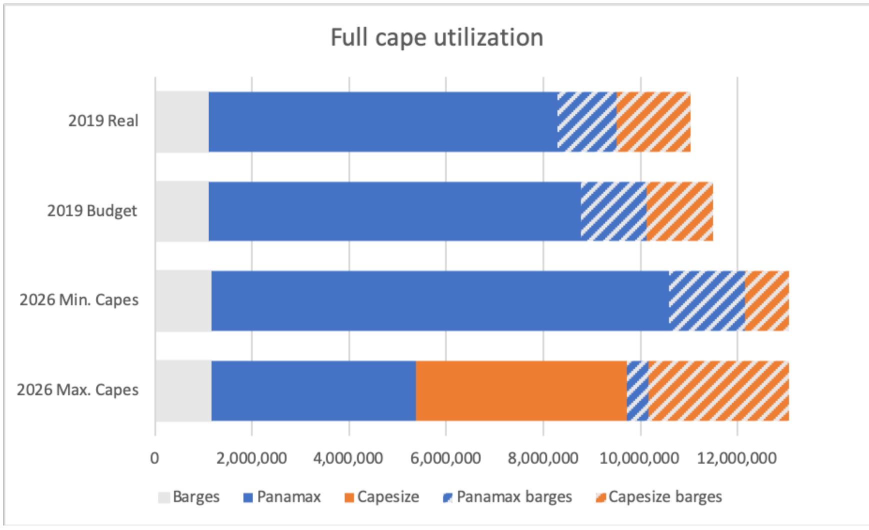

Figure 29: Quay arrivals with minimum and maximum cape utilization

Figure 29 shows what the impact of maximum cape utilization (2026 Max. Capes) can be compared to the reference scenario where no capes are used (2026 Min. Capes). The distribution between the total amount of material transported by sea vessels and barges does stay relative constant. However, by focusing per product group the results show the opposite. Figure 30 shows the maximum cape utilization for iron ore and coal compared to the base situation. The use of Capesize vessels for iron ore will result in a large increase of the number of barges that will be used. This can be explained by the fact that a Capesize will have to unload 40% of its material to meet the draught restriction while a Panamax vessel averages around 18% for iron ore. On the other hand, the use of Capesize vessels for coal will result in a significant decrease in barge use. The reason for this will be that most of the coals already originate from Capesize vessels at the EMO and are currently requiring 100% barging to get to AMG. The direct use of Capesize will therefore reduce the barging with 60% for most of the Australian coal.

It should be noted that this maximum cape utilization is only calculated to show the full potential of Capesize vessels. In real life there are many restrictions on the use of Capesize vessels. The expected future scenarios will be in between a no cape and a full cape scenario depending on the limitations stated in the next chapter.

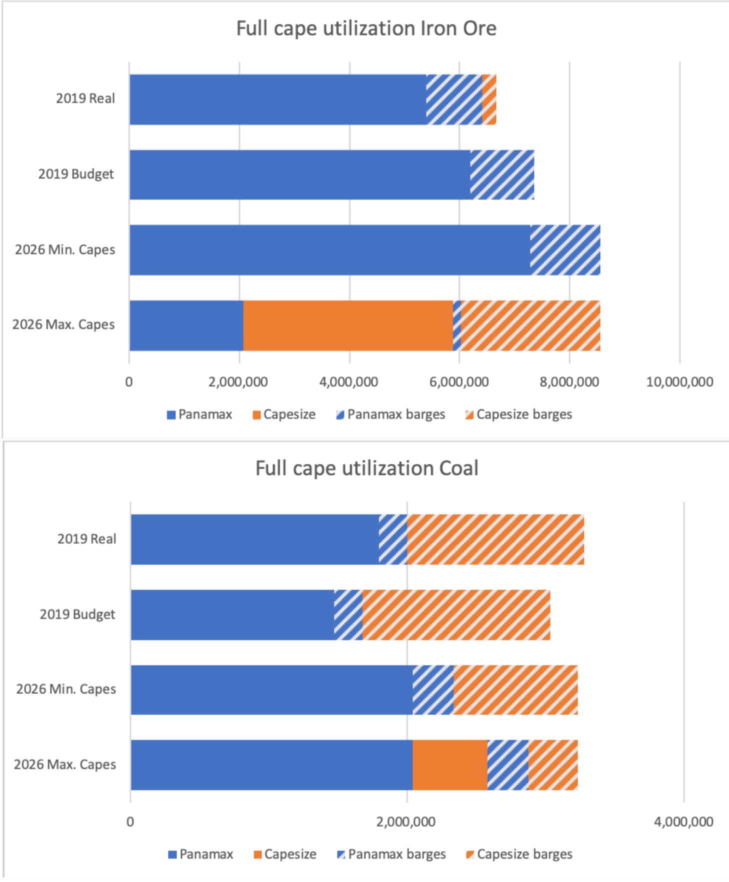

Figure 30: Quay arrival for iron ore and coal separate with minimal and maximal cape utilization

4.5 Main findings Chapter 4

The main findings of this chapter can be summarized in the following bullet points:

- In 2019 the production of 4.9 Mt steel required circa 11 Mt of raw materials of which approximately 60% iron ore (fines and pellets) and 35% coal (coking, PCI and cokes).
- Currently 70% of the shipped material arrives per vessel while the remainder arrives by barges.
- When the external stock is used for transshipment, 50% of the material will be directly barged to AMG, while the remainder stays on the storage for an average of XX days.
- In 2026 the production of 5.5 Mt hot metal will require circa 13 Mt of raw materials of which approximately 65% iron ore (fines and pellets) and 30% coal (coking coal, PCI coal and cokes).
- The share of iron ore (fines and pellets) imported from AM Mining will increase from XX% to XX% of the total amount of iron ore.
- AMG aims to be less dependent on large mining companies such as Vale, Rio Tinto and BHP Billiton in 2026.
- The source ports of up to 55% of the raw materials in 2026 will be able to load Capesize vessels.
- Overall barging will increase with 22% when these Capesize vessels are fully utilized. When using Capesize vessels for iron ore the amount of barging increases while using Capesize vessels for coal will decrease the total amount of barging.

5. Capesize Limitations

Chapter 5 will show the limitations to the utilization of Capesize vessels. This includes upstream limitations for the loading and partial unloading of the Capesize vessels but also downstream limitations on the site of AMG. The shipping limitations focus on the influence of AM Sourcing and AM Shipping in allocating the materials. The competition and compatibilities between different AM steel mills in Europe will have a certain influence on the potential Capesize situation. Other shipping limitations are mainly focused on the last stages of the journey where the vessels arrive in Europe and have to be halted at the pilot or externally stocked. Furthermore, the quay capacity will be discussed, focusing on the difference between sea vessels and barges and the impact of the limited quay capacity on the waiting times. Finally, the on-site limitations focus on the effect that Capesize vessels might have on the downstream installations. With the limitations known, proposed improvements for the quay and downstream supply chain for 2026 are introduced.

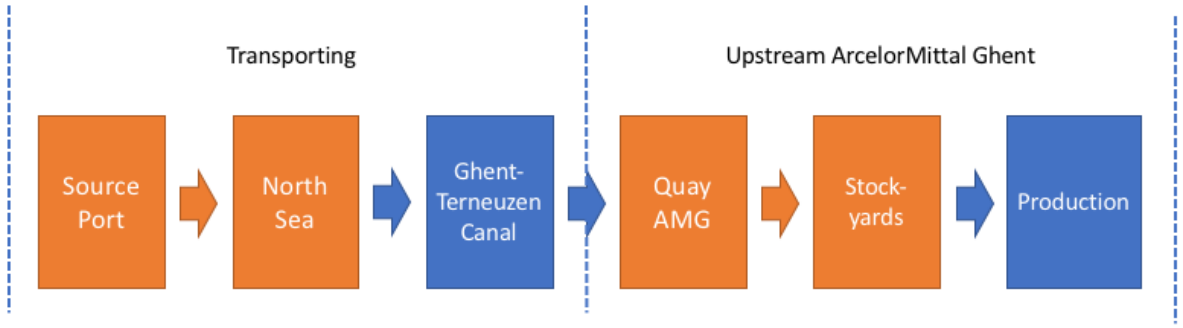

Figure 31: Steps in supply chain that are discussed in Chapter 5 (in orange)

5.1 Shipping limitations

The use of Capesize vessels is limited by different aspects of the upstream supply chain. Chapter 2.3.1 showed the upstream processes that are ranging from the moment the source port till the arrival at the quay of AMG. Table 12 showed the 8 different materials for 2026 that can be transported by Capesize vessel through 6 different ports in Canada, Brazil and Australia. If those ports will actually be allowed to ship their material by Capesize vessels is decided by AM Sourcing and AM Shipping.

AM Sourcing is responsible to provide all European steel sites of ArcelorMittal with raw materials for low prices. Therefore, Capesize vessels are often shared between different locations. This goes especially for Australian coal since the demand for different coal types is limited compared to iron ore and long distances that have to be covered. If a steel site should receive a full Capesize itself this will lead to a large surplus of a certain material on the stockyards. Currently the material that is destined for AMG has the EMO as main destination. The material is there distributed between AMG, AMB, AMZKZ and AM DK. An average Capesize ship contains 9 holds of material that should be divided between the four sites. This can be done by unloading it externally and transport the material by barges or by the vessel itself as an extra stop. For AMG the current situation of barging is estimated to cost XX.XX euros per ton for the total transport. By receiving the vessel instead of the barges these costs can be significantly be decreased for AMG. There are fixed costs that come with the arrival of a vessel in Ghent and therefore it will be more efficient per ton of material to transport more material by the vessel at once. The estimated costs differ depending on how many holds are used. Up to 5 holds the costs are reducing per hold, while from 6 holds on the costs are increasing again. This is due to draught restriction, since all the material above the 60% should be unloaded on barges that come with an increased cost. It should be noted that the transport by ship will always be cheaper for AMG than the XX.XX euros for transport by barge. Normally AMG is receiving 2 holds per Capesize vessel in the form of barges. AM Sourcing communicated that this amount is likely to stay the same or might increase till 3 holds depending on the situation. However, AMG is not the only site that rather will receive the vessel than the barges. An extra stop at AMG will require additional costs for all the material and lead to an increase of the price for other sites. Therefore, AM Sourcing will look to the total cost of operation and will try to distribute the Capesize arrivals evenly between sites. The barging from the EMO is however, much cheaper than transporting the material from the EMO to AMDK or AMZKZ. Therefore, it is estimated that AMG will only be able to receive 25% of the Australian coal in the form of Capesize arrivals while 75% of the arrivals will remain in the form of barges. This amount might increase if less sites are combined for one trip and this discussion will continue till the opening of the new lock.

For the iron ore it can be stated that the situation is the other way around. Even though Capesize sharing can be beneficial for AMG, there is very limited opportunity with other sites. AMG cannot receive a fully loaded Capesize itself and therefore the sharing will require a deep-sea port as a first stop. The only available steel site on the route with this potential is AMA in Spain. Many sites of ArcelorMittal have similar draught restrictions as AMG and therefore the combination of vessels with AMA is in high demand. For AMA itself the sharing will not be beneficial so AM Sourcing will again make a distribution based on the total costs of operation. In the case of AMG, it will be likely to receive one shared Capesize vessel of Brazilian iron ore per quarter. This vessel can be unloaded till 105.000 DWT at the port of Gijon and continue straight to Ghent without additional unloading. Pricewise this is ideal for AMG and therefore the amount of sharing with AMA should be maximized if the opportunity is there.

Sharing Capesize vessels of Brazilian iron ore at the EMO is an option as well, but the only site nearby that makes use of this external stock would be AMB. Currently AMB is already sharing most of its iron ore with AMDK and there is limited opportunity to share more vessels with AMG. Therefore, the only way that AMG can make use of Capesize vessels for Brazilian iron ore, is by ordering full ships by itself and include the extra costs that comes for unloading a storage on an external stock.

Besides the sourcing, the shipping can also be a limitation for the use of Capesize vessels for AMG. Material from Port Cartier (Canada) does have the potential to be shipped by these ships. However, loading port prefer to load Panamax vessels since it has only limited capacity for the loading of Capesize ships. The Capesize vessels that are loaded are all destined for third party clients in China. Furthermore, the distance to Port Cartier is much shorter than for example the Brazilian and Australian ports and therefore the benefits for using Capesize vessels will be much smaller. In general, Capesize vessels from the east coast of Canada and the USA are considered to be infeasible.

The limited amount of Capesize vessels that will be able to transport material to AMG will have other upstream limitations as well. The deeper draught of these ships will require extra precautions from the pilot point till the quay of AMG. The route from the pilot point till the external stock at the OVET and the EMO can have restrictions for fully loaded Capesize vessels and can therefore require extra cost. Furthermore, the effect of using vessels of this size in the Ghent-Terneuzen Canal is unknown. The GNA (Gemeenschappelijke Nautische Authoriteit) is currently investigating the effect of vessel with a width of 45 meters on the stability of the general quays alongside the canal. The results of this study can influence the number of vessels and the speed for which they are allowed to sail to AMG.

5.2 Berth use and waiting time

One of the main limitations for 2026 is expected to be the berth use. The berth use can be described as the amount of time that the berthing spots are in use, compared to the total time that the berths are available. The proposed 12% increase in production will require 12% more inflow of material which will have its impact on the berth use. A high percentage of berth use can result in an exponential growth of waiting times for ships which will come with high amounts of demurrage for ships and waiting fee for barges.

5.2.1 Sea vessels

The waiting queue for sea vessels is a well-studied subject in literature as discussed in Chapter 2.2.2. The quay of AMG is a combination of a sea port and an inland port and therefore the situation does not comply to all literature. In general, it can be stated that sea vessels have priority over barges and therefore do not influence the arrival of sea vessels even though there might be a limited effect in real life. Therefore, waiting queue data of AM Ghent will be compared to that of the literature. Figure 32 shows 2 sets of data derived from literature concerning queueing theory (Radmilovic, 1992). Two random distributions (Erlang and Poisson) were used to simulate a waiting queue for ships with the waiting time and the handling time as main parameters. Literature shows an exponential trend for an increase in berth use. This means that at a high berth use, a small increase in berth use can have large effects on the waiting times. The situation of AMG was examined by plotting data point of the last 4.5 years over the literature values. The waiting time and handling time were directly available from the general data, while the berth use could be calculated by using the total handling time of the ships and the time the berths were available throughout the year. It can be concluded that the quay of AMG follows the same general trend as the literature.

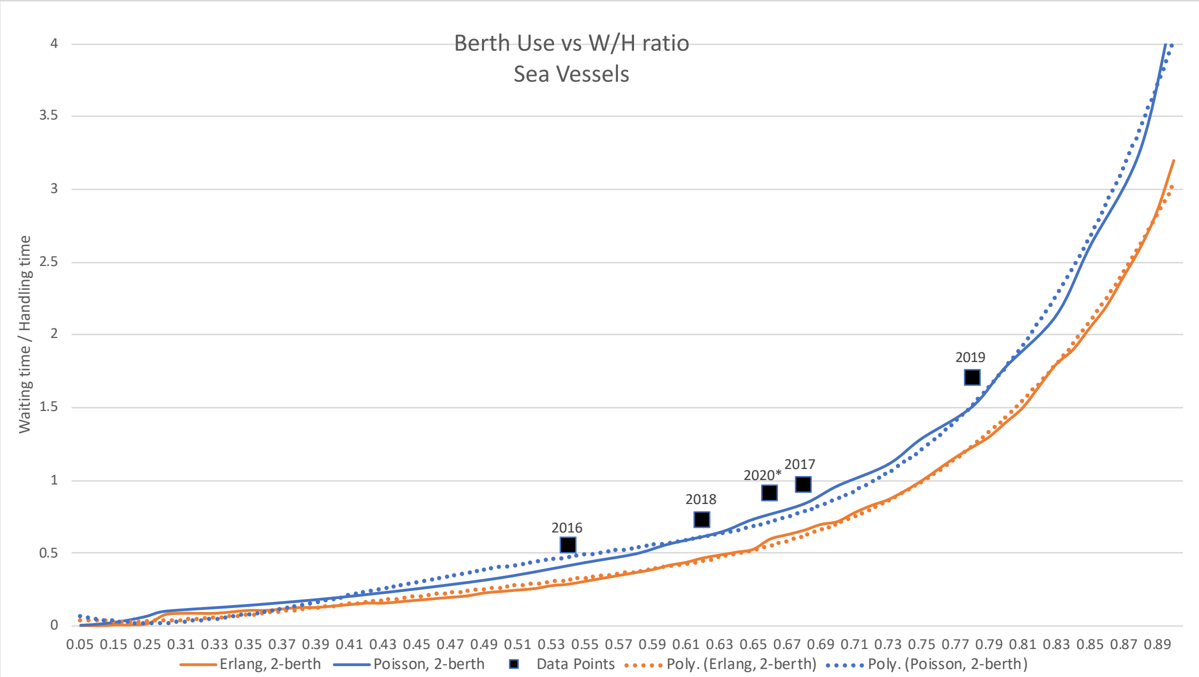

Figure 32: W/H ratio compared to used quay capacity

In 2019 the quay of AMG was on a high berth use due to a limited amount of total berth availability. The installment of a new crane (A9) caused certain berth unavailability and downstream problems limited the flow of material from the quay to the stockyards. As an effect the waiting queue increased resulting in an exponential growth in demurrage. Table 13 shows how 2019 was an exceptional year in terms of waiting days and demurrage while importing a regular amount of material.

	Volume SV	Vessels	Waiting days	Demurrage costs
2016	X.XX Mt	118	173	€ X,XXX,XXX
2017	X.XX Mt	145	392	€ X,XXX,XXX
2018	X.XX Mt	129	232	€ X,XXX,XXX
2019	X.XX Mt	133	685	€ X,XXX,XXX

Table 13: REDACTED Demurrage KPI's AMG

5.2.2 Barges

Since the sea vessels have priority over the barges, the maximum barge unload capacity is directly linked to the sea vessel capacity. With both berths occupied by sea vessels, the barges can only be unloaded by the B1 crane which is specifically purchased for this purpose. Since most of the barges cannot be scheduled beforehand, they are required to wait near the quay of AMG until they can be unloaded. Figure 33 shows the average waiting time of these barges over the past years with the proposed target of 3 days maximum. This figure also shows in 2019 the impact of the quay capacity on the waiting time. The barges that are derived from the external storage can be scheduled and are therefore expected to wait for less time than unscheduled barges.

