

# DEEP-SEA MINING: A ROAD-MAP TO POSITIONING IN THE PRODUCTION CHAIN

THE INFLUENCE OF PRODUCTION CHAIN CONCEPTS ON THE POSITIONING AND  
BUSINESS PORTFOLIO OF THE COMPANY IN THE DEEP-SEA MINING INDUSTRY



## Author

C.M. RUTGERS VAN ROZENBURG  
#1324381



# Preface

This is the report of my master thesis. The master thesis will finalize my masters Transport, Infrastructure and Logistics (TIL) program at the Delft University of Technology. The thesis is on the topic of deep-sea mining (DSM) and commissioned by the Innovations Department at The Company Engineering Delft.

Considering my logistical perspective the DSM market is approached from a production chain (PC) approach. The different themes that are highlighted in this report (DSM technology, business strategy, actors) allow for a multidisciplinary approach. A multidisciplinary approach is typical for TIL related subjects and this research offers an ideal combination of TIL work within an offshore company. This approach is an addition to The Company's research into the technical aspects of DSM and offers insights into the interaction of equipment in the PC and strategic choices that reflect on The Company's research and development.

## Reading guide

Chapter 1 is an introduction to the research. The client, The Company, is introduced. The Company's history and current activities are briefly discussed and it is explained why The Company is interested in DSM. The importance of the research into this topic from both a scientific as well as a societal perspective is explained. It also introduces the industry of DSM and the copper industry and PC is described (section 1.4). Also, a schematic concept for a DSM PC is presented. Thereafter, Chapter 2 contains how the research methodology of Dul and Hak is integrated in this study. The literature study (studies done on the industries of DSM, mining and petroleum) is discussed. The opportunities and functions are described and it is evaluated to what extent these fit within The Company's business portfolio (section 2.2). Furthermore, the current technical alternatives required in the PC are discussed (section 2.3). Thereafter the concepts are described as well as the strategy to discover the proposition for theory and the Key Performance Indicators to quantify effects. Chapter 3 executes the comparative case study to discover the relations between the concepts. The next chapter, chapter 4, evaluates the results of scenario tests and the building of theory. Chapter 5 gives the conclusions of the research, followed by the recommendations that give advice on the direction for further research and advisable steps of action.

Coen Rutgers van Rozenburg  
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# Summary

The Company Group is investigating the opportunities in the deep-sea mining (DSM) industry. The company is considering to enter this market if enough positive signs for a successful market entry are presented. DSM has its similarities with the offshore market of the oil&gas industry in which The Company is currently active. Despite that The Company acts as a contractor for pipelay and sub-sea construction in the offshore market, it is realized that The Company is not limited to this similar role in the DSM industry.

To capture the stated needs and the identified problems into a single question, the following main question for this research is proposed:

**To what extent do production chain concepts influence the composition of The Company's business portfolio and its competitiveness in the deep-sea mining production chain in 2020?**

This thesis work is done following the Dul and Hak methodology for theory-building oriented case study research. The following input concepts for the DSM production chain (PC) in the case study are proposed:

**Concept 1.** This concept includes a Raiser and Lift System (RALS) for vertical transport powered by a Production Support Vessel (PSV). The PSV dewateres the ore for horizontal shipping. Shipping to port is done using dry bulk carriers. Both treatment and refining is done onshore at a processing plant.

**Concept 2.** This concept includes offshore treatment (OT). Vertical transport is done by a RALS and horizontal transport by dry bulk carriers. Both systems are considered as continuous transport, which is a requirement for OT. OT is beneficial if *tailings can be disposed of on the seabed* and OT is required if *untreated ore degrades immediately during transport* or if *untreated ore is banned from import*.

**Concept 3.** This concept does not include any OT. This implies that an alternative to the RALS can be applied, namely the single lift option using a Heavy Lift Vessel (HLV). A basic PSV will control the mining operation while the HLV takes care of both the vertical and the horizontal transport.

Theory-building research can only be done using a *Comparative Case Study*. Two cases are treated in this report:

1. The Izu Ogasawara back-arc within the Economic Exclusive Zone (EEZ) of Japan,
2. The Trans-Atlantic Geotraverse (TAG) hydrothermal vent region. The deposits are lo-

cated on the Mid-Atlantic Ridge (MAR) within the Area (high seas under UN jurisdiction) at the Atlantic Ocean.

In general the following is discovered on the relations between the concepts:

- Concept 1 shows overall good performance.
- Concept 2 is not competitive over other concepts.
- Concept 3 performs best on a relative short distance.
- The distance from mine to port influence the economics of concept 3 the most and concept 2 the least.
- Logistical costs are a decisive factor for economics in concept 3. Economics of concept 1&2 mainly depend on other factors.
- OT is not economical. This should only be done if other influences than included in the research demand it.
- DSM is in general competitive w.r.t. conventional mining.

For both cases it is simulated how The Company could be active in DSM. This is done for two scenarios where The Company positions in the market as:

1. mining company; operating the minimal business portfolio (BP) as a contractor,
2. mining integrator; focusing on minimal BP, but possibly expanding the responsibilities.

The scenario analysis for market positioning lead to a general Road Map to build a plan for DSM market entry:

- Step One: apply calculation tool to quantify KPI-1 and KPI-2 for all PC concepts.
- Step Two: use question-list to determine package of functions and range of responsibility.
- Step Three: apply actor analysis to divide functions over The Company and other actors.
- Step Four: evaluate possibilities for cooperation to streamline market entry.

The Road Map gives a general approach on what steps to take and what methods to apply to find an optimal execution for the DSM PC. The Road Map finds the range of the BP, possible partners and how to deal with them.

The PC concept of choice influences the competitiveness of the BP and the PC, but it does not influence the composition of The Company's BP as that is mainly determined by constraints imposed by market conditions and by policies. It is discovered that the distance parameter of deposits determines the choice between PC concepts 1 and 3. Future legislation could cause OT (concept 2) to be executed as well, however it is not competitive over the other concepts.

# Samenvatting

De The Company Group onderzoekt de mogelijkheden in de diepzeemijnbouw (DSM). Het bedrijf overweegt om deze markt te betreden als er voldoende positieve tekenen zijn die een succesvolle betreding van de markt suggereren. DSM laat overeenkomsten zien met de offshore olie- en gasindustrie waarin The Company momenteel actief is. Ondanks dat The Company optreedt als aannemer voor pipelay en subsea-constructiewerk, is het besef aanwezig dat The Company niet gelimiteerd is aan deze rol in de DSM-industrie.

Om de benodigheden en geïdentificeerde problemen vast te leggen in een enkele vraag, is de volgende hoofdvraag voor deze studie geformuleerd:

In hoeverre beïnvloeden production chain (PC) concepten de samenstelling van The Company's business portfolio (BP) en het concurrentievermogen daarvan in de diepzeemijnbouw PC van 2020?

Deze thesis is uitgevoerd met behulp van de methode van Dul and Hak voor theorievorming gericht case study-onderzoek. De volgende invoerconcepten voor de DSM PC in de case study zijn geformuleerd:

**Concept 1.** Dit concept omvat een Raiser and Lift System (RALS) voor verticaal transport, bestuurd door een Production Support Vessel (PSV). De PSV ontwatert de erts om horizontaal getransporteerd te worden. Horizontaal transport naar de haven wordt gedaan met schepen voor droge bulk. Het behandelen en verfijnen vindt plaats op het land.

**Concept 2.** Dit concept omvat offshore treatment (OT). Verticaal transport wordt uitgevoerd met een RALS en horizontaal transport met schepen voor droge bulk. Beide worden beschouwd als continuïsystemen hetgeen noodzakelijk is voor OT. OT is voordelig als de reststof van het erts op de zeebodem teruggeplaatst kan worden en OT is nodig als de erts onmiddellijk verweert tijdens transport of als onbehandelde erts niet toegelaten wordt tot het vasteland.

**Concept 3.** Dit concept heeft geen OT. Dat geeft mogelijkheden om een alternatief verticaal transportsysteem te hanteren, namelijk het enkele liftsysteem met een Heavy Lift Vessel (HLV). Een simpele PSV bestuurt de mijnoperatie terwijl de HLV zowel verticaal als horizontaal transport op zich neemt.

Theorievormend onderzoek kan uitsluitend met een vergelijkende case-study gedaan worden. Twee cases worden in het rapport behandeld:

1. De Izu Ogasawara back-arc binnen de Economic Exclusive Zone (EEZ) van Japan,
2. De Trans-Atlantic Geotraverse (TAG) hydrothermale regio. De afzettingen liggen op de

Mid-Atlantic Ridge (MAR) binnen de Area (internationale wateren onder UN jurisdictie) in de Atlantische Oceaan.

De volgende algemene relaties tussen de concepten zijn naar voren gekomen:

- Concept 1 laat algehele goede prestaties zien.
- Concept 2 is niet concurrerend ten opzichte van andere concepten.
- Concept 3 presteert het beste op relatief korte afstanden.
- De afstand tussen mijn en haven beïnvloedt de prestaties van concept 3 het meest en van concept 2 het minst.
- Logistieke kosten zijn de doorslaggevende factor voor de prestaties van concept 3. De prestaties van concept 1 en 2 hangen hoofdzakelijk van andere factoren af.
- OT is niet rendabel. Dit concept moet uitsluitend overwogen worden als overige factoren die niet in dit onderzoek zijn behandeld daar om vragen.
- DSM is in het algemeen concurrerend ten opzichte van conventionele mijnbouw.

Voor beide cases is gesimuleerd hoe The Company actief zou kunnen zijn in DSM. Dit is gedaan voor twee scenario's waarbij The Company in de markt gepositioneerd is als:

1. mining company; uitvoeren van de minimale BP als aannemer,
2. mining integrator; focus op de minimale BP, maar met de mogelijkheid om de verantwoordelijkheden uit te breiden.

De scenario-analyse voor marktpositionering leidt tot de algemene Road Map voor het maken van een plan om de markt te betreden:

- Stap 1: pas de calculation tool toe om de Key Performance Indicators (KPIs) te kwantificeren voor alle PC concepten.
- Stap 2: gebruik de vragenlijst om het pakket van functies te bepalen alsmede het bereik van de verantwoordelijkheden.
- Stap 3: pas de actorenanalyse toe om de functies over The Company en actoren te verdelen.
- Stap 4: evalueer de mogelijkheden voor samenwerking om het betreden van de markt te bespoedigen.

De Road Map geeft een algemene benadering voor welke stappen te ondernemen en welke methoden toe te passen voor een optimale uitvoering van de DSM PC. De Road Map geeft de omvang van de BP, de mogelijke partners en hoe met hen om te gaan.

Het gekozen PC-concept beïnvloedt het concurrentievermogen van de BP en de PC, maar beïnvloedt niet de samenstelling van The Company's BP omdat dat hoofdzakelijk door inperkingen vanuit marktomstandigheden en beleid wordt beïnvloed. Het is ontdekt dat de afstandparameter van afzettingen bepalend is voor de keuze tussen PC-concepten 1 en 2. Toekomstige regelgeving zal bepalen of OT (concept 2) ook uitgevoerd zal moeten worden, want deze is niet concurrerend met de andere concepten.

# Abbreviations

<b>Area</b>	Area (high seas under UN jurisdiction)
<b>B2B</b>	business-to-business
<b>bbl</b>	standardized oil barrel
<b>BP</b>	business portfolio
<b>CAPEX</b>	Capital Expenditure
<b>cSt</b>	centistokes
<b>DSM</b>	deep-sea mining
<b>DSTP</b>	Deep-Sea Tailing Disposal
<b>DWT</b>	dead-weight tonnage
<b>EA</b>	Environmental Agency
<b>EEZ</b>	Economic Exclusive Zone
<b>EIA</b>	Environmental Impact Assessment
<b>EL</b>	environmental legislation
<b>EoS</b>	economies-of-scale
<b>EU</b>	European Union
<b>F&amp;I-sector</b>	Finance and insurance sector
<b>FLNG</b>	Floating Liquefied Natural Gas production vessel
<b>FPSO</b>	Floating Production, Storage and Offloading vessel
<b>HLV</b>	Heavy Lift Vessel
<b>IEA</b>	International Energy Agency
<b>ISA</b>	International Seabed Authority
<b>KPI</b>	Key Performance Indicator
<b>ktpa</b>	kilotonne per annum
<b>LME</b>	London Metal Exchange
<b>Loc.Aut.</b>	local authority
<b>MAR</b>	Mid-Atlantic Ridge
<b>MIPrc</b>	mineral processing
<b>MRI</b>	marine research institutes
<b>Mt</b>	megatonne
<b>t</b>	metric tonne

<b>mtpa</b>	megatonne per annum
<b>MW</b>	megawatt
<b>MWh</b>	megawatthour
<b>Nat.Aut.</b>	national authority
<b>NGO</b>	Non-Governmental Organization
<b>OT</b>	offshore treatment
<b>OPEX</b>	Operational Expenditure
<b>PNG</b>	Papua-New Guinea
<b>PC</b>	production chain
<b>PSV</b>	Production Support Vessel
<b>RALS</b>	Raiser and Lift System
<b>RC</b>	Refinement Charge
<b>R&amp;D</b>	research and development
<b>RMB</b>	Renmibi
<b>ROV</b>	Remotely Operated Vehicle
<b>REE</b>	rare earth elements
<b>SMS</b>	Seafloor Massive Sulphides
<b>SPT</b>	Sea-floor Production Tool
<b>TC</b>	Treatment Charge
<b>UN</b>	United Nations
<b>UNCLOS</b>	United Nations Convention on the Law of the Sea
<b>\$</b>	United States Dollar
<b>USGS</b>	United States Geological Survey
<b>VAT</b>	value added tax
<b>VOT</b>	value-of-time



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# Chapter 1

## Introduction

### 1.1 The Company

The Company is an offshore contractor with a wide working experience in the deep-sea. The Company is interested to apply its experience and technical knowledge on existing and new offshore market segments and also wants to investigate which opportunities are available in the industry of deep-sea mining (DSM). The The Company (founded in 1985) is a worldwide operating company, active in the offshore pipeline installation and sub-sea construction market. The Company is privately owned and is considered to be a global leader within its market of expertise. The Company employs over 2600 people worldwide. The Company owns and operates a versatile fleet of six specialized pipe-lay and support vessels.

In order to maintain the market-leading position, innovation and research and development (R&D) takes a central place in The Company's organization. The offshore-energy market for the exploitation of oil&gas-fields keeps looking for opportunities at locations and in circumstances that are more demanding to work in. For instance the greater depths or activities in the arctic region and the North Sea. But The Company's scope is not limited to the petroleum industry only, and its interest for DSM is prove of that.

### 1.2 Problem introduction

The World Mineral Production survey of the British Geological Survey reports a 19,5 million metric tonne (t) global refined copper production in 2011 (steadily growing from a 17,8 million t in 2007).[6] Despite a declining growth (prospect) for the leading economies due to the financial crisis, emerging economies are expected to push up the global demand for metals and all other resources in general.[44] This expected increase in demand, combined with confined resource reserves on land, suggests that DSM for minerals will become economically feasible in the near future. Similar to the petroleum industry, increasing demand prospects cause increasing commodity price levels which will allow for exploration of previously uneconomical reserves. The market for base metals and rare earth elements (REE) is ready for a similar development, allowing exploration for potential offshore deposits in the deep-sea.

The client statement, the problem and need given by The Company, is the basis for the problem definition and the main question treated in this study. Between this view that DSM might offer opportunities and the start of actual mining lie a variety of challenges and many questions. How can these deposits ideally be exploited? How should The Company execute this production chain (PC) and what should The Company role be in this PC? And what are variables that influence the answers to these questions? These questions will be the main focus point of this

research. First the client statement will be introduced, then the research goal will be set, followed by the research scope and the thesis outline. Thereafter, DSM and the mining PC are introduced.

### 1.2.1 Client statement

The The Company Group is examining the opportunities in the DSM industry. The company is considering to enter this market if enough positive signs are presented. DSM has its similarities with the offshore market of the oil&gas industry in which The Company is currently active. Despite that The Company acts as a contractor for pipe-lay and sub-sea construction in the offshore market, it is realized that The Company is not limited to this similar role in the DSM industry. Therefore, next to technical research into mining methods and equipment, research from other disciplines (law, economics, supply-chain) is needed as well, so that an as complete as possible representation of the industry can be formed. Therefore, research is necessary to map the DSM production chain, including mineral processing (MlPrc) and metal distribution. It is also needed to identify the opportunities and to design a PC concept and business portfolio (BP) for optimal market positioning. To conclude, this research deals with a study of entering the DSM market. It especially focuses on the PC and the opportunities and functions available to The Company.

### 1.2.2 Research goal

To capture the stated needs and the identified problems into a single question, the following main question for this research is proposed:

**To what extent do production chain concepts influence the composition of The Company's business portfolio and its competitiveness in the deep-sea mining production chain in 2020?**

Within this research it is investigated what fundamental choices The Company has on the set-up of the PC of DSM and how this affects the BP and financial results. The fundamental PC choices need to be made on how to arrange vertical and horizontal transport and where to process the ore (what can be done offshore?). If the conceptual PC is mapped, it is investigated what The Company contribution to this is and how this is best organized.

## 1.3 Research scope

The scope of the research determines what factors are included in the research. The focus is on copper-rich Seafloor Massive Sulphides (SMS) deposits. SMS is focused on because the deposits usually occur on lesser depths (1500-4000 meter) than other deep-sea deposit types such as Manganese Crusts or Polymetallic Nodules (4000-7000 meter).[25] The Company focuses on the shallower waters first before exploiting the even deeper deposits. Also, the SMS occur both in (international) deep waters as in shallower waters within Economic Exclusive Zone (EEZ) under national jurisdiction. Therefore SMS deposits offer more flexibility in terms of PC arrangement. As already mentioned, DSM is focused on copper-rich deposits found in SMS. In current known SMS deposits, copper is often found and copper is also relatively valuable in the current market with respect to other base metals. Precious metals and REEs are even more valuable however less abundant or harder to detect.

Next to that, The Company initially anticipates a role as mining company on a contracting



basis with the possibilities to expand its responsibilities. If active in the DSM industry, The Company will within any case at least design and operate the DSM tools and vertical transport system as well as the vessel(s) to support these systems (Production Support Vessel (PSV)). Summarizing, the two important assumptions are that:

1. The Company's minimal BP is the design and operating of DSM equipment, vertical transport system and PSV,
2. the deposits of interest are copper-rich SMS deposits.

### 1.3.1 Contribution to science and society

DSM is not (commercially) done so far but it is expected to be a new source for minerals. The European Union (EU) DG Maritime Affairs and Fisheries, states in their report *Blue Growth strategy* that by 2030 10% of the mineral production will be realized by DSM.[17] The EU expects this industry to reach an annual turnover of United States Dollar (\$)14 billion by the year 2030. DSM is also expected to be a resort to the demand for mineral resources on the longterm. In SMS deposits alone, the deep-sea is estimated to hold amounts of copper comparable to the deposits that are so far discovered on land.[40]

### International interest

Many national funded research campaigns have been executed in the past by research institutes like Ifremer (France) or Geomar (Germany). Other nationally sponsored institutes are COMRA (China), JOGMEC (Japan), Interoceanmetal Joint Organization (Cuba, Bulgaria, Czech Republic, Poland, Russia and Slovakia), G-TEC Sea Mineral Resources BV (Belgium), UK Seabed Resources Ltd. (UK). Other countries such as India, Nauru, Tonga, Kiribati, Russia (independently) and South Korea are also sponsoring research.

The presence of resources is one of the basic boundary conditions for the durability of a society. A growing demand for resources, that are subjected to depletion, provide reason for concerns on both economical and political level. To keep society and the current way of life at the desired quality level, recycling is not the only answer to fulfill a growing demand for resources. This subject is therefore a political-strategic one as well. Many national governments protect their interests and try to get hold of the resources their society requires. From a national interest point of view, the costs a society can make for a commodity, are a multitude of what is paid on the exchange. Because the revenues, from a societal point of view, can be found in the entire society and the durability of the current way of life and are not only found back on a companies' annual report. This means economical feasibility from a companies' perspective can differ significantly from a national perspective. This explains the large interest of national funded research institutes.

## 1.4 DSM and the mining production chain

The DSM PC will in some way be integrated in the existing copper chain because the same costumers with the same product demand will be served. Therefore the conventional mining PC is analyzed. The focus lies on the life-cycle of a mine, the production process from mineral to metal and the logistics involved in this. It will also discuss the impact of the introduction of DSM on this PC. Beforehand, DSM deposits are introduced. This section finalizes with a general conclusion for a DSM PC concept, based on the concept of Nautilus Minerals (see appendix B), the most advanced DSM company. Furthermore, an introduction to mining economics is



Figure 1.1: Copper B2B product: bars



Figure 1.2: Copper B2B product: wire

provided that is used as benchmark throughout the report.

The market of mining is limited to business-to-business (B2B) interaction. The B2B costumers of copper products typically demand a variety of (semi) end-products of which a few examples are depicted in figures 1.1-1.3.

#### 1.4.1 Deep-sea mining

DSM is the extraction of resources from the ocean floor at great depths. DSM should not be confused with offshore mining, which is the offshore extraction of mineral resources at depths up to 500 meter. Offshore mining is already operational, for example the mining of diamonds off the coast of Namibia and South Africa. DSM refers to all offshore mining activities at greater depths than 500 meters. From a commercial point of view, there are three main categories of high potential deposits in the deep-sea. This research focuses on the SMS deposits, however to give an overview, other types are briefly mentioned as well.

**Seafloor Massive Sulphides** The exploitation of SMS deposits is commercially interesting.[25] These deposits are comparable to the onshore Volcanic Massive Sulfides and originate at (for-



Figure 1.3: Copper B2B product: plates

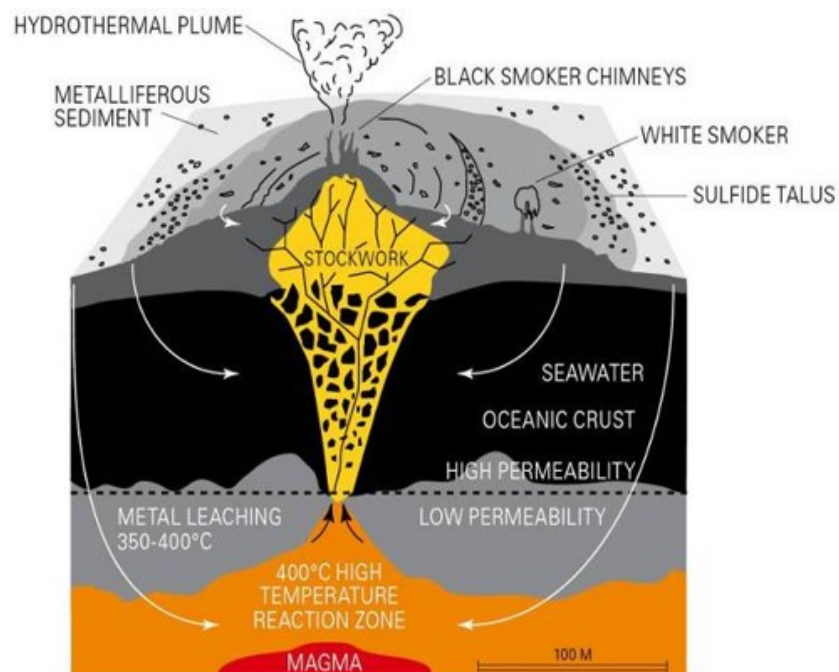


Figure 1.4: The development of SMS deposits [36]





Figure 1.5: SMS(left) and Cobalt-Rich Crust(right) [34]



Figure 1.6: Nodules field [23]

mer) high temperature hydrothermal locations, first discovered on the East Pacific Rise in 1977. The SMS precipitates from sub-sea hot springs ('black smoker chimneys', figure 1.4) and contains minerals such as copper, zinc and gold. These deposits are found at water depths ranging from 1.000 to 5.000 meter. Current efforts are aimed at mining of SMS deposits because these are located at the least depth compared to other mineral rich deposits. The SMS are depicted in picture 1.5 (left).

**Cobalt-Rich Crusts** Another deep-sea source for minerals is the Cobalt-Rich Crusts (see picture 1.5). These crusts occur on the flanks, ridges and plateaus of sea-mounts (submarine mountains). The crusts can be up to 25 centimeters thick and are slowly precipitated (about 1-6 millimeters per 1 million years) out of the seawater onto the rocks, probably by the aid of bacterial activity. Next to cobalt, several other minerals can be found in the crust.[25]



Figure 1.7: A typical mine site life-cycle

**Polymetallic Nodules** A third deposit type are the potato-sized polymetallic nodules (1.6), which were first discovered as early as 1868 in the Kara Sea (arctic ocean of Siberia). The nodules contain high grade mineral deposits and are distributed over the deep sea-floor (4.000-7.000m). Nodules are considered to be much more profitable than SMS deposits because of very high metal grades and high abundance. However, the nodules generally appear on greater depths.[25]

### 1.4.2 The life-cycle of a mine site

Figure 1.7 shows a typical life-cycle of a mine site according to Hartman in his book *Introductory Mining Engineering* [21]. It shows the actions that are required before a mine is operational up until closure and rehabilitation of a mine. First a tenement and/or a license for exploratory activities is acquired and exploration can begin. If an economically feasible deposit has been found, a mining license can be obtained. The mine is developed and becomes operational, production peaks at some point in the life-cycle and then declines until the mine site reaches the point of (economical) depletion.

The life-cycle of a DSM site is not altered visually, so figure 1.7 also applies to DSM. However, DSM sites are assumed to have a much shorter life-cycle. This depends off course to the production rate and the deposit size. Nautilus Minerals plans to exploit Solwara1 for 3 years, while land-based mines are sometimes operated for decades. However, Nautilus already has explored 18 other fields in the area and will probably be operational in the Bismarck sea for decades as well. Nautilus might be able to use the same equipment with minor adjustments on all 19 fields which would dramatically reduce Capital Expenditure (CAPEX) and the annual costs for depreciation. Investment costs are therefore hard to asses. Furthermore, DSM sites are expected to leave a much less degraded mine site. This is because the overburden, a layer covering the layer of interest, is absent or thin. However, the (longterm) effects on the marine environment are currently mostly unknown.

### 1.4.3 The production process

The basic process is visualized in figure 1.8. The PC of metals starts with **mineral mining** at a mine site; a mine produces ore. Ore is material that contains valuable minerals, but also a lot of other (worthless) material such as rock and dirt. The past years copper mines produced ore with copper grades below 1%, which means that at least 100 times of material needs to be mined to produce pure copper. The waste part is called tailings. Ore can contain multiple minerals that are valuable to some extent. However, due to a combination of processing costs and market prices and the fact that different minerals are often not extractable in a single processing step, tailings can still contain valuable minerals that are not economically extractable (at the current prices). Copper is often found and produced in combination with zinc. During copper processing also small, but valuable, amounts of gold and silver is recovered. Especially SMS deposits typically contain multiple higher grade minerals.

Conventional mining methods are often executed through blasting or excavation. The ore consist of lumps that are too big to handle properly. Therefore, a variety of sequential size-reduction equipment is located at the mine site. The next step is further removal of the tailings. The initial



Figure 1.8: The mining production process

processing step is called **treatment**. This is processing up to concentrates between 20-60%. The material of interest is now referred to as *concentrate*. Further processing is called **refining** and is processing to a global standards concentrate of  $\geq 99,95\%$ . The material of interest is now called *refined ore*. The entire processing procedure requires various steps often including several methods of chemical treatment, flotation techniques and eventually smelting. Ultimately, the purified ore can be smelted, molded and **manufactured** into products demanded by the B2B market like rods, ingots or plates.

Obviously, DSM is located offshore, which raises the question what type of processing should be done before transport to shore. Offshore processing can be beneficial if:

- tailings can be disposed of on the seabed.

Offshore processing can be required when:

- untreated ore degrades immediately during transport,
- untreated ore is banned from import.

Offshore disposal of tailings will significantly reduce the volume and mass of the material that needs transportation. However, it can not be predicted what research on environmental effects will produce and how regulation and policies will develop and thus to what extent tailings will be allowed to be placed back on the seabed.

Ore is extracted from the deep-sea where it has been for a long time under extreme circumstances, such as high pressure. Currently, it is not known how the different types of ore will react on sea level conditions. For example, changes in atmospheric pressure, increased oxygen level, sunlight or dewatering. Therefore, the scenario needs to be considered that immediate treatment is required in order to protect the valuable material from degradation which would increase processing cost onshore. Another scenario is that the ore from the seabed is in some way toxic or harmful to the environment, which will force immediate treatment because regulations do not allow untreated ore to enter the mainland for instance. The necessity of offshore treatment (OT) is unclear at this time, however the possibilities and consequences deserve attention.

#### 1.4.4 Logistics of the copper production chain

Figure 1.9 shows four locations in the PC. Mining, processing and manufacturing are usually, however not necessary, different locations. Activities can be bundled to save money on transportation and minimize inventory cost. Processing can be split up in a concentrator (treatment) and refinery. However, since virtually all the facilities and equipment require large investments

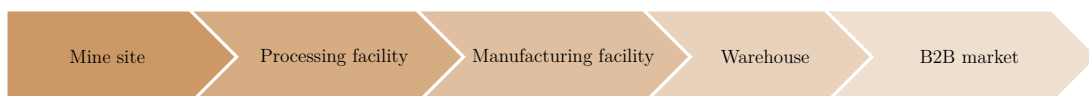


Figure 1.9: The locations in the copper production chain



Figure 1.10: The locations in DSM production chain

and have different lifetimes, the functions are not always practical to combine. Because, for instance, building a processing facility at a relative inaccessible mine site, is a great risk. Because the mine will eventually deplete, what will cause the plant to lose its supply whilst being in a bad competitive position on this inaccessible site. Therefore, processing plants might choose to be located near ports so that the plant is accessible by many mines over its entire lifetime, as long as shipping remains economical. Next to that, there is a large economies-of-scale (EoS) effect. This causes not only mines to be more economical as production increases, but especially processing plants and manufacturing facilities where this effect is even larger than for mining operations. Processing plants and manufacturing facilities are not bound to a single (depleting) source of minerals. It is very costly to move them and the bigger they are the better they perform (EoS), independently of the other facilities up and down the chain. Combined with relatively low costs for transportation this has caused mines usually not to have their dedicated on-site processing and manufacturing facilities. However, comminution and segregation activities do take place at the mine site for transportation reasons. A treatment facility can be on site as well. This depends on the deposit size and mine lifetime if such an investment is economical or not. Transportation and storage is possible between each block shown in figure 1.9 but can also take place inside the *Ore Processing* block shown in figure 1.8. This is due to the fact that the three processing steps (size reduction, treatment and refining) can be split over the mine site and the processing plant(s).