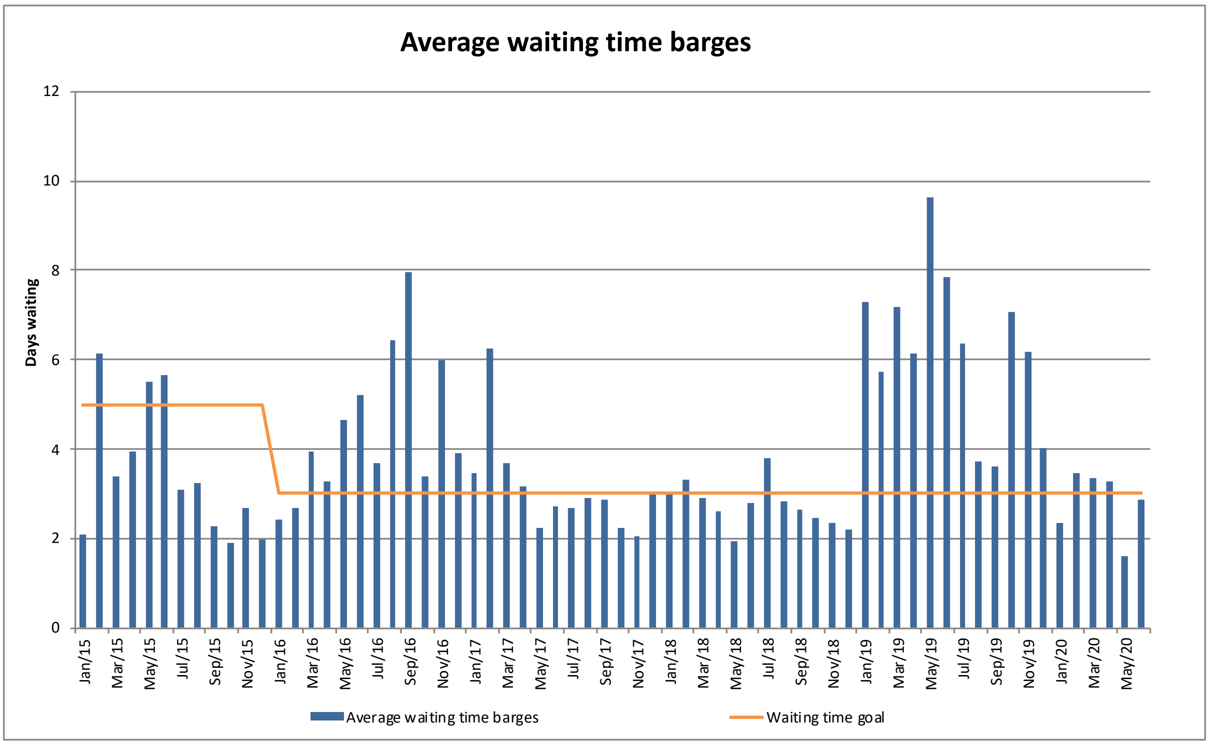

Figure 33: Average waiting time barges AMG per month

5.3 On-site limitations AMG

The use of Capesize vessels will cause larger loads of materials that arrive at the quay at once. The current downstream equipment might not have the dimensions or capacities to handle this properly and therefore might limit the arrival of Capesize vessels. There are three phases to consider which are the unloading by the quay cranes, the transport of the material to the stockyards and the stock yarding itself.

5.3.1 Cranes

The current quay layout is described in Chapter 2.3.2. After the deconstruction of crane A1 there are 4 remaining bulk cranes which are from south to north: B1, A2, A8 and A9. Each crane has its own characteristics such as maximum unload capacity, height and beam length. The implementation of Capesize vessels require certain characteristics such as sufficient height and beam length and therefore some quay cranes might be unable to be used on vessels this size. The B1 is constructed for the purpose of efficient barge unloading and does not have the required height to unload Capesize vessels nor the beam length. The A2 crane has a sufficient height to unload Capesize vessels but lack the beam length to cover an entire hold. Currently the A2 is not able to fully unload certain Panamax ships and is therefore considered to be unsuitable for the even larger Capesize vessels. The A8 is a relatively new crane that has proved to be highly efficient on Panamax vessels. However, the beam length lacks 2.5 meters to reach the farthest point of a Capesize holds which is considered to be at 35.5 meters. Therefore, it can used to unload a part of the holds, but cannot be used to finish a hold. The newest quay crane of AMG is the A9 which was installed in 2019. This crane was designed with the option of unloading Capesize vessels in case these vessels will be able to berth at AMG after 2023.

The unload capacity of the A8 and A9 crane is material specific and also depends on the vessel size. The increased hold size will increase the amount of free digging but the handling time of each crane movement will increase due to the longer beam distance it has to cover. According to the bulk specialists at the OVET bulk storage in Vlissingen, the average unload time per ton is similar to the unload time of Panamax vessels.

5.3.2 Transport of material

The quay cranes unload the raw material from the vessel onto a quay conveyor from where the material is further transported down the steel site. Currently there are 3 quay conveyors available for the B1 crane and 2 for the other cranes. This means that crane A2, A8 and A9 cannot unload different materials at once due to the limit of conveyors. Furthermore, each quay conveyor also has a maximum capacity. To unload a Capesize vessels as quickly as possible it is common to work with multiple cranes on the same vessel. However, when both these cranes are at free digging capacity, the combined crane capacity surpasses that of the single quay conveyor. Therefore, there should be coordination between the different cranes. If there are no available quay conveyors, the material can be unloaded on the pre-stock (intermediate stockpile) from where it can be transported down the site later on. The amount of material that can be deposited on the pre-stock is limited to 20,000 tons and will not be sufficient for a full Capesize vessel.

The quay conveyor is not only limited to the unloading capacity of the quay cranes. When the material is unloaded on the quay conveyor, a specific track is selected throughout the park to bring the material to the destined stockyard. The capacity of the track is limited by the bottleneck part with the lowest capacity. Furthermore, it means that every component of the track will be in use and cannot be used by other tracks. When working with two or even three cranes on a Capesize vessel it might seem an option to use both quay conveyors. However, this might lead to problems downstream since there should be two different tracks available leading to the two different stockyards that are not allowed to share any components. Currently it is preferred to stock the same material on one stockyard and the option for using both quay conveyors should be further investigated.

This also applies to material that is transported from the stockyards to production facilities. Production does usually have priority over the incoming materials so if a specific track is blocked by a production line, it will lead to a limitation in the unloading process of the vessels. Capesize vessels will lead to higher quantities of the same material at once and therefore will require less switches in track paths throughout the year.

5.3.3 Stockyards

The last part of the downstream supply chain that is influenced by Capesize vessels will be the stockyards. The stockyards make use of stacker-reclaimers which have a certain capacity that can be the bottleneck of a certain material track. Since it is a stacker-reclaimer and not just a stacker, the same equipment is also used to reclaim the material from the stockyards for production. This causes certain stockyards to be inaccessible for the incoming material which can be problematic.

The design and capacity of the stockyards does heavily influence the arrival of vessels. Each material type has a safety stock with enough material to guarantee a certain amount of days of production. When the stockyards are below the safety stock level, vessels containing this material will have priority over other vessels in the waiting queue. This can lead to a decrease in overall efficiency. Furthermore, when the stockyard reaches its maximum capacity, the vessels containing this material will not be able or allowed to berth at AMG and therefore accumulate waiting time.

With the arrival of Capesize vessels the loads of materials increase while the frequency of the arrivals decreases. This can lead to an overflow of materials on the stockyards, higher amount of required safety stocks and more dependency on planned arrival times. The strategic planning of stockyards will be of increased importance when Capesize vessels are used.

5.4 Improvements

The proposed production increase of 12% will require a higher capacity for the quay and downstream facilities. Therefore, the improvements that are scheduled for the next year should be included when considering the Capesize vessels. These improvements can be divided into quay improvements and downstream improvements.

5.4.1 Quay improvements

The main quay improvement will be the arrival of a new quay crane. Since the A2 crane is almost 50 years old and has a limited functionality on Panamax and Capesize vessels, it is proposed to replace it with a new crane. This new crane will be called the A10 and will be able to unload as well sea vessels as barges. In contrary to the other cranes, this crane will be able to rotate its grab 90 degrees. This makes it suitable for smaller vessels such as barges and coasters with a capacity that can be compared to current A8 crane. For sea vessels it will use a normal grab orientation like the A8 and A9 cranes. The capacity and properties of the crane for sea vessels are considered to be similar to the A9.

The exact location where the A10 will be placed has not yet been decided. There are two possible options that both will be evaluated during this thesis. Figure 34 below shows both options for the future quay orientations. When using the A10GNT orientation the A10 will be located on the same place as the current A2 crane. This will have the advantage that the new crane can be connected to the third quay conveyor (F22). The other option will be the A10ZZ orientation where the A10 is located at the most northern side of the quay.

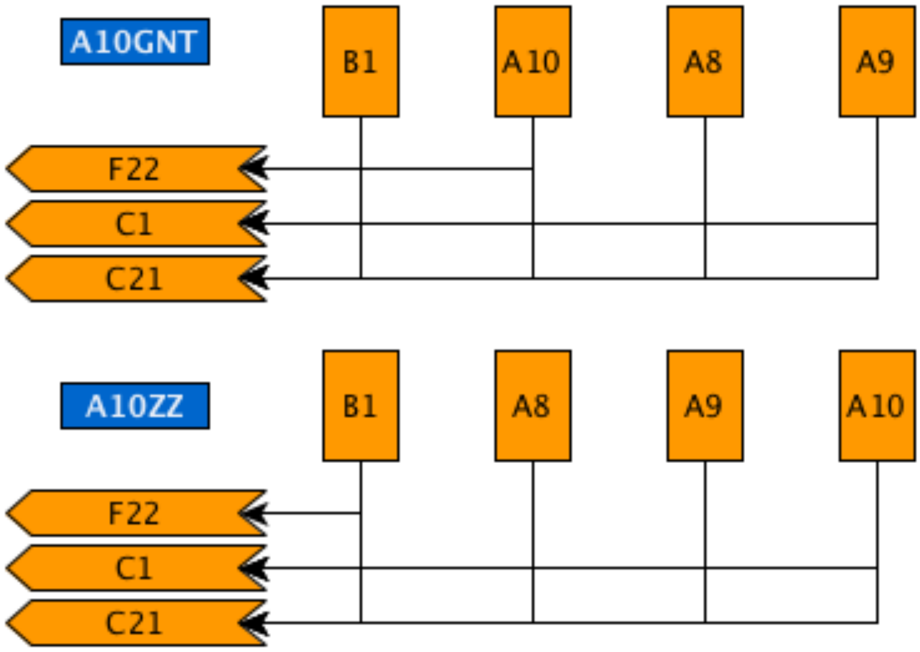

Figure 34: Two different options for A10 positioning

Another quay improvement would be to extend the length of the quay. Currently the quay length for raw materials is over 650 meters which is sufficient to berth 2 Panamax vessels of 230 meters while still being able to unload barges with the B1 crane. Capesize vessels require 70 meters extra length compared to a Panamax vessel so when two Capesize vessels are berthed at the same time there will be no possibility to unload other vessels or barges. However, the quay length can be extended to the north of the quay. Currently this quay is used for the loading of finished steel products on inland and sea vessels. The loading of these products will be moved from this quay to a brand-new dry dock warehouse making space for a quay length improvement.

5.4.2 Downstream improvements

The downstream handling of material can be improved if the new A10 crane will be placed on the same location as the current A2 location. The A10 crane will have opportunity to unload material on three conveyors and therefore the third quay conveyor can be extended till the A10. When the A10 is located on the north side this would not be an option since the extension of the conveyor would require a larger investment and decrease the space on the pre-stock.

Furthermore, there will be downstream improvements to decrease the unavailability of tracks downstream. The stacking-reclaiming process for the iron ore and pellets will be altered so the incoming material can be directly transferred from the quay to the blast furnace by surpassing the stockyards. Furthermore, certain coal conveyors will be increased in size two make the opportunity of 2 different full-scale tracks to the coal stockyards. This will decrease the chance that the production limits the unloading of material. Other improvements will be an increased reliability for machinery and an increased capacity for stacker-reclaimers. Finally, a mobile installation will be installed to take over for stacker-reclaimers in case of a breakdown. The stockyards are currently a bottleneck in the process and therefore the breakdown of a stacker-reclaimer has an enormous impact throughout the supply chain. Figure 35 gives a brief overview of the downstream improvements.

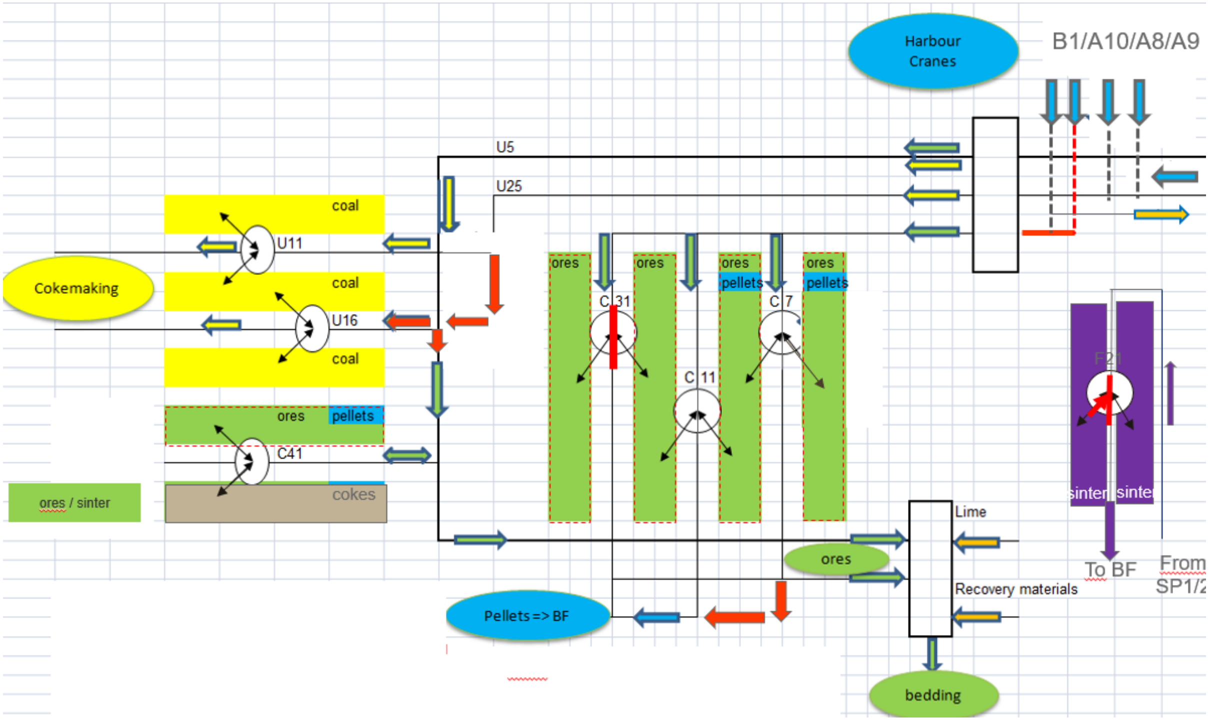

Figure 35: Overview downstream improvements in red (provided by the Raw Material department))

5.5 Main findings Chapter 5

The main findings of this chapter can be summarized in the following bullet points:

- Capesize shipments of Australian coal have to be shared with other sites of ArcelorMittal throughout Europe. This limits the usage of Capesize vessels to only 25% of the Australian coal.
- Due to loading conditions Canadian iron ore cannot be shipped by Capesize vessels and it is also unlikely to be feasible because of the relatively short distance. Only iron ore sourced from Brazil 1 and Brazil 2 can be shipped by Capesize ships.
- The combination of iron ore shipments with other sites of ArcelorMittal is unlikely, only sharing with AM Asturias can be an option with an upper limit of 1 Capesize vessel per quarter.
- The increase to 5.5 Mt of hot metal is likely to lead to capacity issues for sea vessels and in lesser extent for barges. This will result in increased waiting times and demurrage costs.
- Currently only the A9 crane is fully able to unload Capesize vessels while the A8 crane has limited possibility.

- The increased length of Capesize vessels will lead to a shortage of quay length if two ships arrive at the same time.
- The increased loads of materials will affect the conveying of materials from the cranes to the stockyards.
- Due to a decreased frequency the stockyards will have a larger variety in stock level and therefore require increased safety stock.
- A new crane (A10) is proposed for 2026 which will be able to unload as well Capesize vessels as barges.
- There are 2 options in terms of positioning of the A10 crane compared to the current quay cranes which might influence the productivity.
- It is proposed that in 2026 the quay will be increased in length and a third quay conveyor might be connected to the A10 crane.
- Other downstream improvements are planned to increase the capacity and efficiency of the downstream installations.

6. Capesize Scenarios

This chapter combines the previous 3 chapters to predict realistic scenarios for 2026. It takes the potential and limitations of Capesize vessels in consideration for the raw material forecast of 2026. The scenarios are constructed in consultation with AM Sourcing, AM Shipping and the resource procurement department of AMG. By comparing the results of different scenarios, the sub questions in Chapter 1.2 can be answered. Each of the different scenarios will result in a year-long arrival list of the vessels and barges, combined with an external storage list. The sub questions of Chapter 1.2 are repeated below.

1. *What will be the influence of a production increase till 5.5Mt steel per year, on the quay and production facilities of ArcelorMittal Ghent?*
2. *To what extent can Capesize vessels be used for transporting material to ArcelorMittal Ghent?*
3. *How will the arrivals of Capesize vessels influence the downstream supply chain of raw materials?*
4. *Which price differences between Panamax and Capesize vessels are necessary to make the use of Capesize vessels feasible?*
5. *What will be the influence of the addition and positioning of a new quay crane?*
6. *Which external stock will bring the most benefits for Capesize unloading*

Sub question 3 and 4 handled the impact of Capesize vessels compared to the current situation where only Panamax vessels are used. To give different gradations between in cape use, 6 different vessel scenarios were created that were rated as realistic and complied to all the limitations stated in Chapter 5. Sub question 6 can be answered by comparing scenario 3 with scenario 6. These vessel scenarios and a short explanation of each scenario is provided below. Figure 36 shows how this will influence the quay balance between barges, Panamax, Capesize and other vessels.