Storage generally has two functions. One is the decoupling of processes and the other is strategic storage waiting for better prices to sell the goods. Decoupling of processes decreases the vulnerability of the PC. If one process fails to fulfill the demand, a storage or buffer can prevent the other processes to immediately shut down too. Unintentional shut downs can be very costly or damage the relationship with the customer for instance. Storage is also needed to allow efficiency between production facilities and transportation, because different activities should not influence each other negatively. Transportation over longer distances is usually a discrete system that becomes more efficient as shipment size increases. But production processes could very well have continuous inflow and outflow and thus buffering capacity is required. Within production facilities, storage (however in lower volumes) is needed to decouple production steps. For instance because some processes are continuous and others are discrete processes. Storage can also be combined with transportation, when a stack yard functions as a buffer between vessels and the hinterland connection for example. The second reason for storage can be financial-strategic. Prices of commodities tend to fluctuate, so material in storage could therefore increase in value. However, the value can also decrease and (unused) inventory is generally expensive.

Figure 1.9 changes into figure 1.10. The difference is that the mine is now an offshore, deep-sea mine and some processing can be done offshore as well. Similar to the treatment which can also be done at the mine site or the use of Floating Production, Storage and Offloading vessels (FPSOs) in the offshore oil&gas industry. The location of a deep-sea mine is definitely offshore in deep waters. Therefore mining and initial transport is executed offshore. Processing can be done both onshore and offshore on-board. However, currently there is no experience in that area and issues such as power consumption, logistics of supplies and other requirements need to be addressed first.



### 1.4.5 The general DSM PC concept

This research is aimed at revealing the factors that determine decision-making on the choices on logistics in the PC. These choices deal with how to transport the ore both vertically and horizontally. Also, the possibilities for OT are investigated. A general PC concept is considered in this research. The details of the actual operation on the sea-floor will not be included in this report, because it is considered rather inside a technical scope than inside this logistical scope. Vertical transport is generalized. Nautilus will use a system called Raiser and Lift System (RALS) which is a pressurized vertical pipeline, but other systems can be considered as well such as a mechanical repetitive system or a single-lift alternative using a Heavy Lift Vessel (HLV). These options will be discussed in section 2.3.

Horizontal transportation is considered to run between the mine site (PSV) and a adequate port for delivery to a processing plant. Adequacy of a port relies on factors such as the availability of dry bulk handling capabilities, water depth or distance to the processing plant. The intermediate location Port of Rabaul in the Nautilus' case is considered to be such a case dependent variable that it is excluded in the general PC concept. However, in each particular case, a secondary hub could be included if for some reason beneficial.

From a safety perspective, a vessel needs to be constantly on-site in case of an emergency recovery of the Sea-floor Production Tools (SPTs). Also for repairs and maintenance a PSV is required. Furthermore damage to the SPTs by trawlers or anchors needs to be prevented at all costs. Currently, pipelines and other sub-sea structures are guarded by so-called *guard vessels* whilst under construction until safety measures such as trenching or rock dumping is complete. For similar reasons the SPTs will need to be guarded as well. Also, from an economical perspective all equipment and personnel should be able to be continuously productive with as little interruptions as possible. To conclude it can be stated that a PSV is required at the mine site at all times to protect the SPTs and support a continuous mining operation.

As previously discussed, this study will also include to what extent the PSV can be equipped with ore treatment equipment. As mentioned OT can be considered if on the one hand tailings can be placed back on the sea-floor decreasing the volumes to be transported. Or on the other hand if , OT is required because of weathering or deterioration issues with ore mined from the deep-seabed. Because one benefit of OT is the decrease of volume that needs to be brought to shore, this suggests that OT in-transit is not beneficial from that perspective. To fully benefit from the decrease in mass due to OT, shipping should start after the OT is finished. In-transit OT also means that the function of production support (to the SPTs) and OT is separated, which increases CAPEX (and probably Operational Expenditure (OPEX) as well) because in that case two specialized vessels are required. From these considerations it is concluded that OT can not be separated from the mine site and can not be combined with transportation. Furthermore, the capacity and production speed of the OT equipment should not depend on the length of transport routes. And combining transportation with processing has exactly that as a result. These consideration lead to the general PC of DSM which is depicted in figure 1.11. It shows the activities and locations in the PC. The dark-colored boxes show the activities/locations that are included in this research.

### 1.4.6 Introduction to DSM economics

For DSM to be financially feasible two general scenarios are possible: shortages or competitiveness. The conventional land-based mines are inevitably slowly depleting. Their competitive position is declining as well due to declining copper grades. Current production levels are harder and more expensive to hold at level, while on the other hand demand is likely to increase due to emerging countries and their growing population and wealth. Shortages will cause a gap in



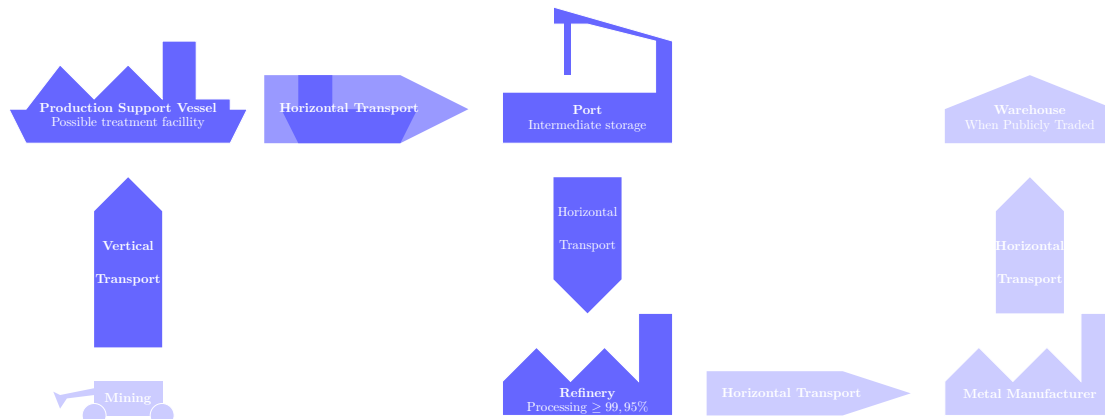


Figure 1.11: Typical DSM production process

order fulfillment that can be filled by DSM. Shortages generally cause prices to rise as well. In the case that DSM will be more expensive, especially in early stages of development, this global development on the copper market, or metal market in general, is essential. Due to technological developments and high grade deep-sea deposits, it is also possible that DSM has lower production costs than conventional mining. In that case DSM is already competitive with respect to conventional mining. Independently (to some extent) of the market value.

### Conventional mining economics

*The Wall Street Journal* stated in a recent article that many mining companies are losing money when the copper price hits \$2,80 per pound, which corresponds to a copper price of 6.173\$/t.[43] Current copper prices float around 6.800\$/t but have been as high as 10.000\$/t in the past decade. Barrick Gold Corporation, a large gold and copper mining company, states three production costs for copper mines ranging from 1,50 to 2,29 \$/pound.[14] This corresponds to 3.307 to 5.049\$/t. These costs refer to C1 costs, which is a standardized measure introduced by the Australian mining industry. It includes operational costs for mining and milling, transportation (to the refinery) and administration. This means that refining of the ore, which is required to receive the earlier mentioned market price, is not included in these production costs yet. The production costs mentioned in *The Wall Street Journal* are likely to apply either to smaller mines or to mines in countries such as the United States where labor is more expensive. These mines will have relative higher costs while a company such as Barrick can operate cheaper because it operates a large number of large mines in cheaper regions.

### Nautilus Minerals economics

According to their operational plan, Nautilus Minerals expects to be producing against costs of 70,47\$/t.[35] This does not include any other costs for refinement or taxes for instance. It is therefore comparable to the earlier mentioned C1-performance benchmark. The costs mentioned by Nautilus reflect to the costs per mined unit of ore. To compare the expected production costs this needs to be converted to production costs per ton refined copper (99,95% purification). The average grade in the earliest stage of production is estimated at 9,2% (land deposit copper grades are currently close to 0,5-0,6%), which means nautilus could produce at  $\frac{70,74 \cdot 99,95\%}{9,2\%} = 766\$/t$ . This grade can drop close to 2,2% and still be competitive in terms of Barrick's C1-performance. This seems to be much more profitable than conventional mining, however this concerns a very high grade deposit, relatively close to shore. Transport costs are

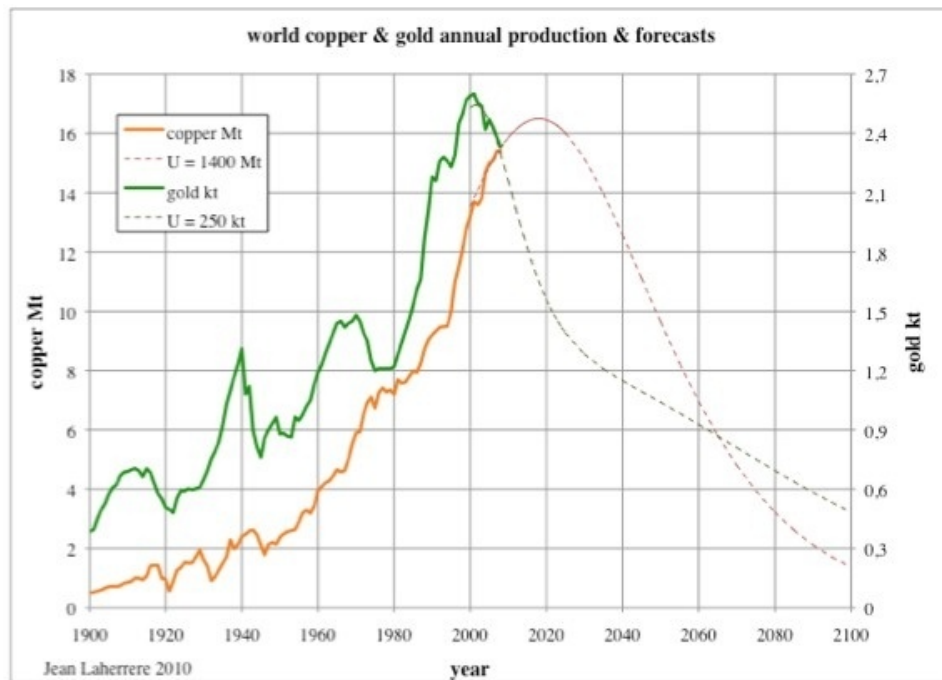


Figure 1.12: Copper production and forecast by Jean Laherrère [28]

included up to the port of Rabaul, 50km from Solwara 1. However, many issues that occur when using a new methodology in a new challenging environment as DSM will still have to be conquered before this project can be realized.

In terms of the economical feasibility of DSM, the C1 production costs will have to be lower than the range 3.300-5.000\$/t in order to be competitive with the larger copper producers that are currently active in the market. Nautilus Minerals expects to be able to produce against much lower costs than conventional mining companies. The alternative scenario is that the copper price will rise (caused by shortages) to a certain value which will make DSM profitable, and that DSM is supplying metals parallel to conventional mining. Especially the latter scenario means that mining of the deep-sea will not be feasible in the next few years, but might become feasible after the year 2020. That is when, according to Jean Laherrère in figure 1.12, copper production will decline due to exhausted deposits and declining ore grades. Simultaneously, the demand for copper is not likely to decline at all and that is likely to cause shortages and rising copper prices. Some of the shortage will be taken in by improved and extended efforts in the field of recycling, however at this time it is not likely that through recycling a closed circle system can be achieved.

## 1.5 Thesis outline

Chapter 1 provides an introduction to the research. The client, The Company, is introduced. The Company's history and current activities are briefly discussed and it is explained why The Company is interested in DSM. The importance of the research into this topic from both a scientific as well as a societal perspective is explained. It also introduces the industry of DSM and the copper industry and PC is described (section 1.4). Also, a schematic concept for a DSM PC is presented. Thereafter, Chapter 2 contains how the research methodology of Dul and Hak is integrated in this study. The literature study (studies done on the industries of

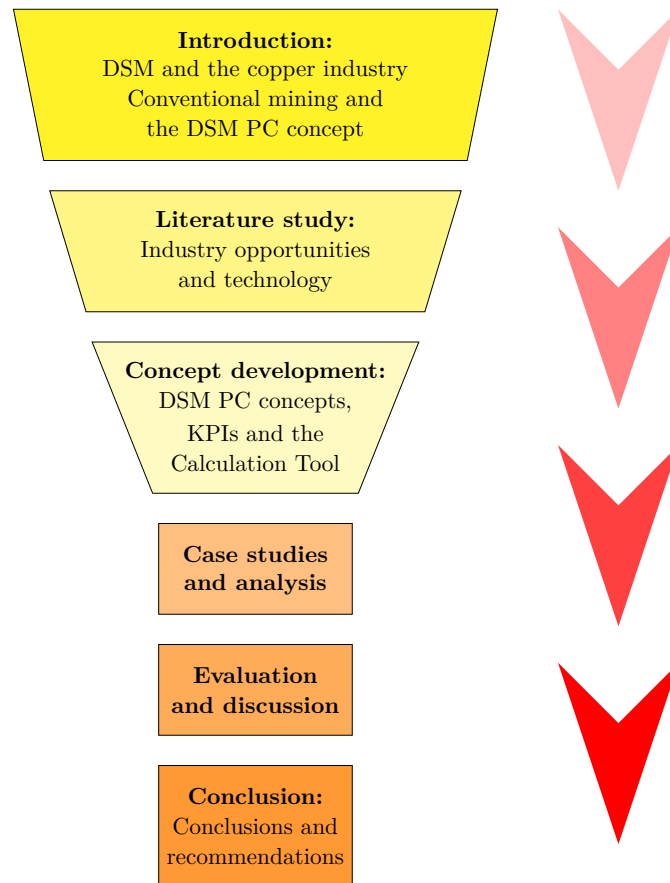


Figure 1.13: Thesis outline

DSM, mining and petroleum) is discussed. The opportunities and functions are described and it is evaluated to what extent these fit within The Company's BP (section 2.2). Furthermore, the current technical alternatives required in the PC are discussed (section 2.3). Thereafter the concepts are described as well as the strategy to discover the proposition for theory and the Key Performance Indicators (KPIs) to quantify effects. Chapter 3 executes the comparative case study to discover the relations between the concepts. The next chapter, chapter 4, evaluates the results of scenario tests and the building of theory. Chapter 5 gives the conclusions of the research, followed by the recommendations that give advice on the direction for further research and advisable steps of action. Figure 1.13 gives an overview of the thesis outline.



## Chapter 2

# Methodology and literature studies

This chapter starts with the description of the research methodology of Dul and Hak which is applied in this research. Thereafter the research approach for the exploratory research is discussed. It discusses the functions, the opportunities and the required products in the DSM market. Furthermore, the technical aspects of the DSM components are discussed. Thereafter the concepts are proposed and the preliminary model is introduced which describes how the concepts are analyzed in a comparative case study.

## 2.1 Methodology

### 2.1.1 The case study methodology (Dul and Hak)

The research is based on the methodology proposed by Dul and Hak in their book *Case Study Methodology in Business Research* [16]. This book offers a guide for case research methodology. First, the researcher must choose between theory-oriented or practice-oriented research. In this case theory-oriented is required because the aim is a generalizable outcome where practice-oriented research offers outcomes suitable for a single practitioner. Theory-oriented research may ultimately also be useful for practice in general. Because the approach of this study is new compared to other studies, which are often technical feasibility studies rather than a PC approach, the theory-oriented study is that of *theory-building*. In such a study the relations between unknown concepts are established by a comparative case study. The objective of this theory-building study is:

*The objective of this study is to contribute to the development of theory regarding the production chain of deep-sea mining for copper-rich Seafloor Massive Sulphides deposits by finding independent concepts A (cause) for a known concepts B (effect).*

Dul and Hak define theory as a set of propositions about an object of study. Theory requires four basic characteristics that need to be defined precisely:

1. Object of study
2. Concepts
3. Propositions
4. Domain

**Object of study** The *object of study* is the stable characteristic in the theory. In this case that is: *the PC of DSM for copper-rich SMS deposits*.

**Concepts** The *concepts* are the variable characteristics in the theory. Concepts need to be defined precisely to allow for measurement of their value in instances. A concept in an instance is called a variable. Concepts appear both as input(A) as well as output(B) and are often presented as cause(A) and effect(B).

**Propositions** *Propositions* consist of concepts and specifications of relations between these concepts. This research aims at discovering the relations and so discovering the propositions.

**Domain** The *domain* is the specification of the universe of the instances of the object of study to which the propositions are believed to be true. Or a set of instances to which the predictions apply and to which they can be generalized. The domain in this study is: *the PC in 2020 from mine to refinery of the DSM industry for copper-rich SMS deposits in both national as international jurisdictions*. **Instances** are the specific characteristic situations in which proposition can be found. Theory-building can only be done by a **comparative case study**. The case determines the values of the variables (concepts), both the input as the output. The results of the case study are then analyzed through **pattern matching** which leads to the discovery of propositions. The outcome will have to be interpreted and validated before actual conclusions can be made on the contribution of the proposed theory to existing theory.

### The comparative case study

The building of theory is done using a comparative case study. Comparative case studies require at least two cases (set of instances) wherein the concepts can be compared against each other (pattern matching). The domain in which the cases should be selected is earlier defined as: *the PC in 2020 from mine to refinery of the DSM industry for copper-rich SMS deposits around the world in both national as international jurisdictions*. The two selected cases have very different instances both in physical aspects (distance from mine to shore, deposit depth), market circumstances as well as jurisdictional aspects. The cases are:

1. The Izu Ogasawara back-arc within the EEZ of Japan. (figure 3.1)
2. The Trans-Atlantic Geotraverse (TAG) hydrothermal vent region. Located between the Atlantis fracture zone and Kane fracture zone. The deposits are located on the Mid-Atlantic Ridge (MAR) and located within the Area (high seas under UN jurisdiction) at the Atlantic Ocean. (figure 3.4)

Both cases are especially interesting because of their differences. The Japanese government has announced the desire to engage in DSM and it is developing a legal framework to support this. It has ridges with known deposits at locations ranging from 200-1200km off the coast. It also has a large MiPrc industry. The MAR case is very different. The deposits are located in international waters (known as the Area (high seas under UN jurisdiction) (Area)). This is governed by a United Nations (UN) subsidiary called the International Seabed Authority (ISA). The distances to shore are very large and there are multiple markets at these great distances. For example, the United States east coast is at approximately 3100km distance and Rotterdam at approximately 5300km.

### 2.1.2 Research methodology

The general research methodology is based on the research methodology proposed by Dul and Hak. This methodology however only provides guiding for the general approach. In this section a more detailed description of the literature study (including subquestions) is provided. This

research is what Dul and Hak describe as exploratory research. The goal is to establish the earlier mentioned *concepts*.

The exploratory research is partly based on the Nautilus Minerals' report on their Solwara1 project. This document provides detailed information on equipment, logistics, production rates and running costs. It is also the only publicly available plan for exploitation of a SMS deposit. Also, previous studies on DSM equipment provide other views on the available technical alternatives. Scientific research and data is often found in literature, previous studies and via the ISA. Practical data on the copper market and mining industry is found at various mining companies and suppliers as well as (national) research institutes, commodity exchanges and consultancies. Furthermore, analogies can be found with both the conventional mining PC as the offshore oil&gas PC. The mining PC is most applicable to the downstream part of the DSM PC, while the offshore petroleum industry provides examples for offshore exploration, OT (FPSO analogy) and exploitation plans in general. The main question is subdivided into subquestion that help with a more phased approach to answer the main question. The subquestions are:

- A) What are the functions and opportunities in DSM?
- B) What are the strategic considerations that determine The Company's BP?
- C) What technology is available for DSM, vertical transport, metallurgy and logistics?
- D) How is the copper PC for DSM optimally executed?

Each subquestion is further explained by a set of questions shown in table 2.1. These questions help clarify the objectives for each subquestion. Furthermore, for each subquestion the methodology is briefly described.

Subquestion	
<b>SQ A:</b>	<b>What are the functions and opportunities in DSM?</b>
	Topics
	<ul style="list-style-type: none"> <li>•What products, services and functions are required in the market?</li> <li>•How does The Company fit in this function overview?</li> </ul>
<b>SQ B:</b>	<b>What are the strategic considerations that determine The Company's BP?</b>
	Topics
	<ul style="list-style-type: none"> <li>•What should be The Company's responsibility?</li> <li>•What should be in-house developed and/or operated by The Company?</li> </ul>
<b>SQ C:</b>	<b>What technology is available for DSM, metallurgy and logistics?</b>
	Topics
	<ul style="list-style-type: none"> <li>•What equipment is available for vertical transport?</li> <li>•To what extent is OT a possibility?</li> <li>•What logistical systems are available to DSM?</li> </ul>

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Subquestion

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**SQ D:**      **How is the copper PC for DSM optimally executed?**

Topics

- What variables determine optimal execution?
- What variables determine competitiveness?
- To what extent can cooperative structures contribute to actor management?

Table 2.1: Overview of the subquestions

**SQ A: What are the functions and opportunities in DSM?** The first subquestion discusses the functions and opportunities of DSM and which of these are of interest to The Company. This is done according to a detailed analysis of all products&services and the pre-requisite steps to offer these products&services. This analysis can be found in appendix C.

**SQ B: what are the strategic considerations that determine The Company's BP?** The second subquestion discusses The Company's identity and capabilities. This is described through The Company's job record, current work and activities. This is used to determine the capabilities of The Company in terms of identity and capacity. This is discussed in section 2.2.

**SQ C: what technology is available for DSM, metallurgy and logistics?** Subquestion C provides an overview of available concepts for DSM equipment and vertical transport. The possibilities of OT are evaluated by analysis the requirements for MIPrc on land. Furthermore, by looking to the oil&gas industry (FPSOs), an estimation is made on the costs for OT. Costs for logistics (shipping and storage) are acquired from literature and information provided by industrial suppliers, such as shipbuilders. This data allows for derivation of formulas for shipping costs. Furthermore this chapter presents figures that serve as guiding input for items such as production rates and running costs. The technical analysis can be found in section 2.3.

**SQ D: how is the copper PC for DSM optimally executed?** Subquestion D discusses results of the case studies and performs scenario tests.

## 2.2 Opportunities in the DSM production chain

**Subquestion A: what are the functions and opportunities in DSM?**

**Subquestion B: what are the strategic considerations that determine The Company's BP**

The DSM industry is a relatively new industry. The Company traditionally operates as a pipeline installation and sub-sea construction contractor in the offshore oil&gas industry and with the arrival of its new vessel the specific HLV will also be involved in platform installation and decommissioning activities. The Company has indicated that it may wish to expand its current activities in the future by entering the DSM industry. A wide set of opportunities is available, however for the purpose of this thesis it is assumed that The Company would operate DSM equipment itself. Considering the company's innovative character this suggests that The Company would be involved in the development of the required equipment. Another assumption is that The Company would act as a mining service provider in the base case scenario, but that the BP may be further expanded, e.g. by operating a deep-sea mine or holding a more integrative function by incorporating activities such as exploration and MIPrc. When taking a closer look at the industry, the opportunities that are most needed can be identified. Each



opportunity has a set of requirements to seize it. For these opportunities it is established to what extent it fits within The Company business in terms of The Company's identity, culture, capabilities or other criteria. This chapter uses background information discussed in appendix C.

### 2.2.1 Opportunities in the DSM industry

The Company is an offshore company with a large focus on technical innovation and new opportunities. Large, long-term investment are not shied away from and have proven to be successful in the past, with Solitaire as the most appealing example. These investments and innovations has allowed The Company to lay pipe in continuously larger depths, increasing pipe diameters and with increasing speed and reliability. Keeping this history in mind it is in The Company's DNA, when looking at DSM, to focus on the mining techniques at the sea-floor. The PSV might include some OT steps as well, but this is a complicated matter. It depends on aspects such as environmental regulation, logistics, economics and PC positioning.

Figure 2.1 is derived from the analysis in appendix C. It shows the primary functions, the general requirements, the product and the costumers in the DSM PC. This is a conclusive figure from appendix C after adding the constraints that follow from The Company's desired minimal BP. Operating the DSM equipment is centralized in this figure. The production and sales of fully processed, refined copper ore is the farthest downstream along the PC as is considered in this thesis.

The central (lighter) **red box** shows The Company's primary interest. Operating DSM equipment. Two darker red boxes show the prerequisite, the development of the equipment, and the product, the DSM service. The three red boxes form a single product strategy where The Company functions as a DSM contractor or mining company. If *Sell raw ore* would be offered to the industry as a product instead of *Offer DSM service*, the **purple boxes** become The Company responsibility too. Note that The Company has now become a DSM operator or integrator rather than a contractor. As an operator it can be decided to fully or partly process the ore (treatment or treatment&refining). Offshore treatment is considered to be an in-house developed and operated process, because The Company has profound experience with offshore production facilities. Onshore processing is assumed to be outsourced, since MIPrc plants are abundant and ownership of such a plant will restrict logistical optimization, while taking on the (financial, environmental) responsibility for this plant and taking additional risks. The ore can alternatively be delivered and sold to this onshore processor what terminates The Company involvement and responsibility for any next steps in the PC. This is also visualized in figure 2.1.

The **yellow boxes** on the left show the strategy that add an exploratory service to the mining operation. This could be a separate business unit. However from an The Company's perspective, where operating DSM equipment is assumed to be the primary service, this would be an additional service. Either The Company is an operator and exploration is done in-house or it is offered as a secondary business unit to others (DSM operators) if The Company functions as a contractor or mining company. The yellow boxes on the right show a similar approach but then for OT. This can be offered as an additional service to the mining operation or as an in-house task in case of an independently operated mining operation where The Company is the operator and integrative party.

Exploration services can be outsourced or developed in-house. That is why these two boxes are attached to each other. The same goes for the processing units, but in that case both choices produce the same products (concentrate & refined ore) whereas the exploration services are only for own use if outsourced but can be offered as an extra business unit to others when the

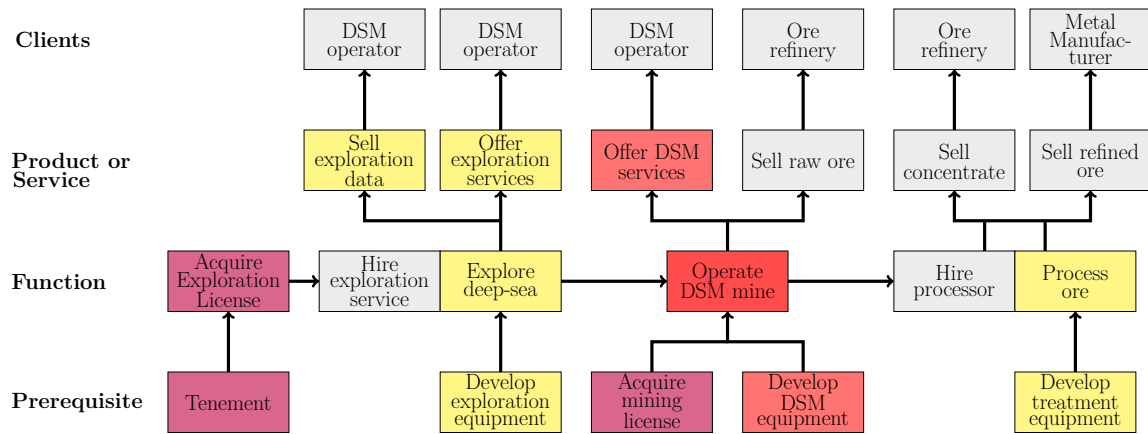


Figure 2.1: Function chain for The Company

techniques and equipment are internalized. Summarizing, from the perspective that The Company will engineer and operate DSM equipment, the following opportunities can be identified in the DSM industry:

1. Offer DSM operation service (as a contractor; minimal BP).
2. Offer downstream DSM operation services (including transport and treatment).
3. Offer upstream DSM operation services (including exploration).
4. Operate upstream DSM (this includes tenements & licensing, exploration, shipping to shore and possibly treatment).
5. Operate upstream & downstream DSM PC (this includes tenements & licensing till delivery to processor or manufacturer (this would mean that processing is also within The Company's responsibility, but this can be outsourced)).

In general, opportunities can be approached in a large variety of ways. All the requirements can be organized (design, construct & operate) in-house, equipment can be leased or partners can be found to do certain tasks. Any variation on this is an option as well. However, from The Company's perspective some options are preferable and more likely over others. Traditionally, The Company designs its own vessels and equipment as far as possible. However, research institutes, like the Maritime Research Institute Netherlands (Marin), have been involved for more specialized design questions. In the case of DSM research institutes could be partners in the field of research on topics such as exploration, MIPrc, biology, geology and environmental studies, required for an Environmental Impact Assessment (EIA). Other partners can be thought of as well. Companies interested in DSM, who are not considered to be competitors, can be approached for joint activities in the field of any operational aspect that is not The Company's primary interest. This could be exploration, MIPrc or logistical and marketing services.

**The Enterprise** Furthermore, the ISA has its own company called The Enterprise. The ISA has put in place The Enterprise. The Enterprise will be the company involved in DSM when the time comes that DSM takes of in the Area. Regulation roughly state that if a company acquires a mining license, another area of similar commercial value should be licensed and relinquished. In practice, this means that for each deposit that is found, only half can be exploited independently. The other half is handed over to The Enterprise. The philosophy is that the treasures

of the deep-sea are part of the Common Heritage and all nations, including currently underdeveloped countries and landlocked countries have equal right to these treasures. Therefore, The Enterprise can either hold on to this deposits for safekeeping until a underdeveloped country is able to mine. The Enterprise can also decide to mine the deposits under its own responsibility. The corresponding article at the website of the ISA [25] is as follows: *"10. An element of the regime for the international seabed area is the so-called "parallel system", whereby, in the case of polymetallic nodules, an application must be sufficiently large and of sufficient value to accommodate two mining operations of "equal estimated commercial value". One part is to be allocated to the applicant and the other is to become the reserved area. The reserved areas are set aside for activities by developing States or by the Authority through its Enterprise."*

These regulations do not make it more attractive for a company to pursue mining in the Area. However, if mining in the Area is considered, The Company should try to include the Enterprise in their entire operation and so gain access to the second relinquished half of the total licensed deposits. This does however mean that both equal size areas are exploited together with The Enterprise, where The Company's official position is co-owner in the first field but mining contractor in the second field. The profits of the first area are shared while ensuring The Company's involvement in the second field. At this time, it is however unknown to what extent The Enterprise is willing to negotiate.