Scenario 1: Business as Usual
Increased production in 2026, no Capesize vessels used, serves as a reference scenario

Scenario 2: Capesize sharing
Increased production in 2026, 1 shared IO vessel per quarter with AMA, 25% of Australian coal by Capesize

Scenario 3: Brazil 1
Increased production in 2026, sharing as in Scenario 2, remaining 350.000t from Brazil 1 (south east Brazil) by Capesize, partial unloading at EMO

Scenario 4: Full capes Brazil
Increased production in 2026, sharing as in Scenario 2, all 3Mt of iron ore from Brazil (Brazil 1 and Brazil 2) by Capesize vessels, partial unloading at EMO

Scenario 5: Extra Capesize sharing coal
Increased production in 2026, 1 shared IO vessel per quarter with AMA, 50% of Australian coal by Capesize vessel

Scenario 6: OVET
Increased production in 2026, sharing as in Scenario 2, all 3Mt of iron ore from Brazil (Brazil 1 and Brazil 2) by Capesize vessels, partial unloading at OVET

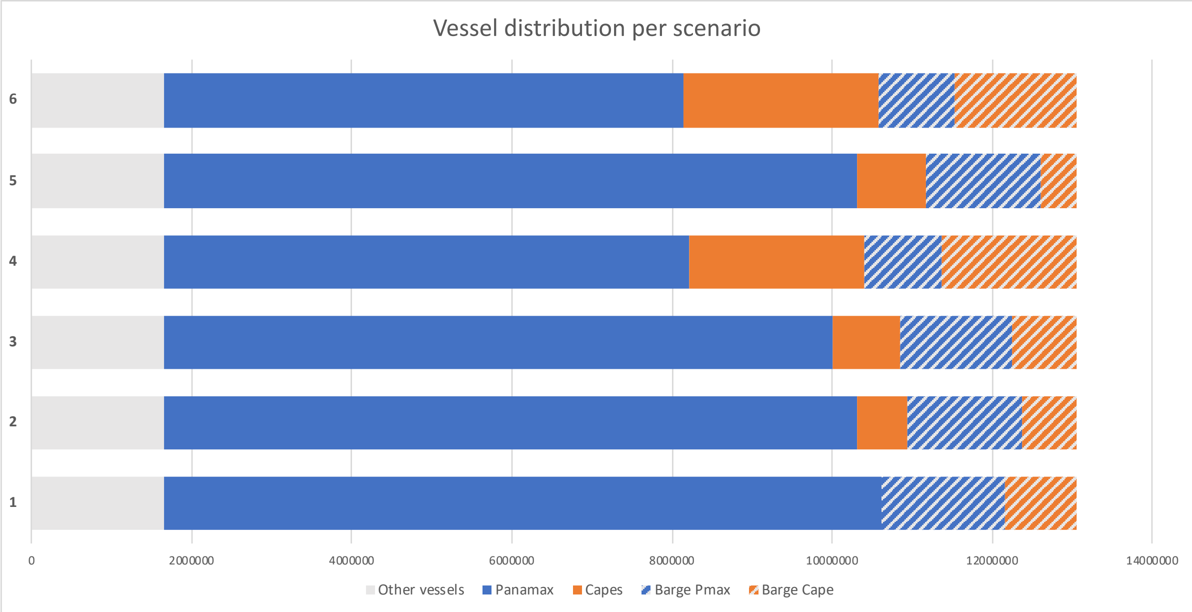

Figure 36: Quay balance sea vessels and barges

Besides comparing different vessels scenarios, a distinction will be made between two different crane scenarios. These crane scenarios involve the installment of the new crane called A10 which is stated in Chapter 5.4. The relative positioning of the crane to the other cranes will have an impact upon which cranes can work together on a certain ship and if the new crane can be connected to a third quay conveyor belt. The two crane scenarios are as follows:

A10GNT: Crane order south to north; B1, A10, A8, A9, the A10 crane is connected to 3 quay conveyor belts

A10ZZ: Crane order south to north; B1, A8, A9, A10, the A10 crane is connected to 2 quay conveyor belts

Sub question 5 can be answered by comparing A10GNT and A10ZZ. Both the crane scenarios use the same 6 vessel lists created by the vessel scenarios and the differences will be purely in the downstream logistics.

The created arrival and external stock lists of each scenario will serve as input data for Chapter 7 and Chapter 8. The arrival time, material type and quantities will be the main required information for the simulation of crane operations, downstream conveying and stock yarding. The vessel type, tonnage and source location are necessary to make a cost estimation of the shipping price. With these chapters in place, the earlier stated research questions could be answered.

7. Quay Modelling

The goal of this chapter is to give an estimation of the impact that Capesize vessels will have on the site facilities of AMG. This will be done by implementing the different arrival lists, constructed in the previous chapter, as input of a process flow model. This model simulates the material flow throughout the downstream facilities with regard of the capacity limitations of the cranes, conveyors and stock yards. The simulation is done in an existing model that have been altered and specified for the Capesize problem statement. New rules have been added and implementations have been made to incorporate the improvements listed in Chapter 5. At the end of this chapter, the proposed results and limitations of the model will be discussed.

This chapter covers the steps in the supply chain that starts at the arrival on one of the anchorage points until the deposal of the materials on the stockyard. The external stock is incorporated as well since the model will request the material from this stock when there is available capacity on the quay for extra barges. The model contains every part of the supply chain that is involved in unloading the material and transporting it down the stock yards.

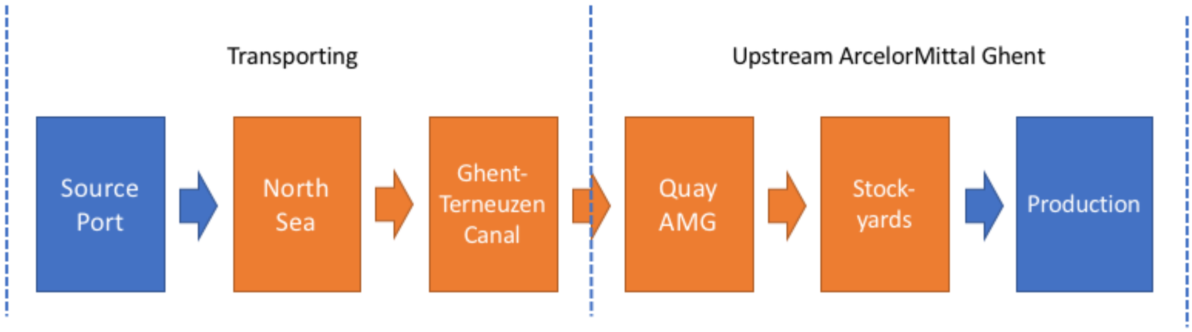

Figure 37: Steps in supply chain that are discussed in Chapter 7 (in orange)

7.1 FlexSim model description

The software that is used for simulating the downstream behaviour of the raw materials is a software package called FlexSim. It is a combination of visual 3D-modelling (see figure 38) and process logics in flowchart form. It is programmed in a C++ based language called *flexscript*. In 2016 the project was started and finished in its current form 1.5 year later by the Systems and Models department of ArcelorMittal Ghent.

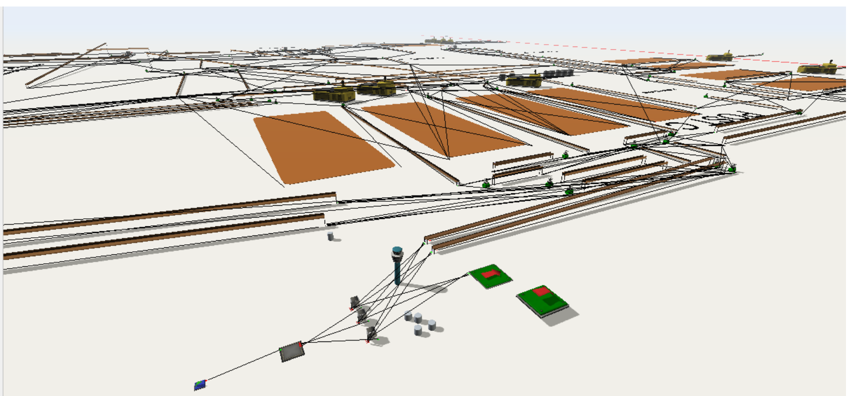

Figure 38: Representation of the 3D quay in the FlexSim model

The planned model should have consisted out of a harbour module which simulates the input from the quay of AMG until the stockyards and a customer module that would handle the varying demand in material for the different production facilities of AMG. However, these models could not be combined yet due to compatibility issues and therefore only the harbour module is used in this thesis. This should not bring any issues since the harbour module is inside the scope of the thesis while the customer module was not. Therefore, a constant outflow of raw materials for production would have no effect on the outcomes of this research. Figure 39 shows the base structure of the material flow that is used for the model. The light grey areas are included in the customer module while the dark grey areas are part of the harbour module with the Arrivals as main input data.

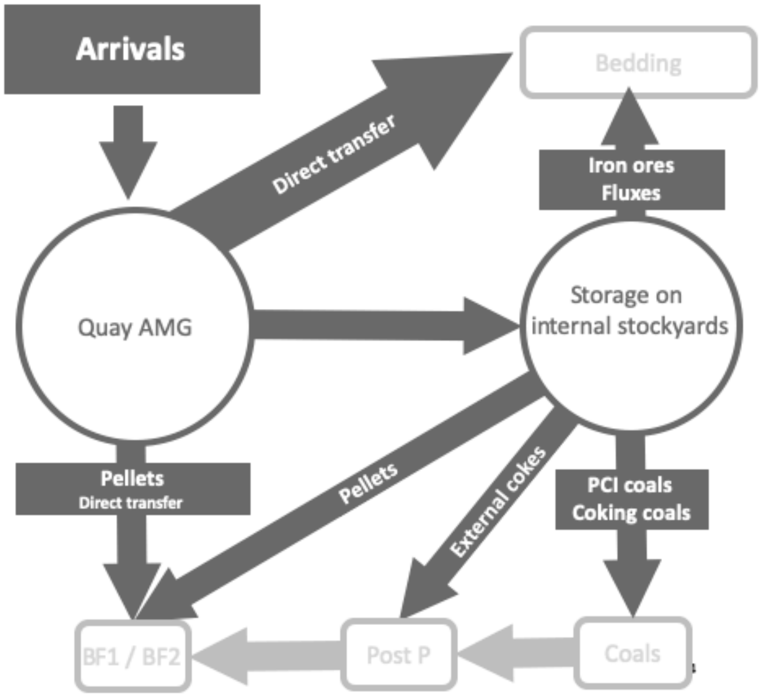

Figure 39: Structure harbor module

The goal of the harbour model is to determine the effect of changes within the downstream supply chain for historical input data. The model works with the arrival data of a full year to account for the different fluctuation of material inflow and outflow throughout the year. A year is divided in 8760 timestamps of an hour. The arrivals consist of the constant arrival of vessels throughout the years and the barges that are unloaded from these ships by BB unloading. Furthermore, there is also a separate input from the external stock which in most cases will be the EMO. The main parameters for the total arrival lists are the arrival time, type of shipment (ship or barge), material type, material subtype, length of the vessel and the amount of material that arrives. Besides the inflow over the quay there is also a limited inflow of limestone by trucks of 150.000 tons per year which is assumed to be constant in the model.

The model does not require any warm-up time thanks to the initial stocks and the steady state conditions that are in place at t=0. Ships are called from the arrival list to the quay on the time they are listed. If both berths are already occupied than the ship has to wait in the waiting queue. When a berthing spot opens up, the ships form the queue get called in on a first in first out (FIFO) sequence. Only when a certain material is below safety stock, the arrival will be moved forward. A vessel will only be called when the quay is not limited by certain constraints. The first constraint is the length constraint. The total length of the vessels on the quay may not exceed the 650 meters including a safety distance in between vessels. Secondly there should be cranes capacity available to unload the arriving vessels. In the existing model there are 4 different cranes (B1, A2, A8 and A9) and two different crane combinations (A2-A8 and A8-A9) to unload ships. The only limitations for these cranes are that a A9 is not allowed to unload barges while the B1 is not allowed to unload sea vessels. Each of the cranes or crane combinations have a different unload capacity. Priority is given to the largest available capacity. The chosen crane(s) will continue working on the vessel until it is completely unloaded. During the unloading of the vessel, the capacity is scaled in three different phases. Figure 40 shows the 3 phases depending on the fill grade of the vessel. During the free digging it uses the full capacity of the cranes since the grabs can freely dig without touching the sides or the bottom of the hold. The second phase is the trimming phase where the capacity is reduced due to the limitations of the hold. The last 2 percentage of each is used for cleaning where only one crane can operate on a very limited capacity.

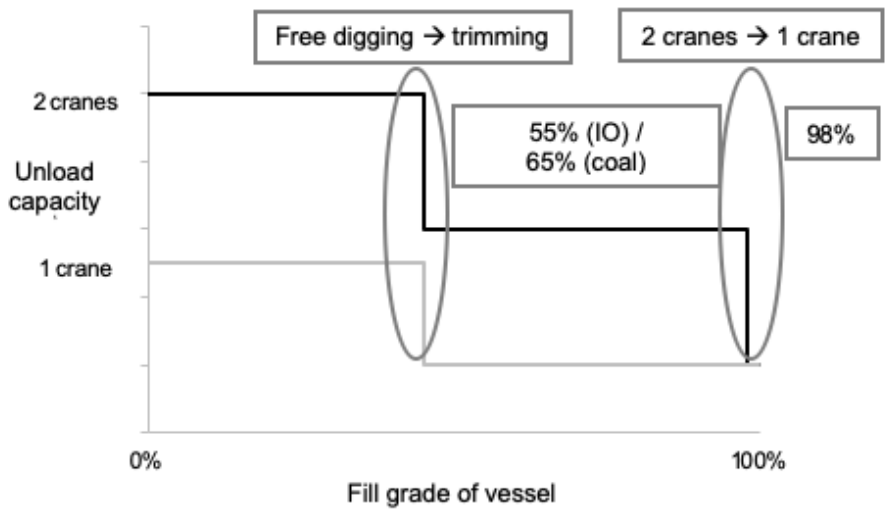

Figure 40: Unload capacity for the modelled cranes depending on the fill grade

When a suitable crane combination is found, the model starts searching for an available downstream path that will lead to the right stockyard for the arriving material. All elements in this downstream may not be already in use by production or by another unloading vessel. If the arriving material is directly required in the production process it can be routed directly to production by skipping the stockyard phase. The model gives priority to this option but it only happens rarely due to the fact that the arrival and production need to line up at the right time. Also, the amounts that are required for production are far less than the average incoming load of material. The first elements in this downstream route are the quay conveyors which are limited by two for sea vessels and three for barges unloaded by the B1. The park conveyors transport the material further down the park to the stacker reclaimers that deposit the material on the stockyards. Each element has a limited capacity, with the lowest capacity as bottleneck for the whole downstream route.

If there is no downstream route available the model chooses to put ship back in the waiting queue or to unload the material on the pre-stock. The pre-stock overrules the downstream supply chain and can be used to unload vessels when there is downstream obstruction. This obstruction can be due to the priority of production or other material flows, but often this obstruction occurs due to (planned) maintenance or machine breakdown. Even though this is almost to predict, the model takes this into account by generating semi random stops of specific machinery based on historical data. Each model can be run multiple times for the same scenario each with different variations of machine breakdown and maintenance. Since unavailability of machinery can have a heavy impact on the functioning of the downstream model, an average is taken from these different runs to approach a realistic scenario. Previous of the model have showed that after more than 15 runs, the average results did not significant change any longer. An addition of extra runs per scenario would result in a model that would take too long to run to complete all calculations.

Finally, the model takes stockyard limitations in consideration as well. These consist of an upper boundary which is the maximum capacity of the stockyard and a lower boundary which is the safety stock. Arrivals can move up the queue if there is need for a specific material or can move down the queue if there is no room on the specific stockyards. The outflow of the stockyards is given by fixed values for production. Ores are divided into different ore subtypes that are required for the sintering bedding in certain percentages and also the coke batteries require different quantities of coking coal subtypes for each batch.

7.2 Alterations to FlexSim model

The goal of the original model was to see the effect of changes within the downstream supply chain for historical input data. For this thesis the model has been altered so it will have a mostly fixed downstream supply chain for different input scenarios. These input scenarios are arrival vessel lists for different scenarios in Capesize utilization. Certain things have been added and modified to make the model useful for this purpose.

First of all, the arrival type of Capesize vessels was included in the generated vessel lists. This includes the increase in ship length and the increased capacity of the vessels. Certain crane rules had to be added as well to take the crane limitations of Chapter 5 into account. The B1 and A2 are considered to be unusable on Capesize vessels while the A8 has only limited possibility. The A10 crane was added as well based on the limited available information and the current information of the A8 and A9 cranes. The unload capacities of all cranes were re-examined as well and inconsistencies with reality have been removed.

Since Capesize vessels make increased use of the external storage, the conditions of arriving barges had to be altered as well. The original model made use of fixed arrival times of material from historical data. Barges were only called upon from the external stock when there was opportunity and capacity to unload them on the quay. However, the new model works with future predictions and therefore the barges cannot be manually planned. Therefore, an extra arrival list was created for the external stock that monitors the amount of material and arrivals on the external stock. A base weekly capacity for sea vessels and barges of the quay of AMG was estimated and when this capacity is not met, extra material will be called upon from the external stock. This is done in batches of at least 3 barges at once, depending on the amount of material available on the external stock and leftover capacity of that week.

The planned capacity increase in production is also taken into consideration in the renewed model. As stated in Chapter 4, new materials are included and the inflow of other materials have been upscaled. This is included into the input data (vessel lists) of the model. Besides the inflow, the outflow of the model had to be altered as well. The absolute amount of bedding and cokes used had to be increased, while also the mixture of the bedding and cokes had to be slightly altered to match the inflowing material. Finally, the quay and downstream improvements stated in Chapter 5.4 were implemented into the renewed model. The following improvements were considered:

- Quay length extension
- Quay conveyor F22 extended till A10 (only in A10GNT scenario)
- Conveyor addition for different tracks
- Increased reliability machinery
- Mobile conveyor for stacker-reclaimer breakdown
- Ideal park configuration (explained on the next page)

With these improvements in place the downstream capacity of the quay should increase while decreasing the risks of breakdown and (planned) maintenance.

7.3 Proposed results and limitations to the model

With the renewed model the impact of Capesize vessels on the quay of ArcelorMittal Ghent could be examined. The vessel lists from Chapter 6 with the increased material inflow can be used as input of the model and with the output different sub questions of the research can be answered. The primary output of the model can be divided in three categories: waiting time vessels, waiting time barges and material on the pre-stock. Furthermore, the model provides other output factors that can explain the primary output. Examples are crane occupation, conveyor occupation, stacker reclaimer occupation, ships in system over time and barges in system over time. Furthermore, it will be possible to see the behaviour of the stockyards for different scenarios and different arrival times of ships.

However, a model is only a simplified representation of reality and therefore it cannot be perfect. This extensive model has its shortcoming. First of all, the actual scheduling of ships and cranes are based on manual decisions. This means that most of the basic rules in the model are followed but under certain circumstances there will be deviations. This can be due to downstream changes but can also be based on cost-based decisions. The model is not a decision or optimization model and does not try to optimize the costs of the scheduling. Furthermore, the model does not allow cranes to change ships or positions before the ship is finished, although they are able to change between unloading on quay conveyors and the pre-stock. In real life this does happen for various reasons such as preparing for the next ship, maintenance or other quay activities besides unloading vessels. One of these activities can be the reloading of the material from the pre-stock to the quay conveyor which is not included into the model.

There are also limitations downstream of the cranes. First of all, the demand for production is taken as a constant while in practice the recipes for the blast furnace, bedding and coke factory can vary over time. Production always has a priority in the model and the inflow of material should match the standard mix of materials that are used. It is true that this is mainly the case but under low stock circumstances this recipe can be changed. One of the largest limitations of the model is the stockyard modelling. The stockyards for each material are in the model. However, in real life there are different stockyard areas that can be divided dynamically. This caused problems during the initial runs and this bottleneck ran upstream throughout the whole supply chain causing vessels and barges to wait for a long time. Therefore, it was decided to work with an 'ideal park configuration' which means that this bottleneck was bypassed and that there is an unlimited supply of material available on the stockyard. The waiting queue still be adjusted if there is too much or too little inflow of certain materials. However, the planning of the stockyards is considered ideal so when material is needed for production there are always stacker-reclaimers available for production. In real life this is not the case and therefore the results may turn out to be more positive, but it will approach a realistic scenario better than running the model with stock limitations. Since this thesis is especially focused on the relative difference between different scenarios of the quay, the impact of this is limited.