At this time, The Enterprise is not an active player nor is it known what it will have to offer. From The Company's perspective, the Enterprise could serve as a substitution for the requirement of a national authority (Nat.Aut.)s support because The Enterprise has the ISAs support already. This way, if The Company is experienced and financially capable of an independent operation, the somewhat forced cooperation with The Enterprise might offer opportunities to reduce the number of total partners as well.

Considerations on the so-called 'make-or-buy' decision have to be made on each separate task of the operation. Exploration and processing are likely to be outsourced because they are not within The Company's area of expertise. However, The Company is capable of developing exploration equipment rather than a MIPrc plant, since Remotely Operated Vehicles (ROVs) with survey equipment are already operated by The Company to prepare and monitor pipeline and trenching projects. If it is favorable to develop an OT facility it is likely that this is operated by The Company, because it is located at the mine site operated by The Company and its functions are combined with those of the The Company operated PSV. However design of this facility could still be outsourced to parties with more experience in this area.

The Company usually designs equipment in-house. If needed, it is partially outsourced, comparable to the current procedures of vessel design. Simulation and testing can for instance be outsourced to a specialized research institute, comparable to how MARIN currently contributes to vessel design. Furthermore, The Company has a history of close cooperation with research institutes like the TU Delft that results in joint research. Detailed design or construction could be outsourced to companies such as IHC. Manufacturing of this equipment is mostly outsourced, unless The Company's production facilities have enough capacity and capability to do so themselves. Especially because DSM will contain specific parts and craftsmanship, the production is likely to be outsourced. However, for maintenance and refurbishment reasons, it would be advisable to have the knowledge in-house available at some point in time to be able to operate more independently. If outsourcing is favorable, for knowledge protective reasons, it is beneficial to choose a variety of suppliers so that the complete design remains in The Company's hands only.

This research tries to establish the factors within the characteristics of each particular deep-sea mine field that determine the following decisions:

The initiative for development of a particular mine site can be:

1. with The Company. So that The Company actively searches for deep-sea mine sites. Either through in-house or outsourced exploration. Tenements & licenses are held by The Company,
2. with another party. The Company is hired to operate a deep-sea mine site. Responsibilities for licenses and procedures lie with the client.

Mined ore can be (see figure 2.1):

1. sold to processor,
2. treated onshore or on-board,
3. treated&refined by The Company or by subcontractor.

Logistical trade-offs need to be made on:

1. how to transport the ore,
2. where to process the ore,
3. how to distribute the product.

All offshore activities are new to the mining industry. Technology for deep-sea exploration, DSM and vertical transport is therefore the most demanded by the industry. However, OT, shipping & handling and logistics differ significantly when comparing DSM to the conventional mining process. Being offshore brings different problems but also advantages compared to conventional land-based mining. An advantage for example is the absence of overburden that covers the material of interest, which make pit excavation or tunneling redundant.

### 2.2.2 Requirements per opportunity

For each earlier mentioned opportunity in the DSM PC, the prerequisite abilities are stated. These abilities do not necessarily need to be developed in-house since outsourcing of activities is an option as well.

**Offer DSM operation service** This is a service which is offered to a mining operator for instance. The Company functions as a contractor or mining company. The client is holder of the tenement and licenses, is responsible for the processes and is owner of the ore. The Company will only be tasked with bringing the ore to the surface. This will include the equipment on the sea-floor, the vertical transport to the PSV and storage or prerequisite processing necessary for transport (such as dewatering or size reduction). Requirements to seize this opportunity are:

- a) design & construct of DSM equipment,
- b) design & construct of vertical transport system,
- c) design & construct of PSV (including strictly necessary treatment equipment).

**Offer downstream DSM operation services** This service is an expansion on the previous service. This includes transport to shore and storage for instance. It could also include more complex treatment processes on the PSV. Additional requirements (on top of a-c) to seize this opportunity are:

- d) transport & material handling system,
- e) OT facility.

An optional requirement (on top of a-e) to seize this opportunity is:

- f) optional: onshore storage facility.

**Offer upstream DSM operation services** Additionally to DSM, The Company can develop exploration equipment. This way a holder of a tenement (operator, integrator) can hire The Company, as a contractor, to explore, develop and operate (potential) mine sites. An additional requirement (on top of a-c) to seize this opportunity is:

- g) exploration equipment.

**Operate upstream deep-sea mine** Operating a deep-sea mine contains all responsibilities for the mine development and the marketing of the product (raw ore/concentrate). For DSM this includes acquiring a tenement for exploration, a mining license, mine (de)commissioning & operation and sales of the product to a refinery on the shore. Mine operations includes mining, vertical transport and horizontal transport. It can also include any necessary treatment before the product is accepted by a refinery. An additional requirement (on top of a-g) to seize this opportunity is:

- h) logistical network to refinery.

Requirements can always be met through outsourcing, provided there is a company available that offers the service within the required standards. Currently that can not be assumed for specific DSM services.

**Operate upstream & downstream DSM production chain** In this scenario the deep-sea mine and production process including refinement is the responsibility of The Company. The Company is a DSM operator/integrator. An additional requirement (on top of a-h) to seize this opportunity is:

- i) certificates to comply with branding standards (in case of public trading).

Also, requirement g), the logistical network, will have to be expanded further down the PC.

**Other operational requirements** The items mentioned above describe the more technical aspects of the DSM operation. It did not mention other, just as critical, items such as health&safety, legal requirements, environmental protective requirements or licensing apart from the mining tenements & licensing.

### 2.2.3 The Company's capabilities and resources

The The Company is a privately owned company with a rich history on innovation and longterm investments. In the past, longterm investments on innovative developments have proven to be successful and the company's urge to go beyond its limits have pushed The Company to new regions, greater working depths and new market segments. With the introduction of new vessels for example, the capacities were larger than anyone could imagine to be demanded or profitable at that time. The new vessels has proven however to be a major asset to the The Company's fleet, however not necessarily in the first years of her arrival on the market. This is an example of the longterm vision of The Company. The Company is also active in the arctic region. This gives a good example of both the innovative identity as the urge to continuously expand the area of expertise. These two characteristics are defining for The Company's positioning in the offshore industry and exactly these two characteristics are indispensable in the development of such a challenging endeavor as DSM.

The Company's history on fleet expansion shows the capabilities of The Company's employees and management in terms of a drive for innovation, financial strength and technical expertise. The development of the technical items for DSM would therefore fit within The Company's identity. This explains the focus on the development of the mining tools, vertical transport system and the supporting vessel. As a private company independence is always an aim as well. This suggests that other functions should be included as well to have a stand-alone operation as much as possible. These two statements are conflicting to some extent and an optimal solution needs to be found.

The Company's has quite some experience with sub-sea survey and the use of ROVs. Before pipe-lay can commence the sea-floor is mapped and a trajectory is designed for the pipe. During operation the pipe-lay process is monitored. Furthermore, The Company's is capable of trenching on the sea-floor which included similar survey activities. Trenching operation have provided extensive experience with the use of large sub-sea equipment working on the sea-floor. These activities suggest that next to mining and vertical transport, exploration activities are closest to The Company's current business portfolio. Mineral processing is typically not in The Company area of expertise and so it needs to be carefully investigated to what extent this should be included in The Company's scope and how that is incorporated if necessary. Furthermore, because The Company has strong ties with research institutes such as universities their R&D capabilities can be considered strong as far as their in-house development is not already capable of handling new challenges. The cooperation with these institutes give access to a network of knowledge and expertise, testing equipment and additional survey data.

### 2.2.4 Subquestion A: conclusion

**Subquestion A: what are the functions and opportunities in DSM?**

**Subquestion B: what are the strategic considerations that determine The Company's business portfolio?**

The findings on the opportunities in this chapter have been combined with various configurations of services that are within The Company's field of interest as well as the capabilities of The Company.

Analysis on the opportunities for The Company in the DSM industry of copper has shown the following:

- Since DSM is an industry in the earliest development, the basic components for mining, vertical transport and OT are most required.

- However less critical, other components such as transportation&handling, storage and branding should not be neglected.
- The Company naturally focuses on design&operate of DSM equipment including mining tools, vertical transport and the PSV.
- Activity can be expanded with exploration and/or MIPrc.
- DSM can be approached from a contractors perspective or an integrative perspective.
- For entering the DSM industry The Company requires:
  1. in any scenario:
    - a) design & construct of DSM equipment,
    - b) design & construct of vertical transport system,
    - c) design & construct of PSV (including strictly necessary treatment equipment).
  2. for additional downstream services:
    - d) transport & material handling system,
    - e) OT facility.
  3. optionally:
    - f) onshore storage facility.
  4. for additional upstream services:
    - g) exploration equipment.
  5. to operate downstream activities:
    - h) logistical network to refinery.
  6. to fully operate a deep-sea mine:
    - i) certificates to comply with branding standards (in case of public trading).
- The Company focuses on longterm developments and investments. DSM could therefore fit within their business portfolio.
- The Company's history shows that the company is willing and able to develop abilities in new market segments and make large investment that come with that.
- From an experience point of view, exploration&survey is the most feasible in-house expansion next to the equipment necessary for mining.
- Expansion of business portfolio is most likely to be aimed at upstream activities based on The Company's experience.
- Cooperative R&D can allow for downstream expansion as well.

**Considerations** The Company is in the first place interested in the development of mining equipment. The mining tools can not function without a PSV. And to have a fully marketable product/service, vertical transport is included as well. These items form the minimal business portfolio for The Company.

Exploration is the next function that is closest to The Company expertise, however to include exploration services does not offer a wider operational service but rather a new separate business unit. Exploration is an activity prior (in terms of a mine lifecycle) to exploitation. Both



are executed under separate licenses. Offering both services to the market does not offer direct benefits, because both activities do not directly influence each other. Expansion of the BP should ideally cause efficiency so that lower costs are realized. If a single mine is considered, having both services available automatically means that if one is operational the other is not. Surely, when one is mining, exploration is already done. Business units and equipment should be fully utilized.

Unless a role as integrator is pursued and tenements and licenses are also acquired and held by The Company, both elements must be seen as separate business units. Both are required in a mine life cycle, but at different phases. It is therefore not directly a logical combination of services unless The Company desires to be involved over the entire lifetime of the mine as a mining integrator. In that case, to guarantee a continuous mining operations, to some extent continuous exploration is required as well.

Downstream services on the other hand, contain less interface with The Company's traditional activities and are already offered in the existing mining PC. But these functions can be offered as a direct expansion of the mining service. The relation with the mining operation is evident, however the relation to The Company is less evident. The Company has for example no experience with MIPrc or the distribution of ore. This is where partnerships can be useful to learn from parties that have the experience on the downstream side, but do not pursue an adventure in mining the deep-sea themselves.

## 2.3 DSM technology

### **Subquestion C: what technology is available for DSM, metallurgy and logistics?**

DSM is a great technical challenge. Water pressure increases roughly by 1 bar each 10 meters. Nautilus' Solwara1 field is located at a depth of 1500 meters. Other known SMS deposits depths can increase up to 4000 meters and even deeper. These great sea-floor depths cause the pressure to increase up to around 400 bar.

This great pressure makes it impossible to perform the work with on-site manpower since divers are unable to work in such depths. The human body cannot cope with these circumstances. Furthermore, hydraulics behave differently under these circumstances. Other techniques based on fluid characteristics and gases can also become ineffective because the increased pressure changes the substance behavior. Most gases turn to liquid because of the pressure for instance, changing its volumes and density. By using umbilicals it is possible to deliver power to the seabed, however energy losses occur when transporting electricity. An umbilical is a power line from a vessel to subsea equipment that can transport both electrical energy as information for control and monitoring of a ROV. A profile of an umbilical is depicted in figure 2.2.

Technology, especially in this new area of industry, plays a large role in the feasibility and the economics of the mine field. It is evaluated what can be expected from development of equipment and mining methods, as well as vertical transport and the possibilities for processing.

Besides The Company there are more (offshore) companies that are exploring the opportunities of DSM to some extent. These companies are traditionally active in the markets for offshore/subsea construction and installation, dredging or mining. This way an overview can be generated of the available options and information on running costs, production rates and operating depths. Most of the information is acquired from the detailed report of the Nautilus Solwara1 project, which is discussed in appendix B.

This section provides quantitative input for components of the concepts that are used as input in the case studies. Subsection 2.3.1 states the facts&figures of the Nautilus concept, which provides the best examples of running costs for a vertical transport system and activities at the PSV. The information provided by Nautilus is used for OPEX estimations for mining, vertical





Figure 2.2: Example of an umbilical [37]

transport and the PSV. Subsection 2.3.2 provides information on the alternatives for the vertical transport system. Subsection 2.3.3 shows the evaluation and costs estimation for MIPrc and OT. The oil&gas industry development of FPSOs is used to estimate the costs for mineral processing offshore. Subsection 2.3.4 gives quantitative input for storage in the different stages in the PC. And finally subsection 2.3.5 gives input for shipping and handling costs.

### 2.3.1 Nautilus Minerals' concept facts

Nautilus Minerals provides the most extensive conceptual plan for a DSM mine. Namely, the Solwara 1 project in the EEZ waters of Papua-New Guinea (PNG). Their equipment is in production, but has not been field tested yet.

#### Production rates and running costs

Since DSM tools have not been tested on a large scale so far, the Nautilus mining tools will be used as a reference. The numbers provided on capacity and costs can be used as reference, but can be adjusted if clear factors to do so appear. The CAPEX is stated as well as the OPEX and the operational production costs per ton of (mined) ore. At an intended daily output of 3700t of ore Nautilus mentions the following costs:

	CAPEX	OPEX	
Item	[mio.\$]	[\$/day]	[\$/t]
SPTs	84,1	20.130	5,44
RALS	101,1	23.184	6,27
PSV	30,5	144.796	39,15
Total	215,7	188.083	50,86

Table 2.2: Solwara1 costs producing 3700t/day

A daily production of 3700t mounts up to 1,35 megatonne per annum (mtpa) if no downtime is considered. 1,0 mtpa is reached if 74% uptime is realized. The Bismarck see is sheltered and thus uptime is expected to be reaching 96% since Nautilus expects to be able to produce 1,3 mtpa already in the second year of production.