All together it can be concluded that the model is not perfect but it is currently the only way to predict the impact of large alterations, such as Capesize vessels, on the quay and downstream facilities of AMG. With the proposed adjustment is expected to observe enough relative effect between scenarios to draw conclusions.

7.4 Main findings Chapter 7

The main findings of this chapter can be summarized in the following bullet points:

- To simulate the on-site downstream supply chain an existing model is used which is created by the use of *FlexSim* software.
- This existing model its purpose was to see the effect of changes in the downstream supply chain for a fixed input of arrivals.
- For the purpose of this thesis the model has been altered to see the effect of a variable input of arrivals on a fixed downstream supply chain.
- The model makes 15 runs for each scenario with variation in equipment availability. Each run will simulate a full year of quay arrivals and downstream supply chain.
- Capesize specific rules have been added to the model based upon the limitations that were stated in Chapter 5.
- An additional input list for the external stock have been added so the model can request material from the external stock when there is capacity available at the quay to unload extra barges.
- The main output parameters for the model will be the waiting time for sea vessels, the waiting time for barges and the amount of material on the pre-stock.

8. Cost Impact

In this chapter the costs of the different scenarios will be discussed. These estimations for 2026 are based upon the documented costs from 2017-2020 and how they are predicted to change over time. The costs can be separated in 6 different elements which are listed below.

- Shipping costs
- Double stop costs
- North Sea Port costs
- Barging costs
- Downstream costs
- Waiting costs

Most of the freight contracts of AMG are FOB (Free on Board). This means that the supplier is responsible for the raw materials until the moment that it is loaded on the vessel. Therefore, all costs from this moment are taken into consideration that are related to the shipping procedure. Furthermore, the costs for on-site material handling as included as well until the moment the raw materials are placed on the stock yards by the stackers.

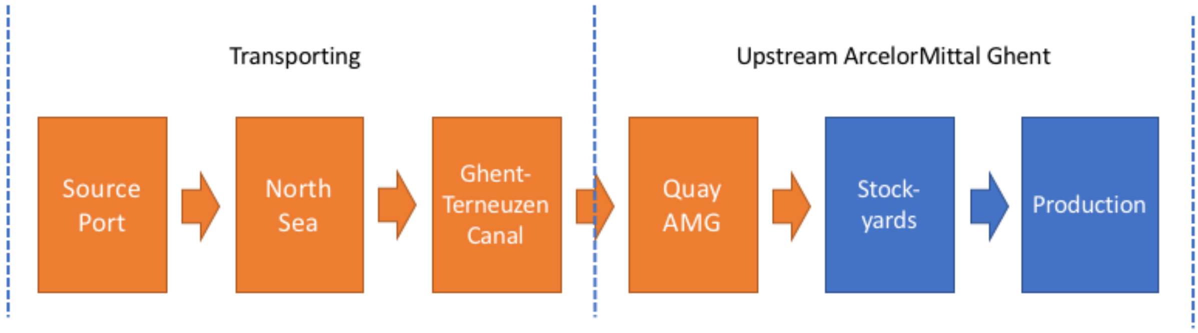

Figure 41: Steps in supply chain that are discussed in Chapter 8 (in orange)

8.1 Shipping costs

The most important factor for the use of Capesize vessels would be the decreased cost of shipping per ton. Chapter 3 gave an indication of the spot rates which is an estimation of the all-inclusive costs per ton. However, since AM Shipping is hiring vessels on a time charter base, the real costs differ from the spot rates. The cost can mainly be divided in time charter costs which are the daily cost for the use of the vessel and the bunker costs. Just like spot rates the time charter costs are volatile and depending on market circumstances. However, when there is an agreement on a certain time charter rate, this rate is fixed for a certain period which is usually for 6 months, 1 year or 2 years. The time charter costs are defined by AM Shipping and are considered to be market competitive. The bunker costs remain fully volatile and have depending on market circumstances.

It is from importance to clearly define what are the contributing factors in the shipping costs so Panamax and Capesize vessels can be compared. The time charter costs and bunker costs are both depending on the amount of days that the vessels are on its way to AMG. The time charter works with day rates which do not discriminate between days on sea and days in the port, while the bunker use and costs are significant higher for days on sea. The amount of days on sea is depending on the average speed of the vessel and the total mileage. The fuel consumption is estimated on 51 tons of bunkers per day for Capesize vessels and 32.5 tons per day for Panamax vessels, both for an average speed of 14 knots. Since the Panamax-Capesize comparison is only from importance for Brazilian iron ore, the mileage is either 6135 nautical miles for the material from Brazil 1, or 5446 nautical miles for the material from Brazil 2. The shipping price of coal is from lesser importance since the material is transported to Europe by Capesize vessel not dependent on the fact if the material reaches AMG by vessel or by barge.

Due to environmental reasons over the past years, the type bunker fuel that is used have changed from the original Heavy Fuel Oil (HFO) bunker types that contain a maximum amount of sulphur. This trend is very likely to continue and therefore the cost indication of the bunkers is based upon the prices of VLSFO (Very Low Sulphur Fuel Oil with a maximum amount of 0.5% sulphur) instead of the HFO that most commonly was used in the past. Furthermore, there are certain zones worldwide, where the tolerance for sulphur is even lower. In the so called SECA zones (Sulphur Emission Control Areas), the maximum threshold of sulphur is defined on 0.1%. The North Europe SECA zone contains among others the North Sea and the English Channel and are therefore on the route of vessels destined for ArcelorMittal Ghent. Instead of regular (low sulphur) bunkers, MGO (Marine Gas Oil) is used which is more environmentally friendly and often comes at a higher cost. This MGO is also used during port manoeuvring and to power the vessel when it is anchored. The costs per ton of fuel are defined in this thesis as 550 euros for MGO and 534 euros for VLSFO. This is based on the Rotterdam bunker prices of the last years, with the exclusion of the price disturbance caused by the COVID-19 crisis in 2020.

Table 14 shows the summarized shipping costs. Appendix C displays an extended version with all the contributing factors. It excludes European port charges and handling costs since these are accounted for in the remainder of this chapter.

	Brazil 1 (P'max)	**Brazil 1 (Cape)**	**PDM (P'max)**	**PDM (Cape)**
Day costs	$ 531,000	$ 766,000	$ 479,000	$ 695,000
Bunker costs	$ 489,000	$ 768,000	$ 431,000	$ 684,000
Total costs	$ 1,020,000	$ 1,534,000	$ 910,000	$ 1,379,000
Per ton	**$ 13.55**	**$ 8.76**	**$ 12.14**	**$ 7.88**

Table 14: Summarized shipping costs for Brazilian iron ore

These shipping costs will serve as main parameter for the calculation and comparison of each scenario. These are only averages and it should be noted that these costs are highly volatile. Therefore, one of the main conclusions of this thesis will be for what cost difference the use of Capesize vessels will be feasible. This so-called break-even price can be used whether or not to choose for a certain scenario depending on the rates at that time.

Even though the listed shipping costs are assumed to be constant for each scenario, there is a cost difference between scenario 6 (Capesize vessels via OVET) and the other scenarios. This is due to the fill factor of the Capesize vessels in the specific case that the OVET is used. Spot rates are weighted averages per ton for a fully loaded vessel. However, the draught limitation at the OVET does not allow fully loaded Capesize vessels. The ship can be loaded to an estimated 155.000DWT while still paying around the same total price for the transport to Europe. Therefore, the cost per ton of the spot rate will increase with a factor equal to 1 divided by the fill factor which is 88.6% in this case.

8.2 Double stop costs

One of the main cost factors against the use of Capesize vessels would be the costs to make an extra stop at an external port before the (partly unloaded) vessel can reach the quay of AMG. In contrary to Chapter 3 where a basic value was used, these costs will be worked out in this paragraph. The double costs can be divided in the port costs and the extra vessel costs due to the increase in transport time. In this case the costs are worked out for the use of the EMO and the OVET. In the case of iron ore combination with Asturias an added cost of $ X.XX per ton was assumed based upon information provided by AM Sourcing.

The port costs for the use of the EMO include the costs of shipping agencies and the costs for the port authority (Port of Rotterdam). The material handling costs for the EMO are given in Chapter 8.3. The first costs occur when the vessel reaches the pilot point of the Port of Rotterdam. From that point on the captain of the ship have to hand over the control of the ship to a pilot. The base rate for this is depending on the draught of the vessel. In addition, there is a route-based rate which is dependent on the draught of the vessel. After unloading these costs occur again for the return trip but with lower costs thanks to the lower draught. Finally, the pilot itself has to be dropped off at a specific point at sea which comes with costs that are called the 'forfaitair rendezvous'. The pilot costs are shown in table 15 below for a Capesize vessel with a loaded draught of 18.4 meters and an unloaded draught of 13 meters.

Pilot rates EMO	Loaded	Unloaded
Base rate	€ X,XXX	€ X,XXX
Route dependent	€ X,XXX	€ X,XXX
Forfaitair rendezvous	€ X,XXX	

Table 15: REDACTED Pilot rates for the EMO

Upon arrival at the port the next costs occur. To berth the vessel in the Port of Rotterdam, a docking rate has to be paid. This rate is dependent on the size of the ship which is measured in gross tonnage (GT). The gross tonnage, which is based on the hull volume of the ship, for the reference Capesize vessel is 91,374 (unitless). The docking rate for the Port of Rotterdam for 2020 is 0.309 per GT. On top of that there are costs for the mooring of the vessel which

XXXX euros for the mooring and the same for the unmooring. Finally, there are costs attached for the transhipment of materials which are 0.50 euros per ton of material. In the base case 70,000 ton is unloaded or transhipped in Rotterdam.

For the use of the OVET similar pilot costs are assumed as for the use of the EMO. The port authority in this case will be North Sea Ports which is also the port authority of Ghent and the quay of AMG. Opposed to the EMO the docking rate and costs for transhipment are solely based on the GT of the vessel. The rate for these port dues is 0.33 per GT plus an additional 0.537 per GT. However, there is a cost reduction of 50% in port dues because of the fact that the ship is berthing twice in the same port authority area (Flushing and Ghent). A mooring fee of XXXX euros is an additional cost.

The additional time that the ship requires for a double stop should be taken in consideration as well. This time start from the moment the ship enters the pilot point of the external stock and ends when the vessel reaches the pilot point of AMG. It is estimated that this time will be 2.5 days for the OVET and 3.5 days for the EMO based on the crane capacity and location. The current situation with Panamax vessels requires 0.5 days of extra time due to the BB unloading before the lock of Terneuzen. The costs for this extra time can be estimated by multiplying the days by the demurrage rate of the vessels. Demurrage is known as a compensation for the lost income of a vessel and should therefore be an accurate indication of the extra costs. Based on historical data a demurrage rate of 12,400 euro per day is taken for transatlantic Panamax vessels and 18,200 euro per day for Capesize vessels.

8.3 External storage and barging costs

A part of the load of the vessel has to be unloaded before the ship can reach AMG and therefore there should be made use of an external stock. Depending on the fill factor of the ship 70,000 tons should be transhipped when using the EMO and 50,000 tons when using the OVET. This transhipment can be divided in board-board unloading directly on barges and storage unloading on the external stock itself. For both cases it is estimated that there is a 50/50 distribution between these two forms of transhipment.

BB unloading at the EMO will cost X.XX euro per ton of iron ore and X.XX per ton of coal. The OVET has a rate of X.XX euro per ton for iron ore and coal. The barges are provided by a third party for a fixed rate depending on the distances that the barges have to cover to reach AMG. From Rotterdam this fixed rate is X.XX euro per ton and for Flushing/Terneuzen this rate would be X.XX euro per ton. These costs include the passage through the locks of Terneuzen and the port dues for the barges.

The other half of the material that is transposed on the storage comes with additional costs compared to the BB unloading. Since the material will be unloaded on the quay and be loaded from the quay on barges, the material needs to be handled at least twice. The EMO charges X.XX euro per ton of iron ore and X.XX euro per ton of coal for this, while the OVET is charging the flat rate of X.XX euro. The price of the storage itself highly depends on the amount of time that the material is located on the external stock. These costs are provided in table 16. For the calculation an average of 70 days on storage is used based on the numbers of 2019. Again, the barging costs should be considered as well.

EMO Iron Ore		EMO Coal		OVET	
0-90 days:	€ 0.0XXX	0-21 days	€ 0.0XXX	0-14 days	€ -
91 - 120 days:	€ 0.0XXX	22- 60 days	€ 0.0XXX	14+ days	€ 0.0XXX
121 - 180 days:	€ 0.0XXX	61 - 90 days	€ 0.0XXX		
> 180 days:	€ 0.0XXX	90+ days	€ 0.0XXX		

Table 16: REDACTED Costs of storage per ton per day for the EMO and the OVET

8.4 North Sea Ports costs

To berth a vessel at the quay of AMG additional port charges should be paid to the port authority of Ghent (North Sea Ports). These costs consist of the docking costs and the transhipment costs of the material. The docking costs for Capesize vessels are 0.XXXX euro per GT of the vessel (91,374GT) and the transhipments costs are 0.XXXX per ton of material (105.000 tons). In case of using the OVET as first stop, a 50% reduction of the docking costs will be considered because of the use of the fact that the vessel is berthing twice in the port authority area. Furthermore, at the end of each quarter there is a refund of 22% for iron ore and 20% for coal on the docking costs. This refund is independent on which external stock is used.

For the use of Panamax vessels, the same rates apply and the refund will be 30% of the docking costs. Furthermore, there is a refund for the BB unloading which averages around X,XXX euros per vessel. The costs for the BB unloading of Panamax vessels at the Put van Terneuzen are estimated on X.XX euro per ton of material that is unloaded. These costs consist of the unloading on sea by floating cranes on barges (X.XX euro per ton), the pusher tugs (0.XX euro per ton) and fixed costs of X,XXX euro (0.XX euro per ton average). Furthermore, the barging fee of X.XX euro per ton is required here as well.

8.5 Downstream and waiting costs

The previous costs in this chapter can be seen as independent of how cranes and downstream installation of AMG are operating. However, there are some costs that are influenced by the functioning of the downstream supply chain which are variable per scenario also within each scenario. These costs are related to the amount of pre-stocking of material and the waiting times of vessels as well as barges.

The costs to transfer the material from the ship to the stockyards by conveying is estimated on 0.50 euro per ton of material based upon historical data of machine use for cranes, conveyors and stacker-reclaimers. The crane movement is considered to cost 0.2 euro per ton of material while the conveying and stocking makes up for the other 0.3 euro per ton. However, when unloading on the pre-stock instead of the quay conveyor, additional material handling should be taken into consideration. This additional handling can be done by the same quay cranes on the quay conveyors which will have an additional cost of 0.3 euro per ton, totalling 0.8 euro per ton of downstream costs. Only 30% of the material on the pre-stock is estimated to be loaded again by the cranes while the other material is moved by front loaders and trucks to the stockyards. This has an estimated additional cost of 1.00 euro while not making use of the downstream conveyors, totalling on 1.2 euro per ton for downstream handling. By taking a weighted average of the numbers it can be said that the costs for using the pre-stock can be estimated on 1.08 euro per ton compared to the 0.5 euro per ton in a normal situation. For the total costs the additional 0.58 euro should be multiplied by the total tonnage of material on the pre-stock per year. The total tonnage on the pre-stock for each scenario can be derived from the simulations of Chapter 7.

The waiting time of the material before it can be unloaded on the quay of AMG can be divided between sea vessels and barges. For sea ships this waiting time should be multiplied by the demurrage rate of the corresponding ships. Waiting time is defined as the total time from when the is registered at the pilot point till the moment it leaves the quay of AMG minus the time that is contractual agreed upon in the charter party. This agreed time is depending on the amount of material that should be unloaded on the quay. A rate of 30,000 tons per day is considered as average in the charter party, although it can vary per material type. Furthermore, the travel time between the pilot and the quay of AMG (8 hours) is included in the agreed time. The BB unloading time for Panamax vessels at the Put of Terneuzen (12 hours average) is not included in the agreed time. The agreed unloading time means that a Panamax vessel (62,000 DWT at the quay) should be unloaded within 2 days while a Capesize vessel (105,000 DWT at the quay) will require 3 days. When these targets are not met or the ship is required to wait on the pilot point, demurrage should be paid. The simulations in Chapter 7 provided estimations of the total time that the ships are within demurrage range. By subtracting the agreed time per ship type (Handymax, Panamax and Capesize) the waiting times can be calculated. Since not all vessels are fully loaded the average DWT of each ship type should be divided by agreed unload rate of 30,000 DWT per day. With the waiting times known, they can be multiplied by the demurrage rates for the three vessel types which are respectively X,X00, XX,X00 and XX,X00 euro per vessel per day.

For barges the same theory applies. The total waiting costs for the barges are the amount of waiting days of the barges multiplied by the waiting rate which is 0.XX euro per ton per 12 hours for the first 5 days and 0.XX euro per ton per 12 hours from day 6 on. The waiting days can be derived from the simulations of Chapter 7 as well.

9. Results

This chapter displays the results of the quay modelling (Chapter 7) and the cost impact (Chapter 8). Before the main output of the quay modelling are presented, secondary results are used to explain the reasoning of the model.

The waiting time of vessels, waiting time of barges and material on the pre-stock are the main results of the quay modelling in which the scenarios are analysed. Secondary output is used to explain how these values have been obtained from the model. One of these values is the overall quay occupation throughout the year. The arrival time of the vessels is directly derived from the vessel lists while the stay time of the vessels depend on the waiting queue, cargo of the ship and the unload possibilities. Figure 42 and 43 show the sea ships arrival for a situation without Capesize vessels (scenario 1) and a situation with Capesize vessels (scenario 4). It should be noted that these are only single representations of 15 runs per scenario. The arrival time of each vessel is independent on the machine breakdown and therefore each of the 15 runs per scenario looks similar. However, due to machine breakdown a vessel might have a longer handling time. On a year-long scale such as the figure 42 and 43, this is hardly noticeable. Compared to each other, the graphs are very similar as well because they use the same arrivals for material that cannot be transported by Capesize vessels. It can be noted that figure 43 has less frequent arrivals than 42 while the different peaks do connect for a longer time. This a logical result from the fact that a Capesize vessel needs more time to unload which causes other vessels to wait until there is a free berthing place.

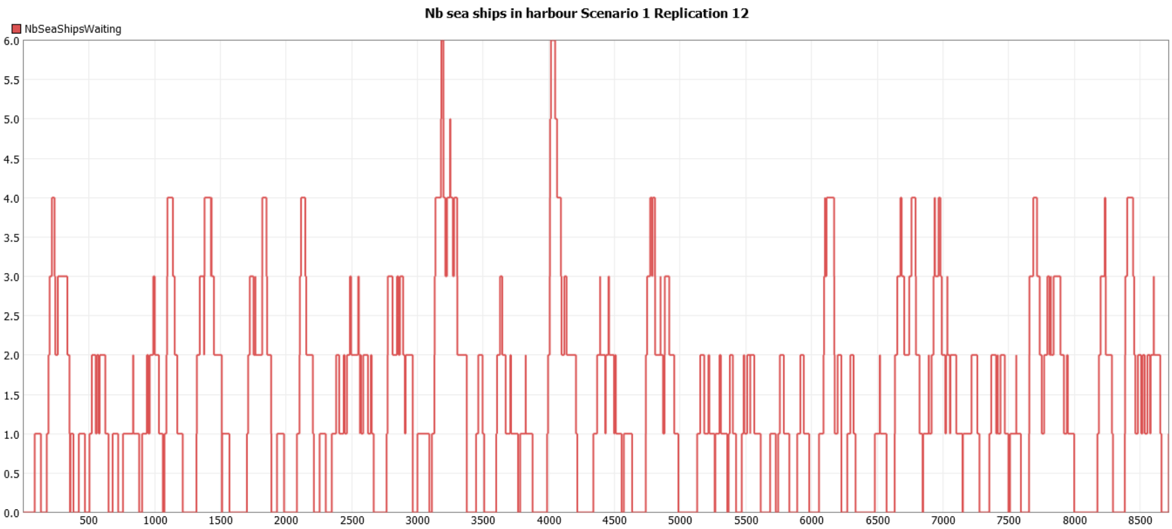

Figure 42: Number of sea ships within the model over the year (scenario 1)

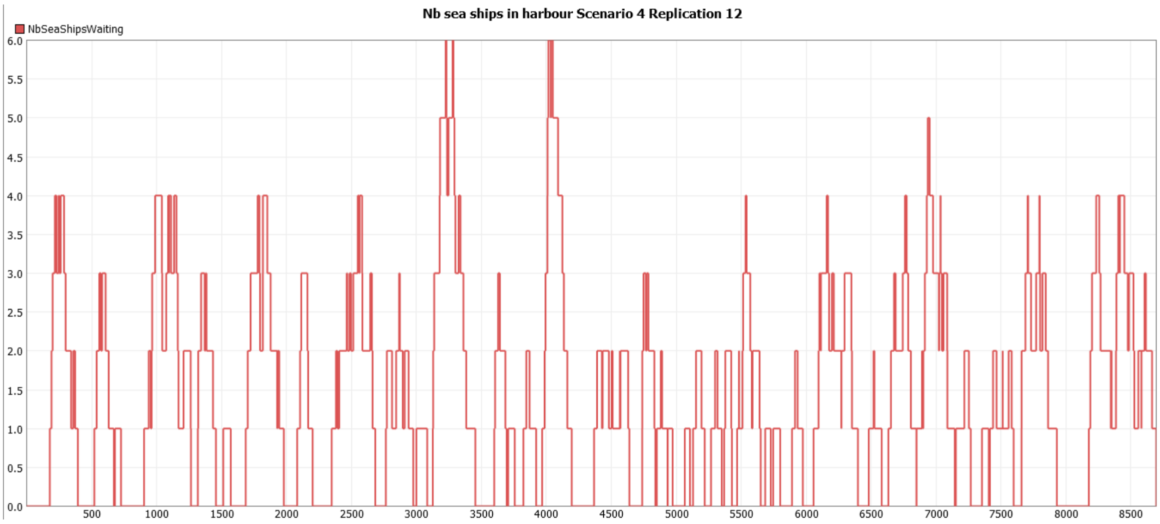

Figure 43: Number of sea ships within the model over the year (scenario 4)

In contrary to the sea ships arrivals which did not much differ, the arrival of the barges is heavily influenced by the implementation of Capesize vessels. Figures 44 and 45 show an example of 1 of the runs for the arrivals of barges over time (in red) and by subgroup (other colours) for scenario 1 and scenario 4. Enlarged figures can be found in appendix D. Both figures show a balanced arrival of barges with fluxes and cokes (showed in pink). The barges used for BB unloading of Panamax vessels and BB unloading from the EMO are also nicely distributed throughout the year with some peak moments when the motherships are lining up. The largest difference in both figures is the green line which shows the material originating from the storage. The model calls for this material when there is enough quay capacity available to unload them in a reasonable time.

The largest difference between figure 44 and 45 is the scale of the y-axis. The large-scale use of Capesize vessels results in a higher percentage of unloading compared with Panamax vessel (40% instead of 18%) to reach draught limitations and therefore results in an increase of barging. Furthermore, the Capesize arrivals at the EMO to unload material, will result in direct BB barges and storage material. Figure 45 shows that these two barges normally do not appear at the same moment which displays that the model wait with the storage material till a more appropriate time.

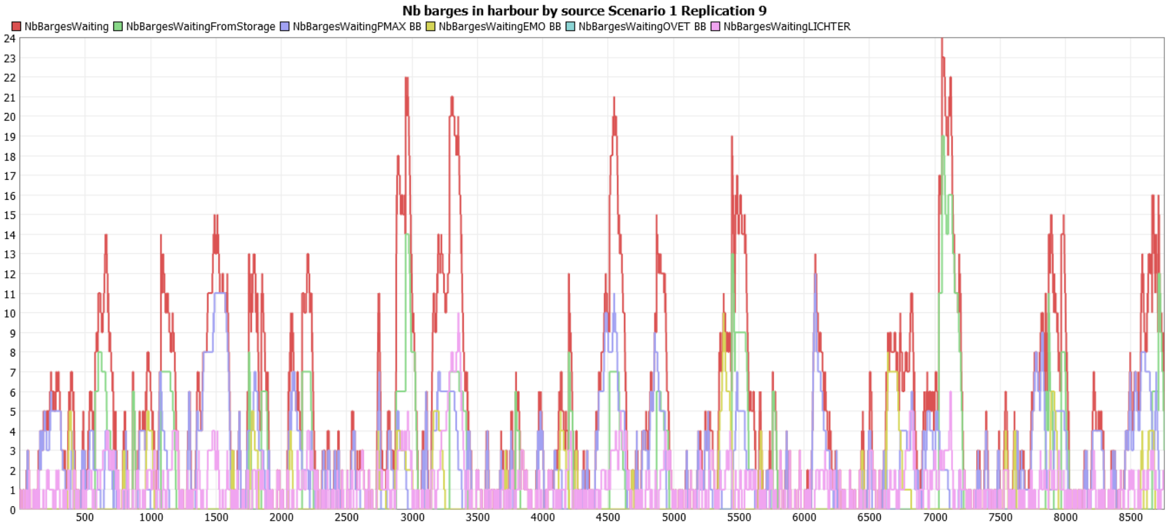

Figure 44: Number of barges within the model over the year (scenario 1)

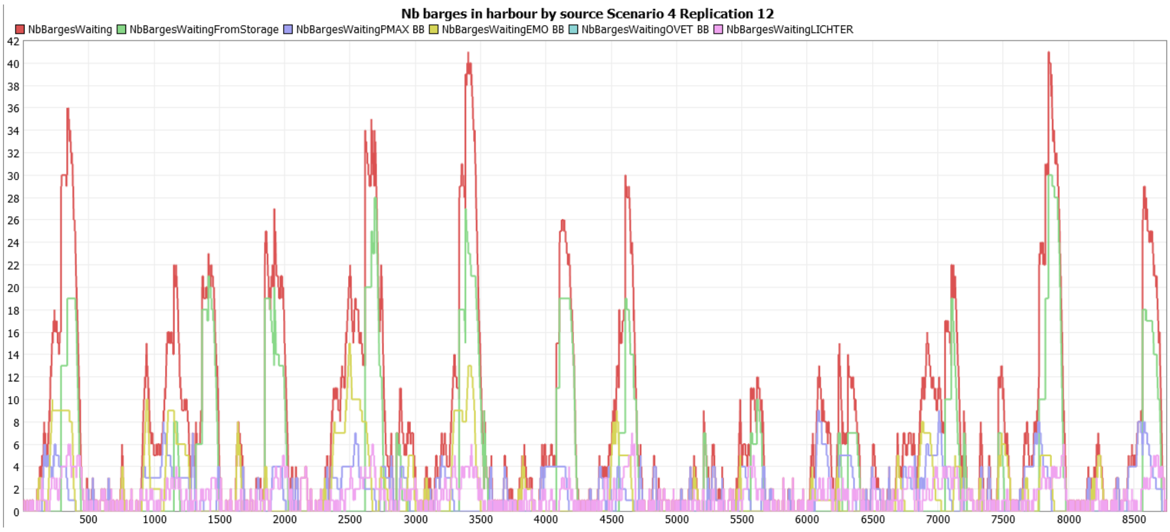

Figure 45: Number of barges within the model over the year (scenario 4)

9.1.1 General results quay modelling

The previous figures were examples of the arrivals of 2 runs from 2 different scenarios. For both crane positioning options 15 runs have been done for each of the 6 scenarios. Figure 46, figure 47 and figure 48 show the main results for each scenario and run when the A10 crane is placed on the Ghent side of the quay. The summarized results can be found in the table 17 below.

	S1	S2	S3	S4	S5	S6
Total stay time sea vessels [h]	**13920**	**14630**	**14630**	**13910**	**15100**	**14370**
95% interval (+/-)	109	107	147	117	153	108
Total stay time barges [h]	**46200**	**39910**	**43980**	**66780**	**33430**	**59290**
95% interval (+/-)	849	900	1696	1399	738	1467
Total tons on pre stock [t]	**1638000**	**1656000**	**1698000**	**1622000**	**1771000**	**1724000**
95% interval (+/-)	52500	63600	66100	87000	51800	47600

Table 17: Summarized results of the 15 runs for each scenario with 95% interval

For the total stay time of the sea vessels there is a significant difference between each of the runs per scenario. This difference is caused by the semi random generated machine breakdown and maintenance. However, none of these runs are considered to be outliers and each are considered to be in the reasonable margins. It does show why the choice has been made to have multiple runs of the scenario to create a reliable average for each scenario. When comparing the scenarios, a clear relation can be seen between the percentage of material that arrives per vessel and the resulting total stay time of the ships. Scenario 1 has a relative low amount of total stay time since there is no sharing of Capesize vessels resulting in a larger percentage of barging. The other 5 scenarios do include sharing and with scenario 5 portraying double the amount of Capesize sharing.

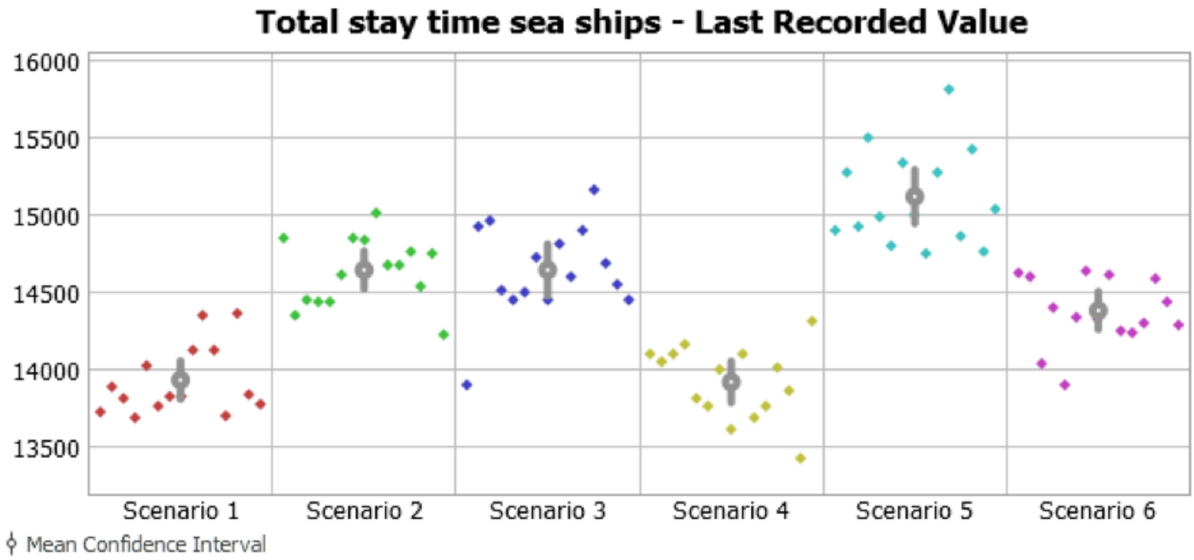

Figure 46: Total stay time sea ships for each scenario and 95% confidence interval

The total stay time of the barges in figure 47 show an inversely proportional relationship to the figure 46. This can be explained by the fact that the increase of the percentage of barging will automatically result in a decrease of the percentage of material that reach the quay by sea ships. However, where there was only a small difference between the highest and lowest average of the scenarios for sea vessels (7.9%), this difference is much larger for the waiting time of the barges (49.9%). The relative variety between different runs appears to be smaller than for sea vessels but this is only due to the scaling of the y-axis.

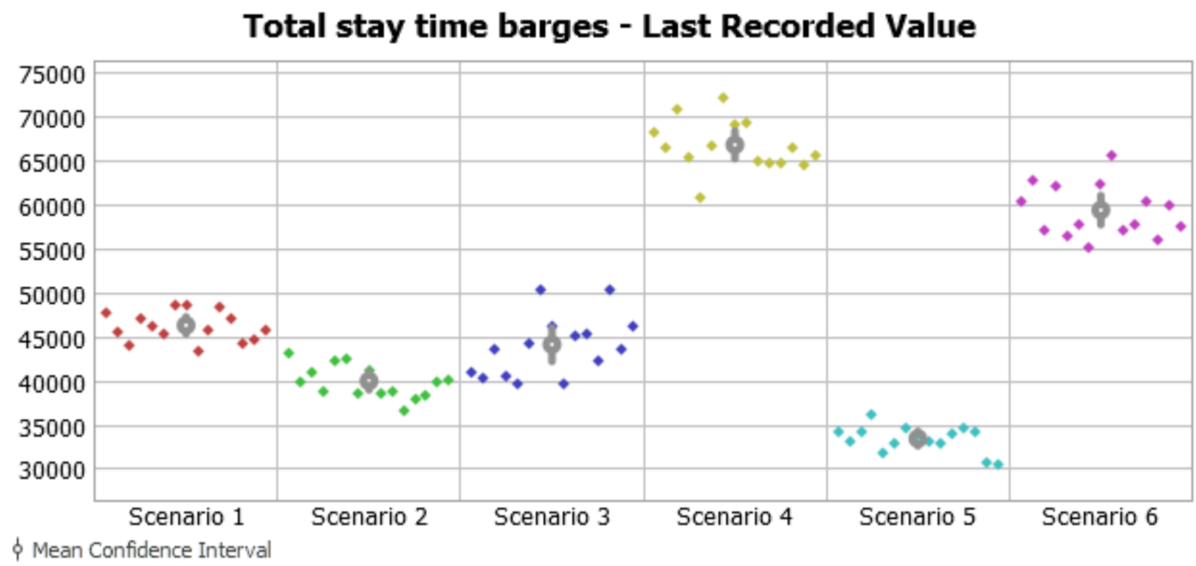

Figure 47: Total stay time barges for each scenario and 95% confidence interval

The last main parameter, which is the total weight of the pre-stock, is less depending on the different vessel and barge arrivals and more on machine breakdown. Therefore, it is harder to find a relationship between the scenarios. The different runs can variate up to 700,000 tons per year on the pre-stock for different scenarios which will have an enormous impact on the functioning of the quay and the costs. The results of the pre-stock appear to be a lesser indication to compare the different scenarios with one another.

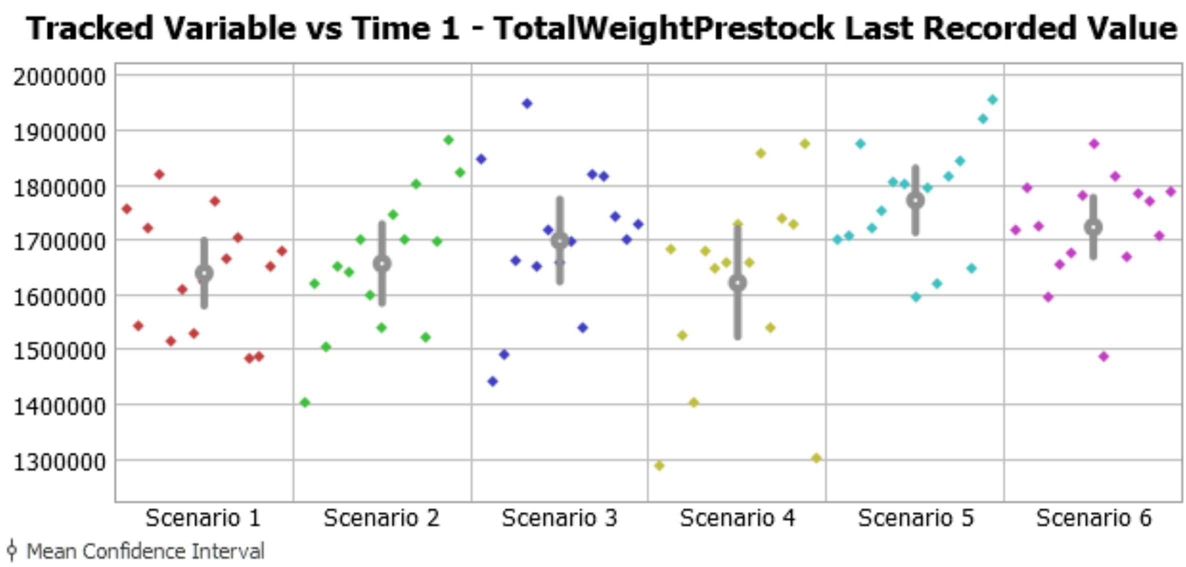

Figure 48: Total material on pre-stock for each scenario and 95% confidence interval

9.1.2 Crane scenario results

The previous three figures were only for the crane scenario that the A10 is located on Ghent side of the quay. The results of the other option, with the crane locate on the Zelzate side, are provided in Appendix E. Table 18 shows the average results per scenario for both options together with the absolute difference between them.

A10 GNT	S1	S2	S3	S4	S5	S6
Total stay time sea ships [h]	13918	14627	14634	13913	15104	14368
Total stay time barges [h]	46200	39910	43980	66780	33430	59290
Pre-stock [ton]	1637800	1656100	1697700	1621900	1771000	1723500

A10 ZZ	S1	S2	S3	S4	S5	S6
Total stay time sea ships [h]	13992	14525	14660	13987	15026	14260
Total stay time barges [h]	40600	34200	38680	56670	29590	51560
Pre-stock [ton]	1513700	1643800	1607700	1556100	1628400	1559100

GENT-ZZ	S1	S2	S3	S4	S5	S6
Total stay time sea ships [h]	-74	102	-26	-74	78	108
Total stay time barges [h]	5600	5710	5300	10110	3840	7730
Pre-stock [ton]	124100	12300	90000	65800	142600	164400

Table 18: Main output parameters for A10GNT and A10ZZ with the difference between the two

The difference between the total stay time of the sea ships can be considered negligible since it is smaller than the 95% interval of each scenario. The barges on the other side, have a significant larger stay time when the crane is located on the Ghent side of the quay. Especially for increased barging scenarios (4 and 6) this difference becomes more visible. Also, the total amount of material on the pre-stock sharply increases when the A10 is located on the Ghent side. These differences are hard to explain by just looking at the scenarios, the location of the cranes and the main parameters. Especially since the A10GNT set-up will have access to a third conveyor, the difference can be considered as unexpected. Therefore, a closer look is required to the occupation of the downstream machinery. The main difference can be found in the use of the quay cranes and the quay conveyors.