Figure 2.3 shows Nautilus as a company integrated in the function overview presented in section 2.2. Nautilus has in-house exploration since it is exploring many fields continuously. It has also developed (to some extent) the equipment and will be operating the equipment themselves. The

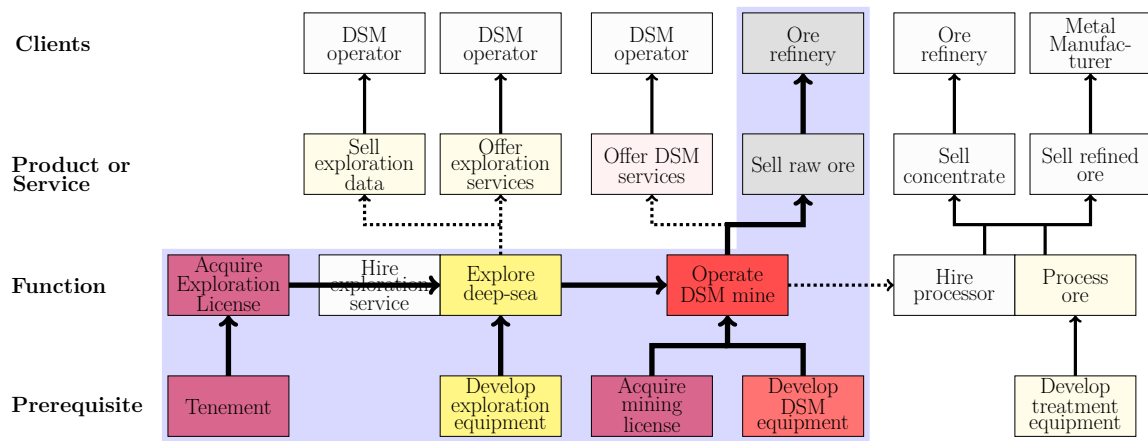


Figure 2.3: Nautilus' function chain

ore is sold to the processor so after transportation to the processor Nautilus' involvement in the PC is terminated.

### 2.3.2 Vertical transport technology

Vertical transport (figure 2.4) is one of the major challenges in DSM. Transport of the ore from a sea-floor as deep as 4km to the PSV is an issue. Transport and handling equipment of bulk goods, such as copper ore and most other commodities, can be divided in continuous systems, such as a pipeline or belt conveyor, and batch systems, such as a grab crane. The bulk material can appear in liquid bulk, like oil, or as bulk solids, such as copper ore. So when discussing the handling of bulk materials two main categories can be distinguished:

1. solid bulk or dry bulk,
2. liquid bulk or wet bulk.

But ore can be mixed with water as well so that it forms a slurry which behaves more like a liquid than a solid. According to Cruickshank (1968) several types of vertical lift systems for DSM can be distinguished and these are depicted in figure 2.5. The vertical transport systems are divided into mechanical repetitive, mechanical continuous and hydraulic continuous systems. Previous The Company's studies have added two systems to this: the container or bucket lift system (mechanical repetitive) and the pressure pump system (hydraulic continuous). A bucket hoist system is a container that is lifted to the PSV and is a mechanical repetitive system. The pressure pump is actually a variation on the suction pump.

#### Mechanical repetitive systems

Mechanical repetitive systems are typically not suitable on larger depths. This has to do with limited cable capacity, low filling rates of the grabs and increasing cycling times with an increasing depth. The Boskalis Grab Excavating System (GES) is a system using a large clamshell controlled by a ROV for maneuverability. This system can operate at an extraordinary 1.000 meters, which still has no practical use for SMS deposit exploitation. Note that these systems aim at combining mining and vertical transport. Also, maneuverability and the force of impact to mine also poses issues on larger depths combined with a tougher sea-floor. Steel cables have natural limits on the applicable depth due to the own weight. At an increasing depth the load capacity is gradually consumed by its own weight. Stronger cables are generally thicker/heavier

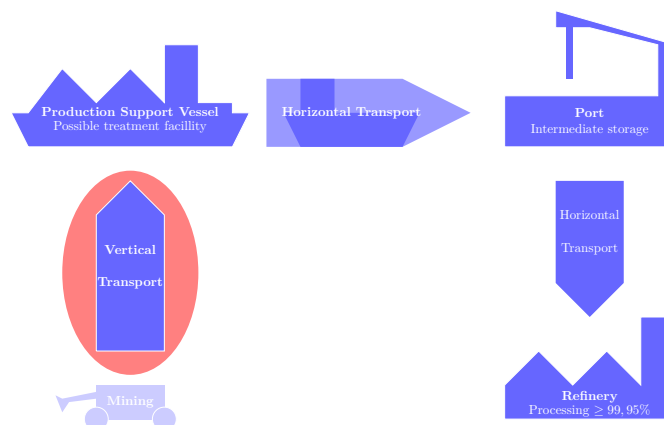


Figure 2.4: Typical DSM production process

	(1) MECHANICAL REPETITIVE			(2) MECHANICAL CONTINUOUS		(3) HYDRAULIC CONTINUOUS		
LIFTING COMPONENT								
	DIPPER	DRAGLINE	CLAMSHELL	BUCKETLINE	CONVEYOR	SUCTION	AIRLIFT	JET LIFT
LIMITS	LENGTH OF ARM (100 FT (30m))	HOISTING RATE WEIGHT OF ROPE DEPTH LIMITS UNDEFINED		<200 FT (60m)	VERY LIMITED	MECHANICAL LIMITS ON LADDER FRICTION	?	DEPTH LIMITS UNDEFINED
EFFECTS OF ENVIRONMENT	UNSTABLE ON FLOATING PLATFORM		WASHING OF LOAD		MOTION ON RIGID LADDERS			TRANSVERSE MOTION ON FLEXIBLE RISERS

Figure 2.5: Vertical raiser systems [21]

as well so this is not endlessly expandable. Development in the field of synthetic cables can increase the usability of such systems.

An example of a 44mm steel wire rope with an own weight of 9,8kg/m and a breaking load of 190t, gives a maximal length of  $\frac{190t}{9,8} = 19,4km$ . In this stadium the capacity is consumed by its own weight. However, after applying safety factors (that easily accumulate to a factor 3) about 6,5km working depth is left of this. And this still does not include any equipment (buckets) or actual load.

A system that only focuses on vertical transport is the bucket hoist system. It consist of a simple concept of a container that is hoisted with a single or multiple wires. As mentioned before, the limitations of such system is the capacity of wire ropes. Also, in case of using multiple wire ropes, tangling of the wire ropes due to currents is an issue as well.

**A specific HLV** A vessel like the specific HLV could be used to lift the ore from the seabed as a high volume but low frequency transport system. The vessel would operate next to the PSV, which is still required for power delivery and control of the mining operation. The winches of the specific HLV have a combined capacity of 25kt. If a combination of, yet to be developed, of synthetic cables or buoyancy techniques (and so ignoring limits of current cable technology) is assumed, the following calculation is applicable. When ignoring tangling cables issues and assuming a hoisting speed of 1,0m/s, an assumed cable capacity of 50% of the strength at 4.000m, this vessel could hoist  $\frac{25kt * 50\%}{8.000s} * 3.600s/hr = 5,6kt/hr$ . Assuming a capacity of 300.000 dead-weight tonnage (DWT), 53,3 hours of loading/lifting are required. This only includes time for hoisting and the descent, so no (un)loading time of the container. The hoisting speed increases rapidly in shallower waters. Assuming a 300.000DWT and a mine output of 1,0 mtpa, the visit frequency is every 3,6 months.

In terms of running cost, HLVs daily charter costs examples range from \$200.000 (Stanislav Yudin [11]) to \$1 million (Heerema Thialf). This includes a profit margin leaving the running cost still between 60-90% of that. For the specific HLV daily cost of approximately 800.000 \$/day provide a good estimate.

## Mechanical continuous systems

This type of systems receives less attention in literature or in practical concepts. A bucket line could for instance be an alternative continuous system that could operate sub-sea, however the own weight of cables poses a direct limit on the capacity of a system, especially at greater depths. The use of multiple cables poses a hard to control risk of tangling, which makes this alternative often less attractive than the RALS. A bucket line, with many moving parts, is also expected to require much more maintenance due to wear.

## Hydraulic continuous systems

Two examples of pressure pump systems are known. The Nautilus RALS and the system of IHC. IHC uses multiple centrifugal pumps along the pipe. Nautilus uses pumps on the PSV to power a water-pressure powered Subsea Slurry Lift Pump (SSLP) on the seabed that pumps the ore into a pipeline to the PSV. Currently, at least for the greater depths, many research is aimed at the development of RALS. Despite it looks like dredging methodology, the situation differs substantially from dredging, because of the greater depths and because the material of interest has a much higher density. Also, because the slurry behaves very different from a fluid such as oil, the situation is quite different from what is known from the oil&gas industry. Generally it can be stated that dredging uses large diameter pipes and low pressure while oil&gas risers are much smaller and more pressurized. Moreover, the (required) working depth of dredgers is

much more limited, while the oil&gas industry does not have to deal with the behavior of solid materials.

**The technique** Bulk solids can be transported as a liquid bulk in a continuous system such as a pipeline. It is mixed with a liquid (often water) and transported as slurry. The carrying fluid is pumped to the surface and because of the friction between the solids and the fluids, the solids will start to move upwards as well. The particle size of the bulk solid will have to be reduced significantly for this application to avoid clogging of the pipe and to improve the mass/surface ratio. Surely, the gravitational forces because of the mass need to be overcome by friction between the fluid moving upwards and the solid. The friction also depends on the surface area. Smaller particles have more surface relative to the mass (or volume). The optimal particle size depends on the diameter of the riser pipe and the size of particles that the applied mining method will produce. But because particles of different size will travel at different speed, clogging can still occur even with reduced particle sizes due to particles overtaking each other. Especially bends will have to be avoided because of this reason.

**Energy consumption** Furthermore, particle size reduction is a very energy inefficient process and size reduction will have to be done on the seabed itself, which means electrical power needs to be brought down. And due to power loss during transportation, the inefficiency is even increased. This means that the entire operation will consume quite some energy. According to Nautilus, the RALS could operate with a daily power consumption of approximately 700W/t. This is for diameters ranging from 30-90cm and a capacity of 1.000-20.000t/day up to a depth of 3.000 meters. Adding booster stations would probably increase the working depth, however the consequences on the behavior of the RALS are not investigated.

**Capacity** Table 2.2 shows the running cost for a RALS running at 3.700t/day. In case of a year with 200 effective working days, the output of such a system is 0,74mtpa. Nautilus Minerals expects the total system to deliver 1,3mtpa, however in the sheltered Bismarck Sea downtime will not be a large problem. This is something that, for instance in the open oceans, can not be assumed. Furthermore, it is not specified which item (SPTs, RALS or PSV) is the limiting factor here. Anyway, a RALS can be easily expanded by adding a second system, because there is no risk of interference/tangling and it would actually increase redundancy to deal with downtime for maintenance for instance. Of course, this increases the investment costs significantly. Furthermore, the pipe diameter can be increased as well, without influencing the efficiency of the RALS. The Nautilus pipe diameter is 39cm and this is expected to be expandable up to 90cm without increasing the marginal power consumption.

### 2.3.3 Mineral processing and offshore treatment

In case of mining offshore, offshore treatment can be beneficial. Moving the processing activity offshore brings about several issues. The logistics responsible for delivery of consumables and personnel and waste management is more complicated. The operation causes a certain environmental risk but especially accidents can be very harmful for the environment. The same applies to the safety of personnel, products and equipment. Next to increased risks and operational challenges, the required space and the energy consumption play a role when assessing to what extent OT is feasible. One of the reasons to treat the ore offshore close to the mine site is to reduce the total volume of material that needs shipment to shore, assuming that Deep-Sea Tail-ing Disposal (DSTP) is possible. The mass of ore is directly related to the metal concentration in the ore. The mass is estimated by the formula:  $mass_{new} = \frac{mass_{old} * grade_{old}}{grade_{new}}$ . The subscript

*new* refers to the metal grade in the ore after a processing step. And *old* refers the situation before the same processing step.

Looking at the development of FPSOs in the oil&gas industry, environmental risks and risks for personnel, equipment and products are acceptable offshore. The chemicals used for MIPrc are however very harmful to the environment and this will require additional safety measures. Possibly greater than the measures required for petroleum (waste) products. Furthermore, when considering deep-sea mined ore with copper contents up to 10%, still 90% (weight percentage) is left as tailings taking the entire process into account. Whatever part of this process is done offshore, it will cause additional issues, both logistically and environmentally, with the disposal of those tailings and other production waste material.

## Requirements of OT

The physical requirements for offshore processing have been researched by Roel Vissers [49] in his thesis work for The Company on the subject of DSM as well. He has analyzed data available from the *SME Mineral Processing Handbook (chapter 14c)* [50] that has publicized a research among 74 copper operating units. The questionnaires recorded the methods applied and the corresponding equipment used. For all items the power consumption and the required floor space was separately collected. No linear correlation is found since the methods and the characteristics of the facilities differ very much. The production considered typically includes processing of copper concentrates grades up to 30%. This type of processing is referred to as treatment. Further processing is usually referred to as refining and typically includes smelting. Refining (30%-99,95%), and thus smelting includes high-powered furnaces. Next to additional energy and consumption of consumables, this also imposes significant extra risks. Accidents with smelters can have large consequences because of the great heat which could even lead to sinking of the vessel.

The energy consumption per ton for MIPrc, including crushing, varies between 5,5megawatthour (MWh) and 64,8MWh, averaging on 18,3MWh. Further analysis shows that a plant with a 5.000t daily capacity requires approximately 4.550kW. The SME Mineral Processing Handbook also provides insight on the required floor space of copper producing plants. Analysis of the data has shown that a processing plant with a daily capacity of 5.000t requires 1244m<sup>2</sup> on average. This includes all processes from crushing to drying, but excludes storage space for consumables, waste & tailings and storage of ore before, between and after processing. It also excludes any equipment for transport between processes for instance. The data on required surface also shows no clear correlation. This average excludes surface for thickening using large basins, which is a widely applied dewatering procedure. Nautilus uses disc dryers for instance as an alternative that requires far less surface. Alternatives will be more costly because either it consumes more energy (drying by heat) or more material (filters). Summarizing, an offshore plant that processes 5.000t a day has an annual capacity of 1,0mtpa if it is 200 days operational. The required power is estimated about 4,6kW and the required floor space (equipment only) is 1244m<sup>2</sup>.

**The specific HLV as offshore treatment PSV** Appendix D shows the analogies between the offshore oil&gas industry and the possibilities for OT as well as the costs. To see what The Company's specific HLV would be capable of, if it is converted to a DSM PSV with OT capabilities, the requirements are compared to the specific HLV specifications. The specific HLV has a maximum power output of 95megawatt (MW), is 124m wide and 248m long. Keeping some spacing at the board sides, this mounts up to a deck space of  $100 * 240 = 24.000m^2$ .

In terms of energy, applying both the linear average as the non-linear best-fit average the range



is  $\frac{95}{18,3} = 5,2 \text{ kt/day}$  up to  $\frac{95}{4,6} = 20,7 \text{ kt/day}$ . This excludes any power consumption for 'regular' operations. However, it can be assumed that from an energy supply perspective, the specific HLV is well equipped to perform OT, since it is likely that current experience with MIPrc will ensure that in this case, where limiting energy consumption is very important, at least the average value will be realized. Furthermore, the data has been acquired from questionnaires conducted in 1972, therefore it can be assumed that due to technical improvements the energy consumption will have to be at least similar but most likely lower. Also, when production increases the EoS cause the relative power consumption to decrease per produced unit of ore, however the total power consumption has its limits, especially offshore. With an available deck space of  $24.000 \text{ m}^2$ , the specific HLV has more than enough surface to facilitate OT. Power consumption will be the limiting factor for the design of a PSV with OT capabilities.

### 2.3.4 Storage in the PC

Storage in DSM first occurs at the sea-floor and the ore needs to be moved to the PSV. In case of a continues RALS the storage is minimized, but if this is a discrete system like when using a HLV, some level of intermediate storage will be necessary. The same holds for the PSV which links the vertical transport system to the horizontal transport system. Especially when OT steps are involved the importance for storage will increase since more actions are added to the system. Transshipment of the ore can also be done directly into the transport unit to eliminate the storage facility. However, the transport vehicle will be idle for a longer time while slowly loaded and that might induce higher costs. The need for storage and the trade-offs that go along with that are similar along the rest of the PC. Storage cost are always traded off against both the risk of production disruptions and delivery problems to the costumers on the one hand and at the other hand to the costs of higher transport frequencies. Higher transport frequencies (with lower volumes) generally decreases the required storage space, but increase the total shipping cycles.