Figure 49 shows the occupation time of the quay cranes (Kranen in Dutch) which can be divided in conveying, maintenance, breakdown, blocked and idle time. The positioning of the A10 on the Ghent side will result in a high occupation of the new crane. This can be explained by the fact that it will unload vessels as well as barges of various types since it will have access to 3 quay conveyors. The A9 crane will be underused since it can only unload sea vessels and is located on the far side of the quay. The A8 will mainly unload sea vessels but has a higher occupation than the A9 since it will be able to make a crane combination with as well the A10 as the A9. The B1 crane will be in lower use since it can only unload barges and smaller sea vessels which can often be directly loaded on quay conveyor F22 which cannot be used by the other quay cranes, except for the A10 when located on Ghent side of the quay.

When the A10 is placed on the ZZ side of the quay it will be use in a lesser extent than in the GNT scenario. Also, the A8 will be used less since it will no longer be in between the other 2 larger quay cranes. The A9 on the other hand will be used more because it is placed in the middle crane position, resulting in a better distribution between the different cranes. This set up gives better opportunities to the two other cranes to unload large number of barges with the same material in a shorter time span.

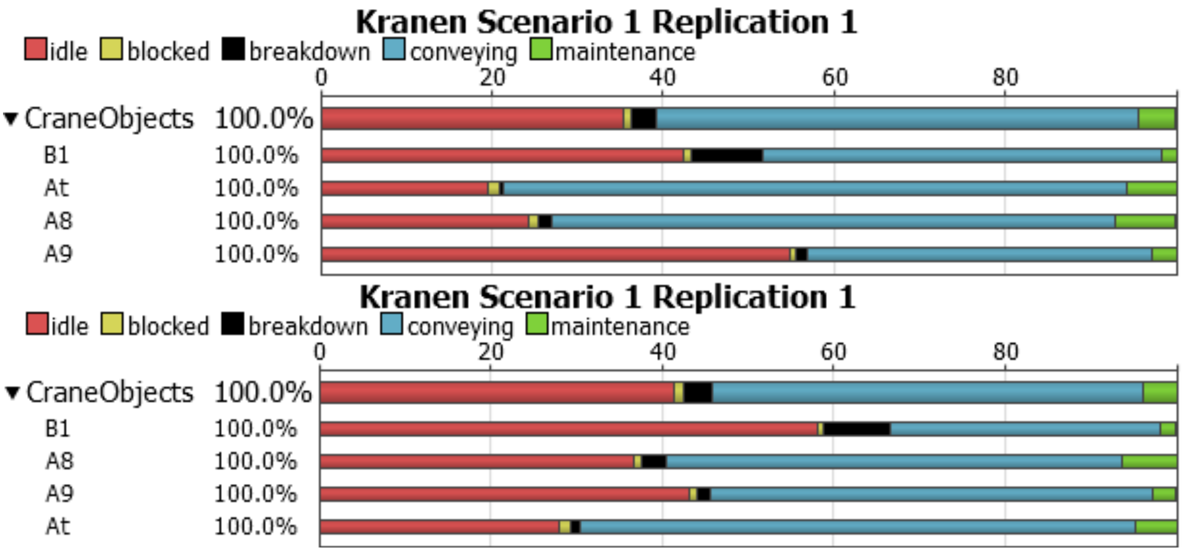

Figure 49: Occupation of quay cranes (Kranen in Dutch) for A10GNT and A10ZZ

Looking at the quay conveyor (Kaaibanden in Dutch) use in figure 50, it can be concluded that the F22 will not be used more when it is connected to the A10 crane. In fact, the average conveying time will decrease from 24.22 (+/-0.17) to 22.38 (+/- 0.16) per cent. This shows that the B1 will unload less material on the third conveyor when the A10 is positioned on the Ghent side and the A10 itself will rarely make use of the F22 conveyor. For both scenarios the main conveyor belts will transport most of the material and are used most often. In general, it can be stated that the effect of the crane positioning on the quay conveyor occupation is from lesser extent than the effect on the crane occupation.

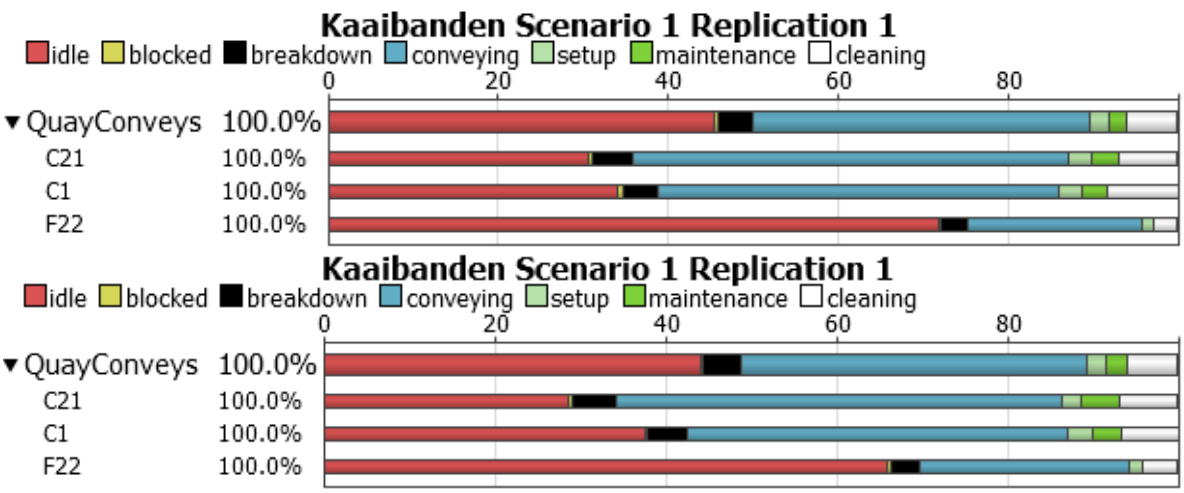

Figure 50: Occupation of quay conveyors (Kaaibanden in Dutch) for A10GNT and A10ZZ

9.2 Cost results

The end goal of the thesis is to give an indication if the use of Capesize vessels can be feasible for ArcelorMittal Ghent. Therefore, the cost reduction of the use of Capesize vessels and the cost increase of their quay impact should be compared. The total costs for source material with Capesize potential is shown in table 19. The table shows the costs per ton for the material that arrives per ship and per barge for each of the options. Since some options use as well vessel as barges, a weighted average should be taken for the total price per ton. Finally, the sharing of Capesize vessels for coal and with AMA will lead to a price increase for other AM sites that are sharing the load. Table 19 show that the price per ton for AMA will increase by 1.28 euro when sharing with Ghent while the price for coal will increase with 0.59 euro for other AM sites when the vessel adds AM Ghent as an extra stop. An extensive version with a detailed overview of all the different types of costs per option can be found in appendices F-J.

Table 19: REDACTED AND REMOVED Summary price per ton for each type of shipping method

The main result is that for the chosen parameters, the use of Capesize vessels will lead to a decrease of transport costs per ton of material. The increase in barging percentage for iron ore is compensated by the reduced price of the shipping and barging. This benefit is substantial for the taken parameters but might variate heavily for the used shipping price. This shipping price depends mainly on the agreed price of the time-charter and the bunker prices. For the main calculation a shipping rate difference of 4.79 dollars was used between Panamax and Capesize vessels from Brazil 1 and 4.26 dollars for PDM. **The break-even price difference for the use of Panamax and Capesize vessels via the EMO is calculated on 2.53 dollar for both ports assuming other parameters stay the same.**

One of these other parameters will be the amount of material that can be directly unloaded BB from Capesize vessels at the EMO. The break-even prices were reconsidered with varying degrees of BB unloading. With 0% BB loading and 70 days average storage, Capesize vessels turn out to be only feasible for a break even difference of 3,03 dollar, while with 100% BB loading, the break-even difference will be at a shipping cost of 2.03. The amount of storage days is of lesser effect with a break-even price varying between 2.38 dollar and 2.76 dollar for 0-140 storage days.

Comparing the costs of the two external stocks, it can be concluded that the use of the EMO will lead to lower costs per ton of material. The costs per ton of the material that stays on the Capesize vessel and is redirected to AMG is 0.78-0.88 euro less expensive than at the OVET. Furthermore, the costs per ton of material that arrives per barge is 0.12-0.22 euro cheaper. However, the higher percentage of material per vessel (68% to 60%) will partly compensate the benefit of the EMO compared to the OVET

The main difference in costs between the OVET and the EMO is the freight costs divided by the fill factor of the ship. With lower shipping costs, the use of the OVET for ores becomes more feasible with a break-even point at 6.45 dollars for Capesize vessels from Brazil 1 and

6.30 for PDM. The percentage of BB unloading and amount of days that the material is stored have very limited effect on the cost difference between the two external stocks.

The results show that the sharing of capes can lead to large cost reductions. When vessels with Brazilian iron ore are shared between AMA and AMG (40/60 distribution), the cost reduction for AMG is estimated on 1.65 euros per ton compared to full Capesize vessels to AMG. On the other hand, it will lead to an estimated cost increase of 1.28 for AMA. For a total cost of operation for both site the result will be positive with 0.48 euro per ton on average.

The largest gain for AMG cost-wise, will be the sharing of Australian coal by Capesize vessels. Currently the material is already shared with other sites and shipped in barges from the EMO to AMG. Adding AMG as an extra stop can reduce the costs for AMG by 5.39 euro per ton of material. On the other site the total transport costs per ton of material will be increased by 0.79 euro for the other sites. For a total cost of operation for all sites combined it will result in an average cost decrease of 0.74 euro per ton on the vessel.

The total transportation costs for material with Capesize potential can be calculated by multiplying the costs per ton from table 19 with the volume per scenario. The results are shown in table 20.

Total ton	S1	S2	S3	S4	S5	S6
Panamax IO	€ 37,012,000	€ 31,803,000	€ 27,245,000	€ -	€ 31,803,000	€ -
Capes IO	€ -	€ -	€ 3,901,000	€ 27,845,000	€ -	€ 28,284,000
Sharing IO	€ -	€ 3,800,000	€ 3,800,000	€ 3,800,000	€ 3,800,000	€ 3,800,000
Total IO	**€ 37,012,000**	**€ 35,602,000**	**€ 34,945,000**	**€ 31,645,000**	**€ 35,602,000**	**€ 32,083,000**
Coal barges	€ 14,566,000	€ 10,924,000	€ 10,924,000	€ 10,924,000	€ 7,283,000	€ 10,924,000
Coal capes	€ -	€ 2,429,000	€ 2,429,000	€ 2,429,000	€ 4,857,000	€ 2,429,000
Total coal	**€ 14,566,000**	**€ 13,353,000**	**€ 13,353,000**	**€ 13,353,000**	**€ 12,140,000**	**€ 13,353,000**
Total costs	**€ 51,577,000**	**€ 48,954,000**	**€ 48,297,000**	**€ 44,997,000**	**€ 47,741,000**	**€ 45,435,000**
Compared to S1	**€ -**	**-€ 2,623,000**	**-€ 3,280,000**	**-€ 6,581,000**	**-€ 3,836,000**	**-€ 6,142,000**

Table 20: Total shipping price for the shipped material with Capesize potential per scenario and compared to S1

The transportation costs are however, not the only costs that are impacted by the implementation of Capesize vessels. The impact on the quay, which is portrayed earlier in this chapter, will have cost effects as well. Therefore, the main output results of the scenarios have to be included in the total costs.

Table 21 show the total costs after the addition of the quay costs. It can be noted that the implementation of Capesize vessels will lead to an overall decrease in transportation costs while leading to an increase in quay costs. Especially the demurrage, accumulated by the increase of waiting time of vessels, contributes to this increase.

Summary Quay Impact Costs	S1		S2		S3		S4		S5		S6	
Costs waiting time vessels	€	3,287,000	€	3,568,000	€	3,600,000	€	3,363,000	€	3,756,000	€	3,512,000
95% interval (+/-)	€	70,100	€	88,500	€	109,800	€	98,900	€	108,500	€	113,700
Costs waiting time barges	€	1,133,000	€	964,000	€	1,070,000	€	1,651,000	€	795,000	€	1,457,000
95% interval (+/-)	€	20,800	€	21,700	€	41,200	€	34,600	€	17,500	€	36,000
Costs unloading on prestock	€	950,000	€	961,000	€	985,000	€	941,000	€	1,027,000	€	1,000,000
95% interval (+/-)	€	30,400	€	36,900	€	38,400	€	50,400	€	30,100	€	27,600
Total	**€**	**5,370,000**	**€**	**5,493,000**	**€**	**5,655,000**	**€**	**5,954,000**	**€**	**5,578,000**	**€**	**5,969,000**
95% interval (+/-)	€	79,200	€	98,300	€	123,400	€	116,300	€	114,000	€	122,500
Compared to S1	**€**	**-**	**€**	**123,000**	**€**	**285,000**	**€**	**584,000**	**€**	**209,000**	**€**	**599,000**

Table 21: Summary quay costs per scenario compared to scenario 1

The total price impact of each scenario can be compared by taking scenario 1, which is the situation without Capesize vessels, as reference scenario. All other scenarios will be more feasible than scenario 1. This is mainly because of the large cost reduction that is a direct result of Capesize sharing. Scenario 2 contains only Capesize sharing while the other scenarios will also have large scale implementation of Capesize vessels without sharing. Therefore, these scenarios can be better compared with scenario 2 as reference. Table 22 shows the results with scenario 1 and scenario 2 as reference. Compared to scenario 2, each of the four scenarios that are using Capesize vessels on a larger scale will lead to a total cost decrease.

	S1	S2	S3	S4	S5	S6
Δ Scenario 1	€ -	-€ 2,499,000	-€ 2,975,000	-€ 6,045,000	-€ 3,651,000	-€ 5,657,000
Δ Scenario 2	€ 2,499,000	€ -	-€ 475,000	-€ 3,546,000	-€ 1,152,000	-€ 3,158,000

Table 22: Net difference of each scenario with scenario 1 and scenario 2

Finally, the cost impact of the crane location is calculated by comparing the quay costs of both setups for all scenarios. Table 23 shows the difference in costs between the setups. The larger waiting time for barges and the increased amount of material on the pre-stock causes the A10GNT set up to be 162,000-296,000 euros per year more expensive than the A10ZZ set up, depending per scenario.

A10GNT - A10ZZ	S1		S2		S3		S4		S5		S6	
WT Vessels	-€	27,450	€	36,990	-€	18,890	-€	56,790	€	32,730	€	11,250
WT Barges	€	137,480	€	137,650	€	128,670	€	249,540	€	90,970	€	189,500
Pre stock	€	71,990	€	7,090	€	52,230	€	38,150	€	82,680	€	95,350
Total	**€**	**182,000**	**€**	**181,700**	**€**	**162,000**	**€**	**230,900**	**€**	**206,400**	**€**	**296,100**

Table 23: Net difference in quay costs between the different positions of the A10 crane

10. Discussion

In the final chapter of this thesis the main research question: '*What can be the impact of Capesize vessels on ArcelorMittal Ghent in 2026*' will be answered. This will be done by answering all of the sub questions that were formulated in Chapter 1.2. Furthermore, recommendations will be given and the limitations to this research will be discussed.

10.1 Answering sub questions

The information given in Chapter 3 till Chapter 8 and the results of Chapter 9 will be used to answer the six sub questions of this thesis.

1. *What will be the influence of a production increase on the quay for 2026?*

The proposed production increase until 5.5 Mt steel per year in 2026 will have an impact on the production, downstream material logistics and the quay of AMG. The amount of incoming material will increase with 12% and the frequency of the arrivals will increase likewise with this extra production if the vessel size stays the same. The current quay capacity already leads to increased waiting times of vessel and barges without a production increase. Last year (2019) a confluence of circumstances caused the quay capacity to be near the limit of its capacity. Improvements to the quay and downstream installations should be made to increase the maximum capacity and accommodate for the increase in material inflow. Some improvements such as the installation of the A9 crane have already been taken to increase the capacity of the downstream installation and in the next 6 years multiple improvements are scheduled to cope with the higher number of arrivals.

2. *To what extent can Capesize vessels be used for transporting material to AM Ghent?*

Only a certain amount of the forecasted material mix, can be shipped from the source port by a Capesize vessel. Furthermore, for a combination of shipping and sourcing reasons, not all ports that are able to load Capesize vessels will do so for vessels destined to AMG. It can be concluded that only Australian coal and Brazilian iron ore can be transported by Capesize vessels to AMG with the possibility of being feasible. Australian coal is already shipped to Europe in Capesize vessels and is distributed between different sites of ArcelorMittal. The new lock of Terneuzen will make it possible for the material to arrive at the quay of AMG by Capesize vessel instead of by barges. Brazilian iron ore can also be shipped by Capesize ships although there is limited room for combination with other sites. This means that AMG have to accommodate for a full vessel including unloading to meet the draught restriction, external storage of material and barging to AMG. All combined it is estimated that a maximum of 3.95 Mt (30% of the total material inflow) can be shipped by Capesize vessels or barges resulting from Capesize vessels. Of this maximum inflow only 2.2 Mt (56%) can arrive per vessel and might result in large cost reductions.

3. *How will the arrivals of Capesize vessels influence the downstream supply chain?*

The influence of Capesize vessels on the downstream supply chain will depend on to what scale they are utilized. Full vessels destined for Ghent will have more influence than shared vessels with only 2 holds destined for AMG. Capesize ships that are used to transport Australian coal to the quay of AMG will result in a decrease of 25 per cent in barge utilization for Australian coal. Capesize vessels used for Brazilian iron ore on the other hand will result in an increase of up to 93 per cent in barge utilization compared to transport by Panamax vessels. The distribution between the arrivals of sea vessels and barges plays a large role in the crane utilization and the downstream supply chain.

The implementation of Capesize vessels are expected to bring a significant increase in the waiting time of barges and a slight increase in the waiting time for sea vessels depending on which Capesize scenario is used. An average increase in the total amount of pre-stock material is predicted as well although this cannot be guaranteed with a high certainty. These influences on the downstream effect will lead to additional quay costs that are partly eliminating the costs benefits in transportation price when using Capesize vessels.

4. *Which price differences between Panamax and Capesize vessels are necessary to make the use of Capesize vessels feasible?*

If the current Panamax vessels for Brazilian iron ore are replaced by Capesize vessels a significant decrease of total transportation costs is expected. The break-even difference when Capesize vessel will be more feasible than Panamax vessels is computed for at least 2.53 dollars per ton. Under current circumstances these shipping costs, which mainly consist of time-charter costs and bunker costs, are estimated at 4.26-4.79 dollars per ton. The largest reduction in shipping costs will be for the ports that have the longest travel time, which at the moment will be the port of Brazil 1, Brazil. Besides the shipping costs that are mainly depending on bunker costs fluctuations, other circumstances can also deviate. The main deviations besides this will be the demurrage rate of the vessels, percentage of material unloaded BB and unloaded on storage, the average amount of storage days for the material and the costs for external port and stock use.