**Storage on the PSV** The PSV provides for monitoring, control and power of the entire mining operation. It usually also is the physical link between vertical and horizontal transport of the ore. The PSV will also provide in any OT. Because both transport systems (vertical & horizontal) are not necessarily aligned perfectly in terms of transport frequency and production rates, intermediate storage will be necessary. Another reason is that downtime of the mining operation or vertical transport operation should not immediately lead to stagnation in the rest of the system or increased charter costs due to idle transport vessels. Offshore storage costs on the PSV relate to additional PSV CAPEX because of increased required deck space. CAPEX are not included in this report, however whenever possible avoided.

**Stockpiles and warehouses** Onshore storage is required at the drop-off point of the horizontal transport vessel. This is probably in a port and not necessarily at the refinery, however many refineries are located close to port. Both in port and at the refinery intermediate storage is required. The size of storage is depending on the transport volumes and frequency. The storage capacity in port will be similar to the on-board storage capacity of the PSV, because it involves the same vessel. Only this time it is offloading. Nevertheless, the full load will have to be stored till the next transport link is picking it up. This is probably a transport link with lower capacity and thus a higher frequency. Preferably inland shipping because of the large volumes and mass. Storage capacities further on the PC towards the end-market will to a greater extent depend on reducing risk of stalling production, failure in order fulfillment or strategic storage of assets.

### 2.3.5 Methods for horizontal transport and material handling

This subsection discusses the horizontal transport and handling equipment. These are the logistical systems required next to the vertical transport. This includes the transshipment from PSV to the transport vessel, shipping to port and transshipment in port. When discussing the handling of bulk materials two main types can be distinguished:

1. solid bulk or dry bulk,
2. liquid bulk or wet bulk.

Typical examples for dry bulk are grain and iron ore. Petroleum is a typical example of liquid bulk. However, ore can appear in both forms. It is usually seen as dry bulk, however if the transport rates allow it, it can be economically attractive to add a liquid (often water) and pump the slurry through a pipeline. Weir Minerals Netherlands B.V [9], an equipment supplier, mentions the longest iron ore pipeline in Brasil, MMX of 550km, and the highest pressure line in Chile of 240 bars. In the PNG DSTP is also applied, this is pipeline tailings transport to offshore dumping locations. [42]

Handling methods for dry bulk can be subdivided into batch systems and continuous systems while liquids are typically handled with continuous systems, because of the favorable flow characteristics. Examples of a batch handling system is a grab crane (figure 2.9). Conveyor belts are an example of a continuous system.

### Transportation costs

In this research the transportation costs only include the horizontal transport between PSV and port. Furthermore it is assumed that a single port is considered which makes it economically attractive to focus the handling equipment on PSV and in port, since these are expected to be less numerous than transport units. This implies that shipping can be done with relatively simple dry bulk carriers and that self-unloading systems are not a prerequisite.

Transport costs are built up by many cost items. Transport vessels are usually chartered and not owned. It also allows for more flexibility in logistics since the size of transport units and the size of the fleet can be easily adjusted. Although many mining companies outsource their shipping activities, this is done under longterm contracts. This provides better pricing and stability for both parties, but it reduces the flexibility because the logistical service provider offers better prices in return for a stable demand. Two main cost items for charter vessels are included in this report:

- Charter cost,
- Fuel consumption cost.

This excludes for example costs for insurance for as far as these are not already included in the charter costs. And the costs represent costs for short term charter and do not include longterm agreement discounts and thus allow for optimal fleet flexibility. Fuel costs occur when in transit, however some fuel is also consumed when in port and during idle time. This is to power equipment and the crew quarters for example. Charter costs occur and are equal, over the entire length of the operation.

Four commonly used bulk vessel categories are investigated and both costs items are investigated. The Handysize, Supramax, Panamax and Capesize. The Handysize (10.000-30.000DWT) is one of the most commonly used vessels for short haul transport, the slightly larger variant is called the Handymax or Supramax (30.000-50.000DWT). The Panamax (50.000-80.000DWT)





Figure 2.6: The 400.000 DWT Valemax in Rotterdam

is a vessel type that is designed to just fit through the Panama locks. The maximum draft of this vessel 12,04m. The Capesize (80.000-200.000DWT) is the largest vessel stated in this table. Because this vessel is too large to use either the Panama or Suez canals, the vessel has to sail via Cape Horn (Chile) and Cape of Good Hope (South Africa). Even larger vessels are for instance the Valemax series, Very Large Ore Carrier (VLOC), operated by the mining company Vale. These vessels have a capacity of 400.000DWT (figure 2.6). However, cost specifications are not available.

**Vessel charter costs** Figure 2.7 shows a data collection on vessel charter costs per category. It shows large volatility over the past years (left) as well as throughout the year (right). It is especially interesting to see that pricing on the Supramax and Panamax do not differ that much and that most recent years the Supramax has even become more expensive, although it is a smaller vessel. The Capesize is much more expensive. This is partly caused by the capacity range being very large (practically any vessel over 80.000DWT) and because vessel size is not linearly distributed over the categories so that the dataset on the Capesize vessels is much smaller. The market and fleet size of these vessels is relatively small, which makes pricing more volatile. The benefit of these vessels occur through EoS which justifies the higher charter costs compared to chartering multiple smaller vessels. Charter prices tend to fluctuate throughout the year. Most striking is the Capesize charter prices in 2013 almost eight-folding between March (\$5.000/day) and October (over \$40.000/day). This particular graph does not provide enough or consistent data to find a clear pattern. However if logistics allow for incidental or seasonal transportation, this phenomenon deserves extra attention to minimize charter costs. The data on charter costs allows to produce a polynomial trend line (Excel; 1-year average) with the formula  $y = 4.10^{-7}x^2 - 0,0023x + 8309,7$ . Where  $y$  being the charter costs per day and  $x$  being the vessel capacity in DWT.

**Bunker fuel prices and vessel fuel consumption** Fuel costs are a combination of fuel consumption and fuel pricing. Figure 2.8 shows the 380cSt fuel pricing in the two large ports of Rotterdam and Singapore. 380cSt is a common marine fuel type available across the world.

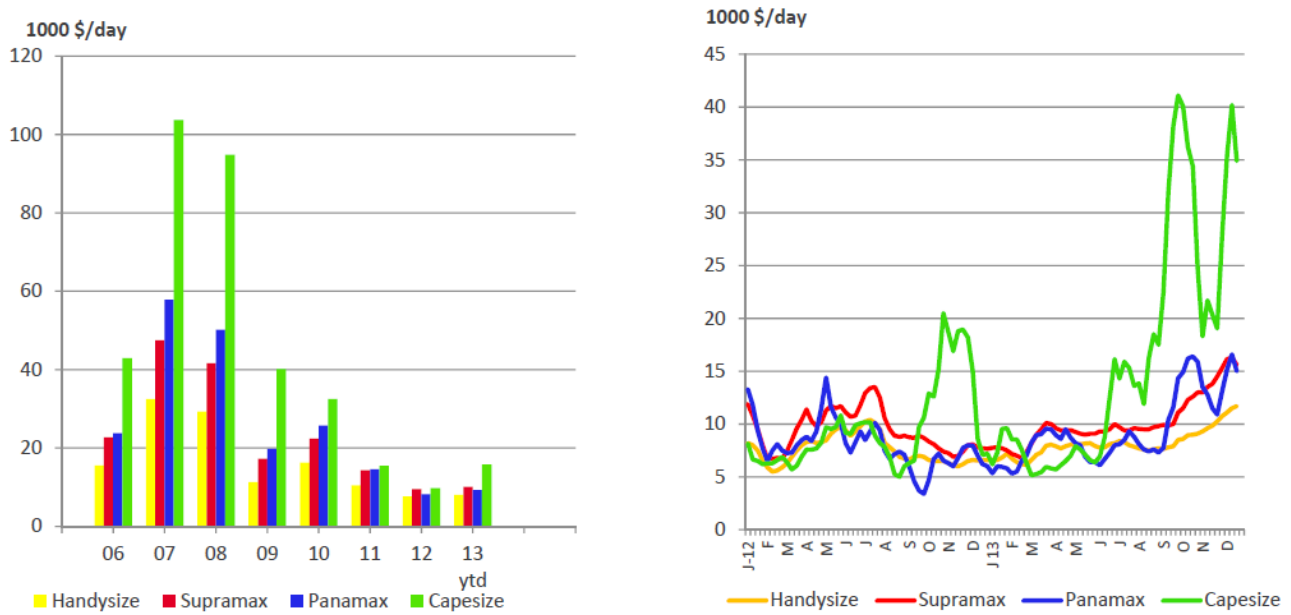


Figure 2.7: Vessel charter costs volatility [39]

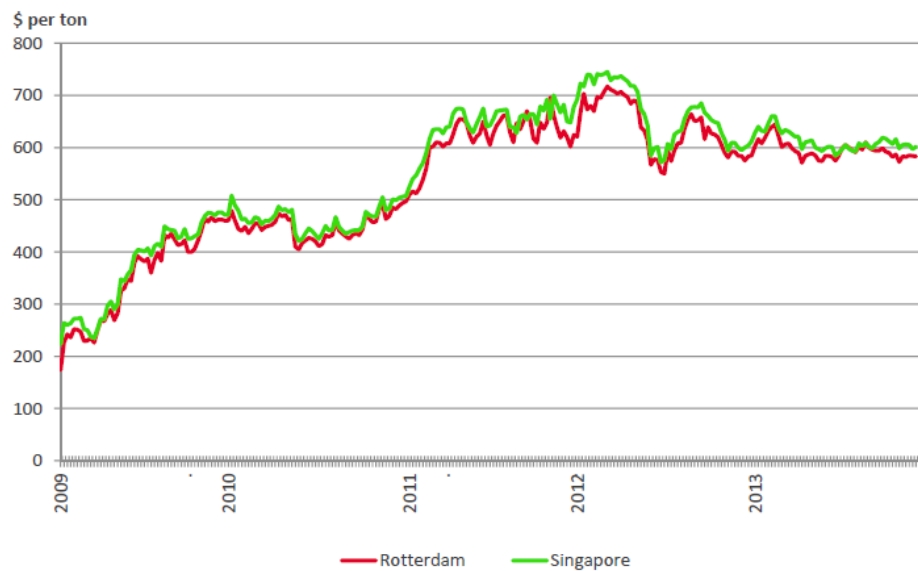


Figure 2.8: History of 380cSt bunker fuel prices [39]

Fuel Consumption	Handysize	Supramax	Panamax	Capesize
Sailing(14kn)	18,8	24,8	41,0	50,0
Handling	2,1	2,8	4,6	5,6
Idle	1,0	1,4	2,3	2,8

Table 2.3: Vessel fuel consumption [t/day] [27][31][26]

Category		Handysize	Supramax	Panamax	Capesize
Capacity	[1000*DWT]	10 - 30	30 - 50	50 - 80	80 - 120
Charter costs	[\$/day]	8.100	10.200	9.400	16.200
Fuel costs	[\$/day]				
	Sailing 14kn	12.032	15.872	26.240	32.000
	Handling	1.337	1.764	2.916	3.556
	Idle	668	882	1.458	1.778

Table 2.4: Vessel category operating costs

Fuel prices tend to fluctuate, but 2013 shows relative steady pricing. Detailed data from over 120 worldwide ports provide a 2013 average pricing for Bunker Index 380cSt of \$ 641/t.[7]

The second factor is fuel consumption. This is much more complex to analyze since fuel consumption depends on many factors, such as vessel size, vessel type and design speed. Container vessels are typically designed for a much higher speed than bulk carriers because containerized goods, like electronic devices and other consumer goods, need to be delivered to the end market much faster than resources do. This has to do with the value-of-time (VOT) of different goods, which allow for some goods to be transported by much faster vessels (up to 22 knots) or even by airplane and still be economical. Dry bulk carriers are typically designed for a speed of around 14 knots or less, which dramatically reduces the fuel consumption relatively to the high speed container vessels. The following formula:  $F = F^* \cdot (\frac{S}{S^*})^\alpha$ , in which  $F$  is the fuel consumption calculated for the actual speed  $S$ ,  $F^*$  is the fuel consumption at design speed  $S^*$  and  $\alpha$  is a engine specific parameter that can be assumed to be 3 for common diesel fuel engines.[49] An example of a high speed (22kn) Panamax container vessel consumes 120t/day. Following the formula, the same vessel sailing at 14kn consumes only 31t/day. Examples have been found of dry bulk Panamax vessels with fuel consumptions of 30 to 40t/day, In this report a cruising speed for dry bulk carriers of 14kn is assumed. Design specifications of a Supramax vessel provide fuel consumption for the design speed (36t/day), handling consumption (4t/day) and idle fuel consumption (2t/day).[22] This data provides with a handling factor of  $\frac{4}{36} = 0,11$  and a idle fuel consumption factor of  $\frac{2}{36} = 0,06$ , which will be used for further calculation on fuel consumption. Various sources of shipbuilders provide information on fuel consumption for vessel sizes. The information allows for the composition of table 2.3. Table 2.4 gives an overview of the collected data. The data on fuel consumption costs allows to produce a logarithmic trend line (Excel) with the formula  $10.922 * \log(x) - 97.053$ . Where  $y$  being the cost per day for a full day in-transit sailing at 14kn and  $x$  being the vessel capacity in DWT. This formula calculates the in-transit fuel costs only. To calculate fuel costs whilst handling a factor of 0,11 needs to be applied.

## Ore handling systems

The material is shipped from the PSV to the transport vessel and from this vessel to the quayside in port. The suitable equipment depends on several factors such as particle size, the transport rate and other substance characteristics like moisture. Slurry can be pumped through a pipeline



Figure 2.9: Offshore double articulated grab cranes [29]

or hose as a continuous liquid bulk. This is suitable if large capacity is required. Dewatered ore is treated as regular dry bulk and can be handled with existing equipment. It also depends on the logistics what kind of equipment is most suitable. In general, if a small number of transport vessels is required and the vessel calls multiple destinations, the investment in equipment moves to the location (the transport vessel) that is least numerous. From an operational point of view, it is more likely that a single destination and numerous transport vessels is used. This means that the PSV and the port need to be equipped with adequate handling equipment. For each separate SMS field it is likely that a single route to the market is assigned. It is therefore recommended to invest in handling equipment on the PSV and search for ports with dry bulk handling equipment. This allows for simple transport barges or vessels that allow for cheap charter cost and high flexibility in the number of vessels. This report will assume this scenario in further analyses. These assumptions are that a single port with dry bulk handling equipment is used as a logistical hub. This allows the horizontal transport to be done with simple vessels, which means that the PSV should also be self-sufficient in terms of material handling.

A widely applied batch handling system is the double-articulated grab crane shown in figure 2.9. The advantage of such system is the high maneuverability because of the rotation points. Figure 2.10 shows a floating material handling barge for material transfer between vessels.