5. *What will the influence be of the positioning of a new crane?*

The addition of the new A10 crane is from great importance for the quay of AMG to increase the quay capacity and to be able to unload Capesize vessels. Two possible options were evaluated where in A10ZZ situation the crane is located on the most northern side of the quay while in the A10GNT situation it is located on the south side next to the B1 crane. In terms of the unloading of sea vessels there is no significant difference between both options. However, the A10ZZ situation is expected to have a positive effect on the unloading of barges and the amount of material that ends up at the pre-stock. It is likely that this positive effect is caused by a better distribution of work load between the 3 large quay cranes. This will lead to a decrease in quay costs ranging from 162.000-296.000 euros per year depending on which Capesize scenario is used. Furthermore, it would eliminate the investment of extending the F22 quay conveyor to the A10 crane.

6. *Which external stock will bring the most benefits for Capesize unloading?*

Both the external stock of the OVET and the EMO were analyzed and compared cost-wise leading till the conclusion the EMO will be the more feasible option for Capesize unloading. The use of the OVET will lead to an increase of 11% in shipping costs due to the fact that there are draught restrictions at this external stock, meaning that the vessel cannot be fully loaded in the source port. This is partly compensated by a reduced amount of barging and lower material handling prices. The total cost increase compared to the EMO will depend on the absolute shipping costs. With the estimated parameters it is expected that the total transportation costs for iron ore from Brazil 1 will be 11.15 euro per ton when using the EMO and 11.39 euro when using the OVET. For material derived from Ponta de Madeira it will result in transportation costs of 10.41 and 10.56 euro per ton respectively. This is only a slight difference which can be undone when the shipping costs of Capesize vessels decrease until 6.30 dollars per ton. Again, these shipping costs are highly volatile depending om market circumstances and bunker costs.

10.2 Main conclusion

The main research question for this thesis was as follows:

'*What will be the impact of the use of Capesize vessels on ArcelorMittal Ghent in 2026?'*

This question cannot be answered shortly due to the large extent of the subject and the difference scenarios in which Capesize vessels can be used for the transport of raw material to ArcelorMittal Ghent. The general answer would be that Capesize vessels can have a large impact on the quay of ArcelorMittal, supply chain wise as well as cost-wise. Capesize vessel can lead to an enormous decrease in shipping price, but the draught limitation of the Ghent-Terneuzen reduces this cost decrease significantly. Although the general cost impact is positive, it does not mean that Capesize vessels should be utilized to the maximum level. The feasibility of Capesize vessels is so heavily reliant on the bunker rates and the charter rates of Panamax and Capesize vessels, that the decision cannot be made at this moment for 2026. Instead an evaluation can be made at the medium-long term (several months to a year) when the market circumstances are more predictable. The benefits in transportation costs can also be overshadowed by the increased quay occupation and the corresponding quay costs.

Therefore, there should be made a substantial difference between Capesize arrivals caused by the sharing of vessels with other sites and Capesize arrivals that are replacing the current Panamax arrivals of raw materials. The sharing of Capesize vessels will always result in large cost reductions in shipping price. This total benefit is estimated on 2-2.2 million euro per year, depending on the crane configuration. Capesize sharing affects the quay of ArcelorMittal Ghent only slightly, since the load sizes for coal will not change significantly and the sharing of iron ore would be minimized to a few vessels per year. The cost reduction in transportation price for AMG will have the result that overall costs per ton will increase and therefore other sites will suffer from a price increase. This however, is something that should be decided by AM Sourcing who will look at the benefits for the total price of operation. It is in AMG its best interest to negotiate and maximize the sharing of materials.

To utilize the Capesize potential, the Panamax vessels with Brazilian iron ore can be replaced by Capesize vessels that should be unloaded till 105,000 DWT at the external stock of the EMO or the OVET. With the estimated parameters, the total benefit of transportation of Capesize vessel by the EMO is expected to be 2.03 euro per ton for Brazil 1 and 1.59 for material from Brazil 2, compared to the use of Panamax vessels. Transport by the OVET will result in a cost reduction of respectively 1.78 and 1.43 euro per ton. This cost reduction is however, partly reduced by the extra quay costs that come with the use of Capesize vessels. The main conclusion that can be drawn for the use of Capesize vessel for Brazilian ore is that the difference in shipping costs (including bunker usage and charter rate of the vessel) should at least be 2.53 dollars per ton to make it feasible.

Finally, it can be concluded that, with the arrival of the new A10 crane, the quay of AMG is properly prepared to unload Capesize vessel if the opportunity occurs. However, it is questionable if the quay of AMG will be ready for the production increase that is scheduled. The effect of this increase will put much more pressure on the quay than the amount of utilization of Capesize vessels. Altogether, 2026 is still six years away and the circumstances as well as the quay capacity itself will change and hopefully improve over time. By then the situation can be re-evaluated and the impact of Capesize vessels will be better definable for a shorter time span.

10.3 Recommendations

The conclusions stated that the potential of Capesize vessels can only be partly utilized by ArcelorMittal Ghent. The feasibility of Capesize vessels for AMG is based upon certain parameters that can change over time. Therefore, the situation should be closely monitored and decisions should be based on current data and prices. The following recommendations are formulated to make the best use of the increased dimensions of the lock of Terneuzen in 2026:

1. Improved collaboration between departments within ArcelorMittal Ghent.

AMG is split up between different departments that all have their own focus area. Shipping related issues however, are scattered throughout different departments. The PSRM department negotiate with AM Sourcing about the incoming materials, BTR is responsible for the external stock, barging and most third-party communication and finally GHV manage the quay and the downstream installations. It is however, GHV responsibility to reduce the waiting queue while the effects of the waiting queue are monitored by PSRM again. For large shipping related projects such as the implementation of Capesize vessels, it is essential that all departments are represented in a working group and share knowledge with one another. This does also strengthen the negotiating position with AM Sourcing and AM Shipping.

2. Increased communication with AM Sourcing and AM Shipping.

Since the site in Ghent became part of the global company Arcelor, the sourcing and shipping of raw materials became centralized by AM Sourcing and AM Shipping. Currently there is a minimal amount of knowledge of bulk transportation available within AMG, while these topics are heavily affecting the costs of AMG. Therefore, it is important increase the communication with AM Sourcing and AM Shipping. For the Capesize project this can be from large contribution with the everchanging spot rates of Panamax and Capesize vessels and variable demurrage rate. Furthermore, clear communication with AM Sourcing is essential in terms of Capesize sharing, which might heavily reduce the shipping costs for AMG.

3. Minimize the additional costs for the use of external stocks.

Besides the spot rates, other parameters are influencing the cost of external stock for the use of Capesize vessels as well. These parameters depend on the quay capacity of AMG and can therefore be minimized. With increased knowledge of the arrivals, the scheduling of barges can be improved. This can improve the amount of BB loading and decrease the amount of storage days and therefore reduce the costs. These reduce costs for external unloading will increase the feasibility of the use of Capesize vessels.

4. Be actively involved in decision making concerning the draught limitations of the Ghent-Terneuzen canal.

The potential of Capesize vessels is undermined by the draught restrictions of the Ghent-Terneuzen canal. Therefore, it is from great importance to stay involved in draught improvements. It is unlikely that the canal will be deepened till AMG, but there are plans for deepening the canal behind the locks. This will give improved access to the OVET Terneuzen which can increase the feasibility of Panamax vessels and create new scenarios. Furthermore, the draught restrictions of the OVET Flushing should be monitored as well since an increase in draught will heavily reduce the costs for the OVET as external stock for Capesize arrivals.

5. Improve the collecting of relevant quay data and KPI's to keep the quay and downstream modelling up to date.

The results of this thesis were generated based quay and cost data that were available. However, not all data was directly derivable and some estimations had to be made. Certain key performance indicators should be added that can be directly use in the quay and downstream modelling. The model itself should be updated and improved to maintain a certainty in the results. With the implementation of the A9 and the A10 the crane capacity input data should be re-evaluated and the model recalibrated. If the model is getting improved some of the limitations can be taken away as well. By making the cranes more flexible better optimizations can be found when they do not have to stay at the ship until it is finished. Furthermore, the option to unload a vessel with all 3 of the main cranes could be included as well. Currently this is limited by the capacity of the quay conveyor, but when unloading the material at two quay conveyors at the same time this can be solved as long as there are two different downstream tracks available.

6. Re run the calculations in 2023 and 2026

The new lock of Terneuzen is planned to be accessible from the middle of 2023. In the next three years many parameters for the Capesize calculations can be affected with the spot rates as largest deviator. With updated cost and quay information the models can be rerun and the conclusions can be re-evaluated. The current model is estimated for 2026, so in 2023 there should be a relative lower inflow of materials and the vessel lists can be estimated more accurately. In 2026 the proposed increase in production should be completed and by then the situation should be re-evaluated again.

10.4 Limitations to research

This thesis estimated the impact of Capesize vessels on the quay of ArcelorMittal Ghent and the corresponding cost impact. This estimation however, is based on certain assumptions that should be emphasized to show the limitations to this research.

First of all, the quay impact is limited to the extent of the model that is used. In Chapter 7 the limitations of the model were discussed. The parameters for the model were derived from historical data which cannot give a guarantee for the situation in 2026. Furthermore, the bypassing of the stockyard bottleneck gives results that are more positive than the situation will be in 2023. The deviation however, would be larger when implementing the current stockyard module that causes enormous increases in all of the main output results. This thesis looked at the relative impact on different scenarios which can be better compared to each other without the stockyard module. However, the absolute results cannot be guaranteed to give an accurate enough estimation of the situation in 2026.

The cost estimations have limitations as well. First of all, they are relying on certain bunker prices and chartering rates which are highly volatile and likely to change. Furthermore, other parameters are expected to change as well over time and can, for now, only be estimated on current data and predictions for the future. The demurrage costs are estimated for fixed handling time for average ships. In reality each vessel has their own allowed handling time and demurrage rate. Therefore, the cost model can be improved if more information is known for these ships, but for now the model can only be based on averages. The parameters for the costs of the external stocks are also based upon historical data. This historical data might not be accurate with increased volumes for the external stock or with scheduling improvements to minimize these costs.

This thesis is focussed on the cost reduction of ArcelorMittal Ghent, but also gave an indication on the effect that the use of Capesize vessels at AMG will have on other sites when ships are shared. The cost impact for other sites is only estimated by the use of certain general numbers provided by certain persons who have experience with Capesize sharing. In reality the cost impact for each site will be more complicated deviate from the estimations. It is up to AM Sourcing to have knowledge about the cost impact of each site and make decisions based upon the total costs of operation for all sites.

Finally, the scheduling of arrivals, the unloading of vessels and the transportation of material are not really an exact science that can be based on literature values and formulas. In reality they are affected by manual decisions and circumstances that cannot be predicted on beforehand. Therefore, most assumptions are based upon experience and rules of thumb provided by operators, schedulers and engineers from ArcelorMittal Ghent. This makes the results for a future scenario more uncertain, since they cannot be validated until the new machinery is installed and the Capesize vessels are actually be able to reach the quay of AMG.

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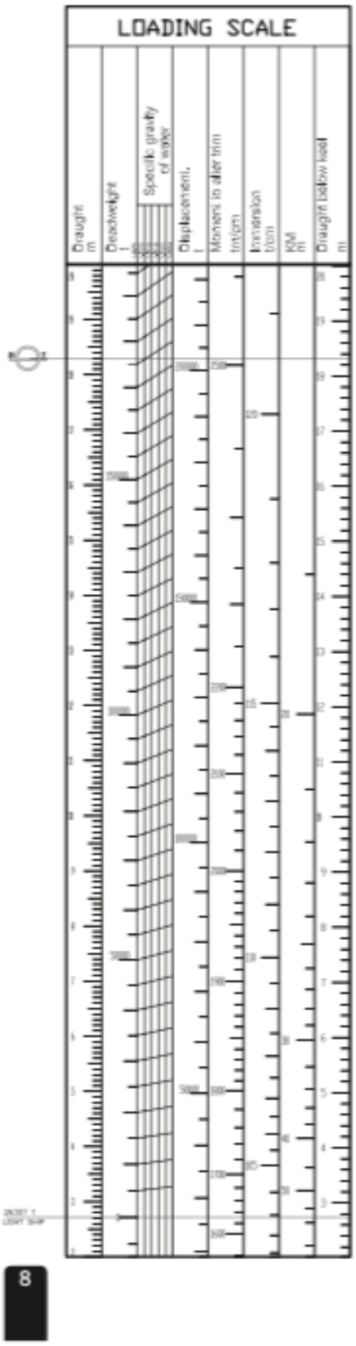
Appendix A - Capesize vessel arrivals AM at EMO (2018-2020)

Vessel name	Material	Max DWT	Draught	Length	Breadth	Year
BULK SPAIN	Ore	176000	18.3	292	45	2011
BERGE ROSA	Ore	180000	18.17	289	45	2006
LOWLANDS TENACITY	Ore	180000	18.22	292	45	2011
CAPE JACARANDA	Ore	181000	18.24	292	45	2011
LORDSHIP	Ore	179000	18.2	292	45	2010
SEA POSEIDENO	Ore	176000	18.3	292	45	2011
PELOPIDAS	Ore	176000	18.3	292	45	2011
KSL SAN FRANCISCO	Ore	181000	18.3	292	45	2014
NEW ELIAS	Ore	174000	18.1	289	45	2007
BERGE KOSCIUSZKO	Ore	181000	18.24	292	45	2014
SUN ORCHID	Coal	181000	18.22	292	45	2010
GOLDEN FINSBURY	Coal	182000	18.15	292	45	2015
CAPE VALENCIA	Coal	181000	18.24	292	45	2012
SEMIRIO	Coal	174000	18.12	289	45	2007
SAIKO	Coal	180000	18.2	289	45	2010
FRONTIER GARLAND	Coal	181000	18.24	292	45	2011
LOWLANDS ERICA	Coal	177000	17.96	289	45	2007
LAKE D	Coal	181000	18.24	292	45	2011
FRONTIER JACARANDA	Coal	183000	18.23	292	45	2011
VITTORIA	Coal	180000	18.2	292	45	2015
NAUTICAL DREAM	Coal	181000	18.24	292	45	2013
CAPE PEONY	Coal	181000	18.24	292	45	2012
BRAVERUS	Coal	171000	17.7	287	45	2009
FRONTIER CORONET	Coal	183000	18.23	292	45	2011
MINERAL KYOTO	Coal	180000	18.17	289	45	2004
NSU NEWSTAR	Coal	181000	18.24	292	45	2014
SIVOTA	Coal	177000	18.3	292	45	2008
GIANT ACE	Coal	179000	18.22	292	45	2009
PELOPIDAS	Coal	176000	18.3	292	45	2011
FRONTIER SKY	Coal	179000	18.22	292	45	2012
TRUE CARTIER	Coal	181000	18.21	292	45	2014
COHIBA	Coal	174000	18.1	289	45	2006
DIVINUS	Coal	170000	17.7	287	45	2010
MINERAL NOBLE	Coal	171000	17.72	289	45	2004
CAPE SPENCER	Coal	169000	17.82	290	45	2010
FERNANDINA	Coal	174000	18.1	289	45	2006
CAPE LAMBERT	Coal	169000	17.82	289	45	2010
AM TARANG	Coal	180000	18.3	292	45	2019
POUNDA	Coal	178000	18.3	292	45	2009
NAVIOS JOY	Coal	181000	18.24	292	45	2013
NEW DELIGHT	Coal	181000	18.24	292	45	2012
ROBUSTO	Coal	175000	18.1	289	45	2006
RAIATEA	Coal	179000	18.32	292	45	2011
FRONTIER QUEEN	Coal	183000	18.23	292	45	2012
OMAHA	Coal	178000	18.3	292	45	2008
CIC OSLO	Coal	180000	18.3	292	45	2014
NAVIOS STELLAR	Coal	169000	17.7	288	45	2009
MINERAL MAUREEN	Coal	205000	18.2	300	45	2012
NIGHTWING	Coal	170000	17.62	289	45	2006
FORTUNE VIOLET	Coal	181000	18.24	292	45	2012

Appendix B - Properties reference ship

"KATE"
"SAVINA"



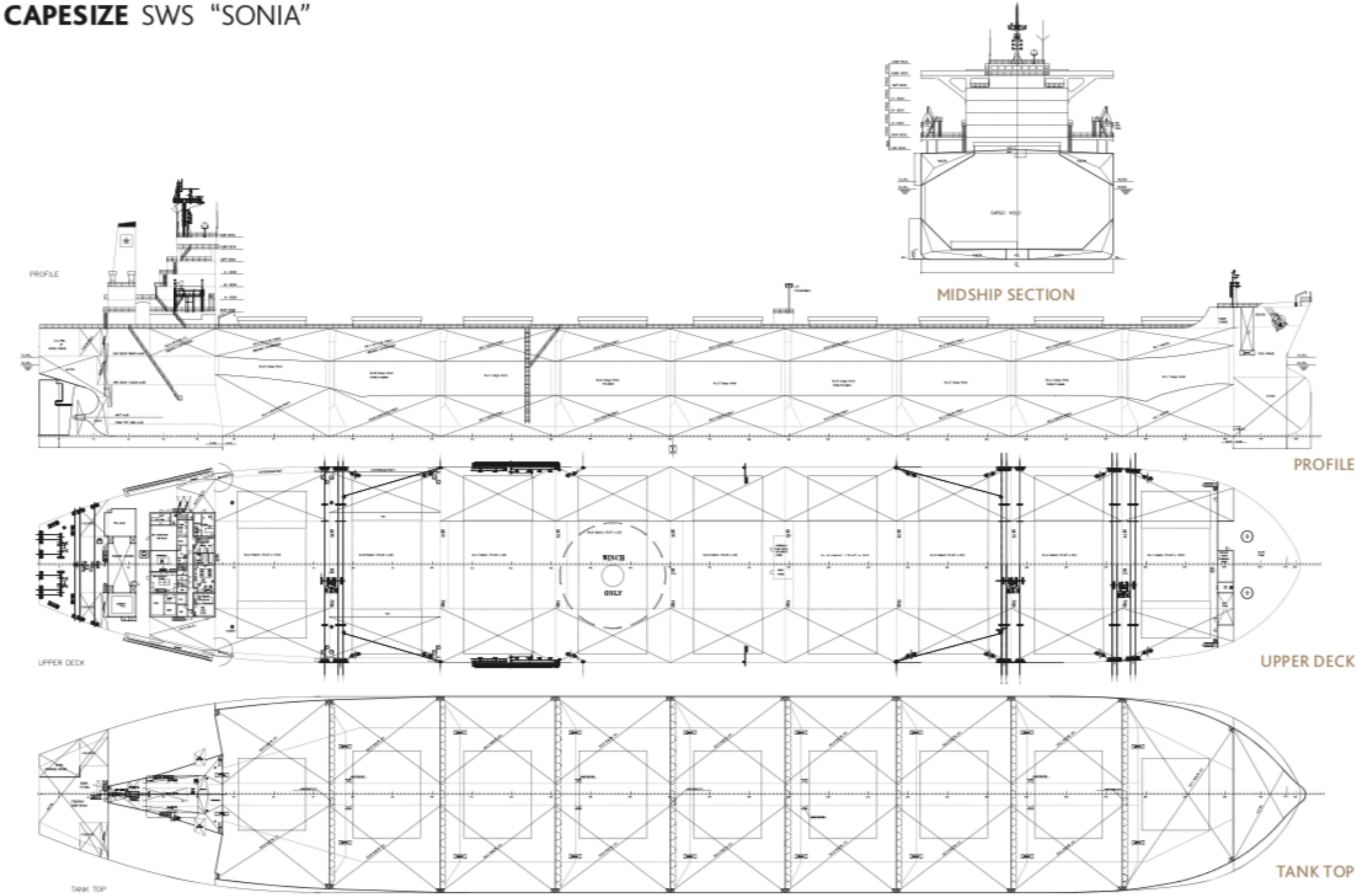
Ship's Name:	"KATE"	"SAVINA"
Builders:	SWS - Shanghai Waigaoqiao Shipbuilding Co., Ltd, Shanghai, P.R.C.	
Date of Build:	16 November 2011	2 December 2011
Owners:	Kate Transportation Corp., Majuro, Marshall Islands. Savina Transportation Corp., Majuro, Marshall Islands.	
Flag:	Marshall Islands	Marshall Islands
IMO Number:	9427304	9427316
Call Sign:	V7WI4	V7WH4
Classification:	Bureau Veritas	
Class Notations:	✠HULL, ✠MACH, Bulk Carrier, CSR, BC-A, Holds 2, 4, 6 and 8 may be empty, ESP, Unrestricted navigation, ✠VeriSTAR-HULL, ✠AUT-UMS, MON-SHAFT, INWATERSURVEY, GRAB(25).	

Length OA:	292.00 m	
Length BP:	282.00 m	
Breadth, moulded:	45.00 m	
Depth, moulded:	24.80 m	
Summer Draft, moulded:	18.30 m	
Freeboard, summer:	6.534 m	
Displacement, summer:	202,712 mt	
Deadweight, sum. draft:	176,405 mt	176,382 mt
Register, Gross / Net:	91,374 / 57,770	

No. of Cargo Holds:	Nine
Cargo Hold Lengths:	Holds 1, 2, 4, 8: 25.48 m Holds 3, 5, 6, 7: 26.39 m Hold 9: 26.17 m
Cargo Hold Hatch Sizes: (L x B)	Hatches 1, 9: 15.47 x 16.50 m Hatches 2-8: 15.47 x 20.00 m
Hold Capacities, grain (Ttl):	194,179 m³
Type of Hatch Covers:	Steel, side rolling, rack & pinion

Main Engine Diesel:	CMD MAN/B&W 6S70MC6
MCR:	22,920 bhp @ 91 rpm
Generators:	3 x Yanmar diesels x 900 kW
Fuel Grades:	Main & Auxiliary Engines: H.F.O. 380 cSt

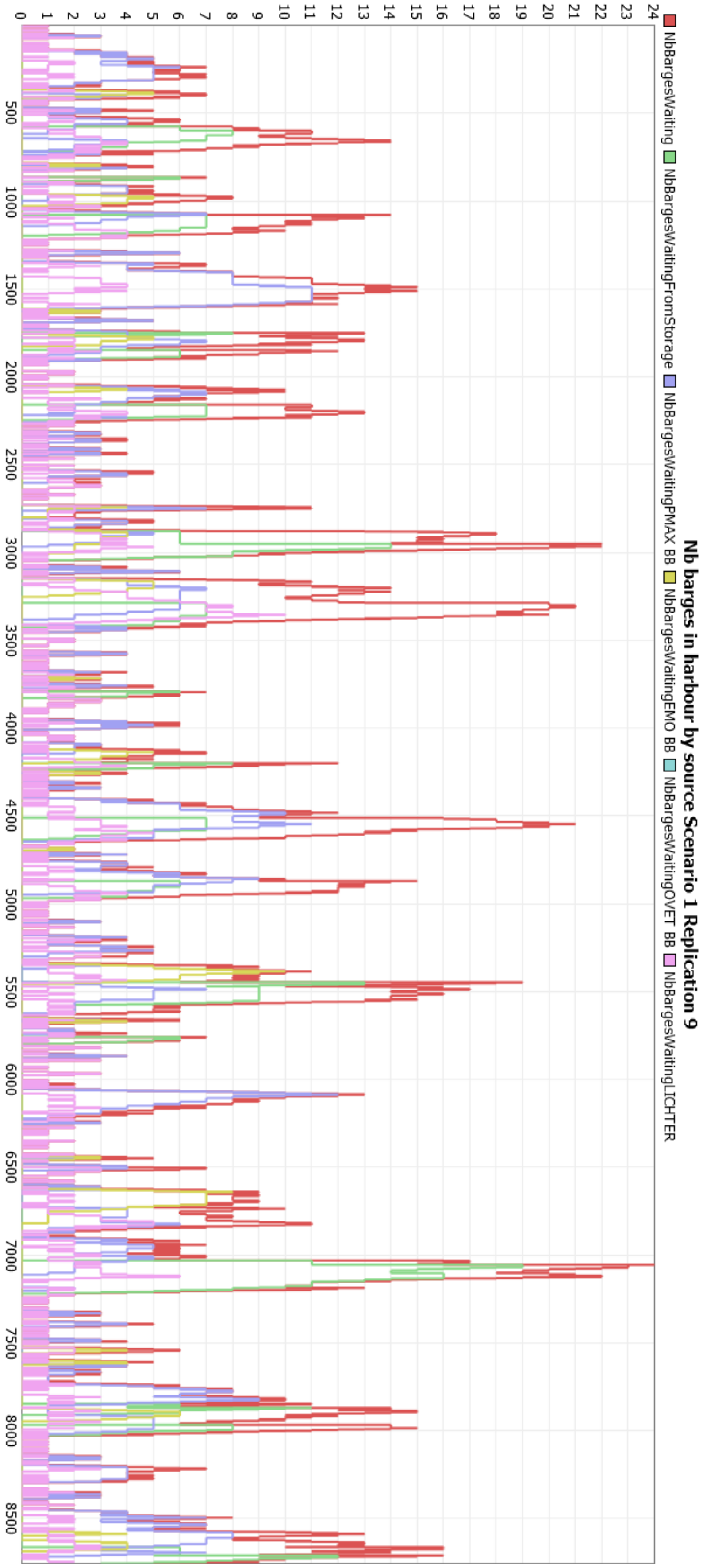
CAPESIZE SWS "SONIA"

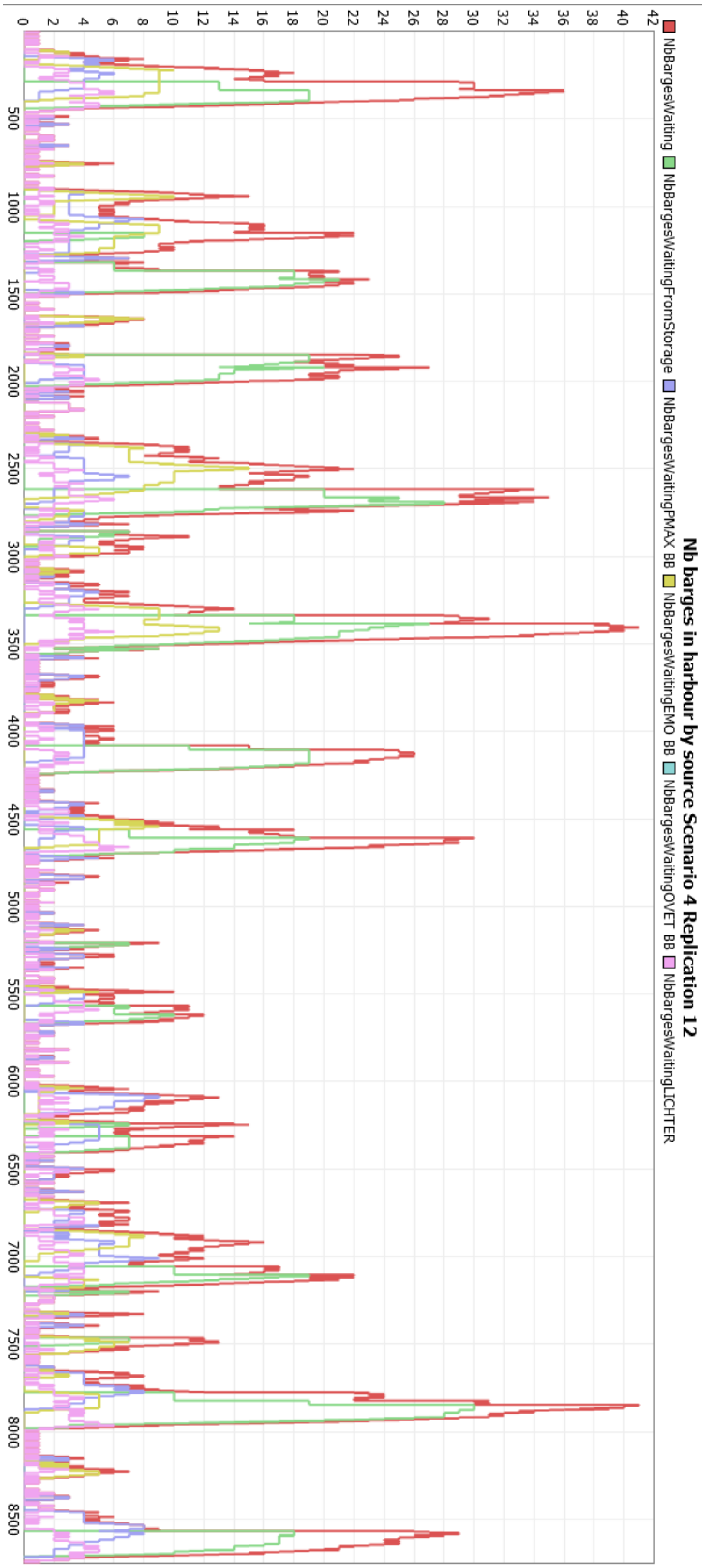


Appendix C – Shipping cost parameters

Source	Tubarao	Tubarao	PDM	PDM	
Vessel type	**Panamax**	**Capesize**	**Panamax**	**Capesize**	
Mileage	6135	6135	5446	5446	nautic mile
Tonnage	75000	175000	75000	175000	DWT
Day rate	12800	17200	12800	17200	dollar / day
Bunker rate VLSFO380	534	534	534	534	dollar / ton
Bunker rate MGO	550	550	550	550	dollar / ton
Speed	14	14	14	14	knots
At sea cons. VLSFO380	32.5	51	32.5	51	tons / day
In port cons. VLSFO380	2.5	3.5	2.5	3.5	tons / day
In port cons. MGO	1	1.5	1	1.5	tons / day
Exchange rate $ euro	1.2	1.2	1.2	1.2	dollar / euro
Sailing days	18.26	18.26	16.21	16.21	days
Loading days	2	3	2	3	days
Unloading days	3	5	3	5	days
Sailing retour	18.26	18.26	16.21	16.21	days
Total days	41.5	44.5	37.4	40.4	days
Day costs	$ 531,429	$ 765,707	$ 478,933	$ 695,167	dollars
Bunker costs sailing	$ 316,884	$ 497,264	$ 281,296	$ 441,418	dollars
Bunker costs port	$ 9,425	$ 21,552	$ 9,425	$ 21,552	dollars
Bunker costs sailing retou	$ 158,442	$ 248,632	$ 140,648	$ 220,709	
Total costs	$ 1,016,179	$ 1,533,155	$ 910,302	$ 1,378,845	dollars
Per ton	**$ 13.55**	**$ 8.76**	**$ 12.14**	**$ 7.88**	**dollars**
Per ton	€ 11.29	€ 7.30	€ 10.11	€ 6.57	euros

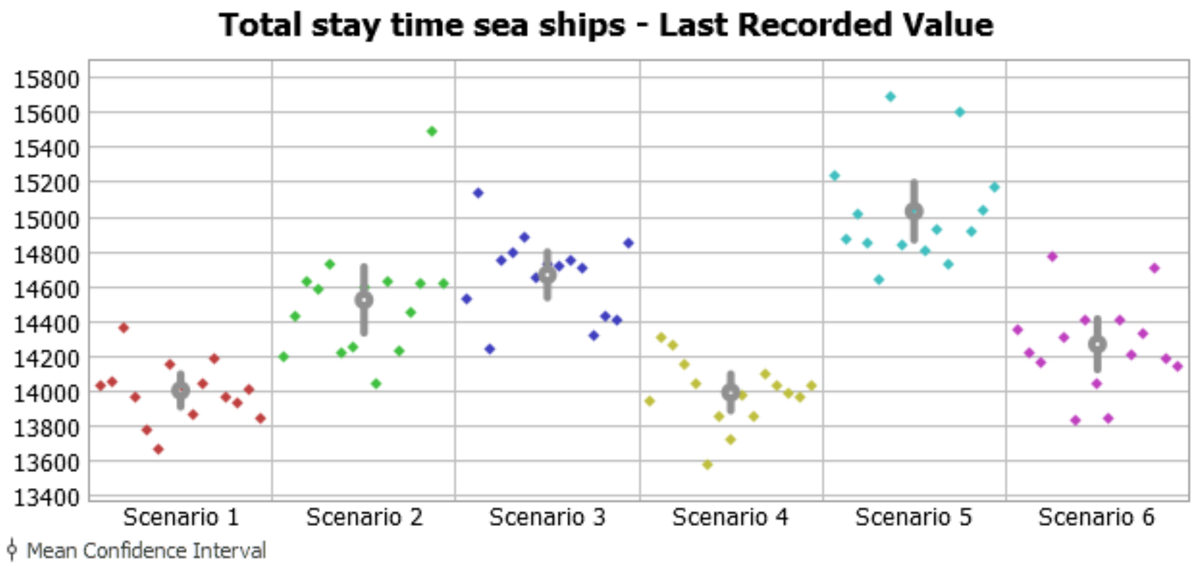
Appendix D – Enlarged figures 44 and 45 (barges within model)

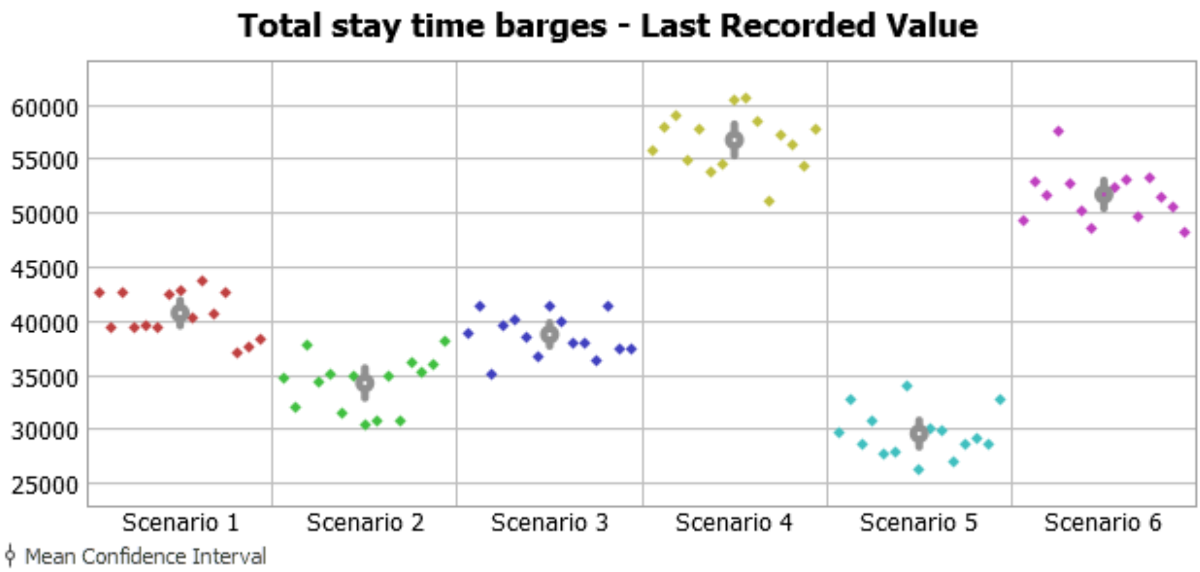


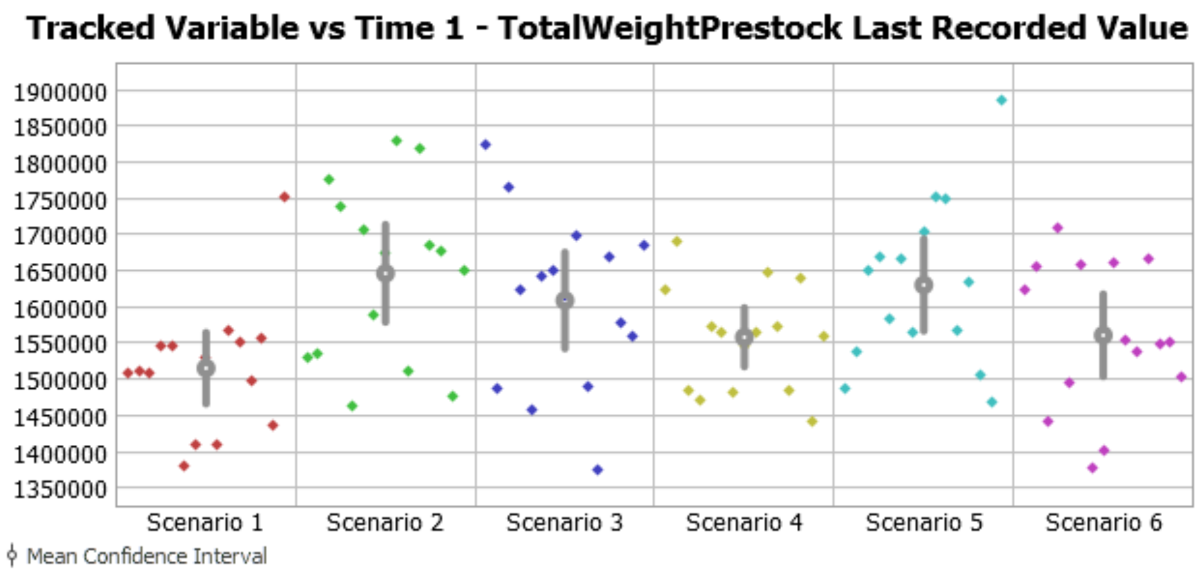


Nb barges in harbour by source Scenario 4 Replication 12
NbBargesWaiting
NbBargesWaitingFromStorage
NbBargesWaitingPMAX BB
NbBargesWaitingEMO BB
NbBargesWaitingOVET BB
NbBargesWaitingLICHTER

Appendix E – Main output parameters A10ZZ







Appendix F – REDACTED AND REMOVED Cost indication Panamax vessel

Appendix G – REDACTED AND REMOVED Cost indication Capesize vessel EMO

Appendix H – REDACTED AND REMOVED Cost indication Capesize vessel OVET

Appendix I – REDACTED AND REMOVED Cost indication iron ore sharing AMA

Appendix J – REDACTED AND REMOVED Cost indication coal sharing via EMO