The PSV will need to handle the material offshore. The double-articulated cranes shown in figure 2.9 are suitable for that. The maritime-contractor.com website mentions a loading capacity of 1.000t/hr for a single crane.[32] In port a gantry crane can be used with a capacity of approximately 2.000t/hr. It is assumed that the Handysize is loaded by two cranes, the Supramax by three cranes, the Panamax by four and the Capesize and larger by 5 cranes, similar to figure 2.10. This does infer that the PSVs design is adapted to the transport carrier type in use. For instance a certain length and number of cranes is required to service a large dry bulk carrier at these loading rates. The loading rate is described with a trend line (Excel) formula  $y = 1268,6 * \log(x) - 10.225$  with  $y$  the loading rate in t/hr and  $x$  the vessel capacity in DWT. The unloading rate is twice the loading rate.





Figure 2.10: Floating transfer [10]

### 2.3.6 Subquestion C: conclusion

#### Subquestion C: what technology is available for DSM, metallurgy and logistics?

- Current mining tools are electrical SPTs, powered and controlled by umbilicals from a PSV.
- Current vertical lift system to greater depths concepts include RALS or a repetitive hoisting system.
- Nautilus expects to produce 3.700 t/day at 50,86 \$/t including costs for SPTs, RALS & PSV.
- The Company's specific HLV is in terms of deck space and power production well equipped to run an OT plant.
- The DSM PC is assumed to include a single port as a hub, allowing the horizontal transport to be done by regular charter vessels and projecting handling equipment on PSV and in port.
- Daily charter costs of bulk carriers can be approached with the formula  $y[\$/day] = 4.10^{-7}x^2 - 0,0023x + 8309,7$  where  $x$  is the vessel capacity in DWT.
- The in-transit fuel costs can be approached with the formula  $y[\$/day] = 10.922 \log x - 97.053$  where  $x$  is the vessel capacity in DWT.
- The in-port fuel costs at the quay are approximately 10% of in-transit fuel costs.

**Considerations** Assuming that the specific HLV, or similar vessel, can in time be deployed for DSM it should only be used for a single task. Either logistics or OT. OT is an almost continuous process. It does therefore not match the single lift concepts for vertical transport. Furthermore, the duration of the horizontal link should not have to correspond to the time required for processing. That is, if processing would even be possible during transit considering power consumption and vessel movements.

The costs for treatment, refining and shipping are acquired from sources in the market. The

costs are rather commercial prices than actual costs. This means that both processing costs as logistical costs could be reduced through longterm agreements or bargaining. This requires The Company to be a large and reliable player in the market first. This means that these costs will be high when DSM commences and can be renegotiated in the following years for example. This does not apply to the costs derived from Nautilus Minerals, since Nautilus reports their in-house OPEX and not a commercial service price. However, for these OPEX it can be assumed that when production increases the marginal costs will decrease and so the costs per ton will decrease.

## 2.4 The concepts of theory

The Dul and Hak research methodology describes two types of concepts. Concepts that are input and concepts that are output. The input concepts are discussed first.

### 2.4.1 Input concepts

The methodology requires concepts that form the input variables while finding relations in the case study to discover the proposition. The concepts follow from the exploratory research phase that is performed in the previous sections. Three concepts are developed based on considerations discussed in section 1.4 and section 2.3. When generating concepts the following constraints or assumptions are taken into account:

1. mining is executed similar to the Nautilus' system.
2. the PSV can not leave the SPTs or the mine site.
3. vertical transport and horizontal transport frequencies must match.
4. OT requires continuous input.
5. OT produces continuous output.
6. in-transit OT is not possible.
7. tailings can be disposed of on the seabed.

Background on the constraints is found in section 1.4 and section 2.3 and usually concerns safety, process efficiency or storage capacity minimization. The PC concepts are built by selecting a vertical transport system, a horizontal transport system and selecting whether or not to do OT. For vertical transport the mechanical repetitive system using a HLV is selected because it is an interesting option for The Company and developments on buoyancy techniques and synthetic cables can allow for this method to be applicable on the required depths. Alternatively, the Nautilus' RALS is considered because it can operate at the desired depths and because of data availability. The HLV is seen as a batch option and the RALS as a continuous alternative. Horizontal transport is done by regular shipping, which is considered a continuous alternative relative to the batch alternative which is the use of the earlier mentioned HLV. Table 2.5 shows the eight possible concepts. The most right column checks if the concept complies with the above-mentioned constraints. In this way the three concepts for theory-building are generated. The continuous horizontal transport suggests conveyor belts or a pipeline. However, in practice, these systems are not feasible both offshore and on the desired distances. For the sake of conceptual thinking, dry bulk shipping is considered as continuous transport due to the higher cycle times with respect to HLV which will operate on a more incidental basis. This concept is

referred to as the single lift option. In this case single lift means that a HLV will lift the ore using a single container at each single lift, but multiple lifts are required in a single cycle.

Concept	Vertical Transport	Offshore Treatment	Horizontal Transport	Conflict?
<b>1</b>	<b>Continuous</b>	<b>No</b>	<b>Continuous</b>	-
-	Continuous	No	Batch	3
<b>2</b>	<b>Continuous</b>	<b>Yes</b>	Continuous	-
-	Continuous	Yes	Batch	3 & 5
-	Batch	No	Continuous	3
<b>3</b>	<b>Batch</b>	<b>No</b>	<b>Batch</b>	-
-	Batch	Yes	Continuous	3 & 4
-	Batch	Yes	Batch	4 & 5

Table 2.5: Concept generation

**Concept 1.** This concept is closest to the Nautilus Minerals PC. It includes a RALS for vertical transport powered by a PSV. The PSV prepares and dewateres the ore for horizontal shipping. Shipping to port is done using conventional dry bulk carriers. Both treatment and refining is done onshore at an (existing) processing plant. Figure 2.11 (page 44) shows this PC concept.

**Concept 2.** This concept includes OT of the ore. This means treatment between 20-60% copper concentrate. Treatment takes place on the PSV because, as discussed, processing time should be decoupled of travel time for horizontal transport, the extra CAPEX for an additional specialized vessel should be avoided and because logistics should be able to fully benefit of the volume reduction induced by OT. This is while assuming that tailings can be disposed of at sea. If this is not a possibility, OT should only be considered if the ore degrades so fast that immediate treatment is required. Treatment needs a somewhat continuous inflow of material. Some equipment requires batch input, however this is when looking at a relative short timescale. The process as a whole, on a daily scale, can be seen as a continuous process requiring a continuous input. This implies that a system such as RALS is required and a single lift alternative is not suitable, since this would imply additional storage on the PSV. Figure 2.12 shows this PC concept.

**Concept 3.** This concept does not include any OT. This implies that an alternative to the RALS can be applied, namely the single lift option using a HLV. The single lift option consists of a HLV that is responsible for the vertical lifting of the ore on an incidental basis. A small basic PSV will control the mining operation while the HLV takes care of both the vertical and the horizontal transport. The advantage of the single lift alternative is that no costs for continuous transport operations are required. The HLV will be on site on a low frequency, which will limit the operational costs for the relatively expensive HLV. Figure 2.13 shows this alternative concept of the DSM PC.

## 2.4.2 Material flow through the PC

Figures 2.14-2.16 show the differences in material flow and the mass of ore in the three PC concepts. It shows how Concept Two reaches a logistical advantage through OT and DSTP.

### 2.4.3 Output concepts: key performance indicators

Output concepts are the variables in the instances (case) where the effects of the input concepts (cause) are measured. The output concepts/variables allow for performance measurements which show to what extent the propositions/hypotheses are confirmed or rejected in future theory testing research. In this theory-building research the propositions have yet to be discovered. An ideal quantitative performance indicator is the measuring of financial performance. The following financial performance indicators are proposed:

1. C1-performance shows both strategic feasibility of the minimal BP and competitiveness of this BP.
2. PC-competitiveness shows the financial feasibility and competitiveness of the PC including the refinery by calculating all production costs and logistical costs.

To measure the performance of the minimal BP, the horizontal transport to the refinery is included as well so that it corresponds to C1-performance. This performance indicator answers the question if the minimal BP *needs* to be expanded to be competitive. The performance of the entire PC is measured because the chain that The Company is part of should be competitive compared to other chains (conventional mining). This is also a general feasibility check for the project. To conclude, both quantitative output concepts are measured by two KPIs:

1. KPI-1: C1-performance [\$/t],
2. KPI-2: PC competitiveness [\$/t].

## 2.5 Preliminary model

The preliminary model is the strategy where the relation between the concepts in a set of instances is analyzed with the goal to discover propositions. Propositions of theory specify the expected relation between concepts. The propositions describe a relation of cause (input concepts One, Two & Three) onto effect (output concepts KPI-1&KPI-2). Quantitative data needs to be generated to determine the value of the KPIs in the set of instances. KPI-1 is measured through C1-performance and KPI-2 is measured through PC-competitiveness. Both can be obtained through a calculation tool. The calculation tool determines optimal logistics for PC concepts One, Two and Three and gives the values for the KPI-measures.

The constraints of a set of instances is put into work into the calculation tool. This information is of practical nature. The calculation tool has two main functions: selecting optimal vessel capacity for the distance (1) and calculating production costs (2). Distance from deposit to port is in both tools a variable input. Table 2.6 shows the input that the tool includes in the calculation. Thereunder the information from the set of instances is used as input constants in the calculation tool as described in the table.



Varying input	Constant		Unit
Distance	PSV to Port		[km]
Shipping	Vessel capacity		[DWT]
Constant input	Constant	Value	Unit
Deposit specs	Initial copper grade	4,0	[%]
	Refined copper value	7.192	[\$/t]
	Production rate	3.700	[t/day]
Equipment OPEX	SPT OPEX	20.130	[\$/day]
	RALS OPEX	23.184	[\$/day]
	PSV OPEX	144.796	[\$/day]
Offshore treatment	Offshore penalty factor	1,7	[-]
	Treatment Charge (TC)	58,8	[\$/t]
	Concentrate grade	30,0	[%]
Shipping	Vessel speed	14,0	[kn]
	HLV charter cost	800.000	[\$/day]
	HLV capacity	300.000	[DWT]
	HLV speed	8,0	[kn]
	HLV loading rate	5.600	[t/hr]
	HLV unloading rate	10.000	[t/hr]
	HLV mooring time	5,0	t/hr]
Storage	Storage cost	0,02	[\$/t/day]
	Storage duration	30,0	[%]
Refining	Refinement Charge (RC)	130,74	[\$/t]
	Refined grade	99,95	[%]

Table 2.6: Structure of the calculation tool

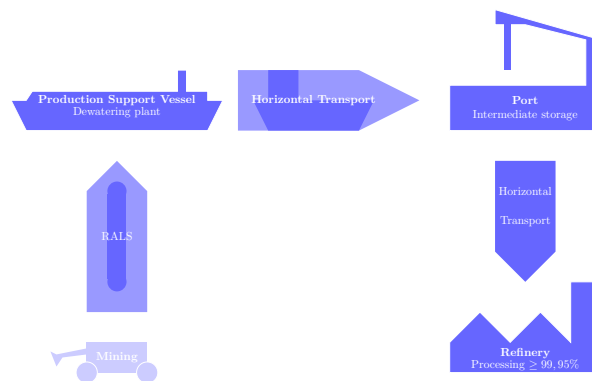


Figure 2.11: DSM PC using RALS (concept 1)

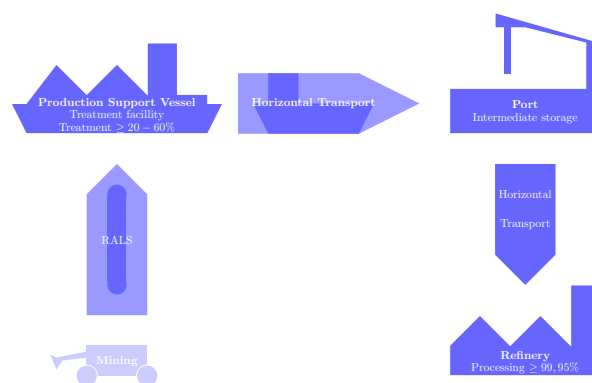


Figure 2.12: DSM PC using RALS and OT (concept 2)

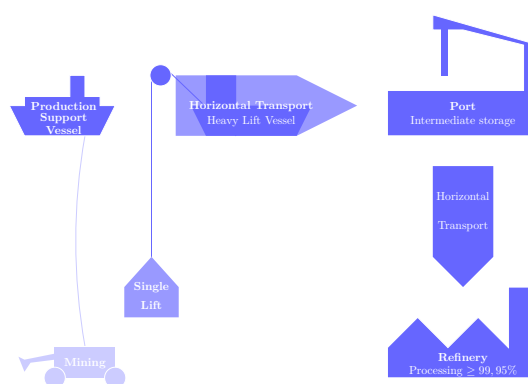


Figure 2.13: DSM PC using single lift (concept 3)

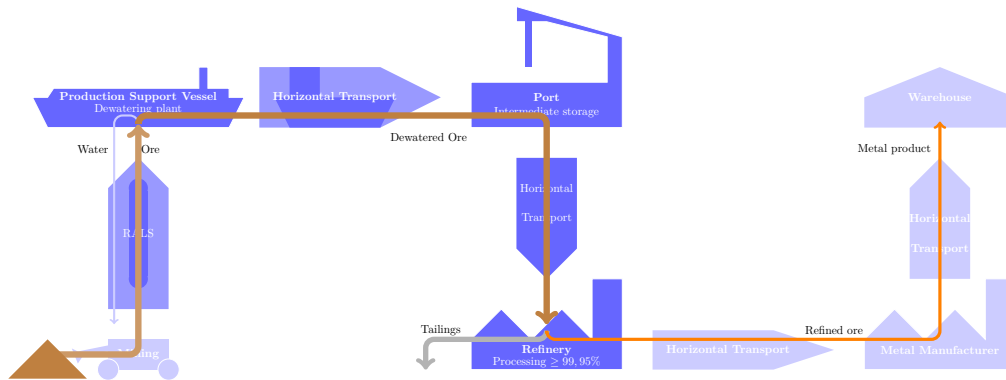


Figure 2.14: Material flow in concept 1 with RALS and bulk carrier shipping

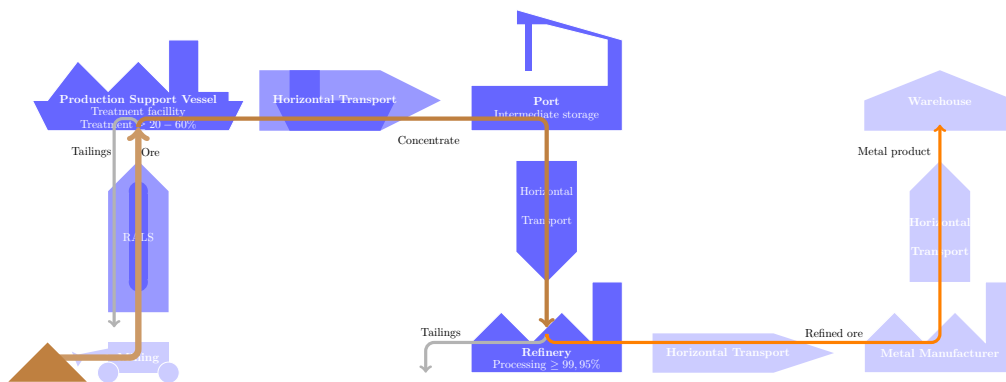


Figure 2.15: Material flow in concept 2 with RALS, OT and bulk carrier shipping

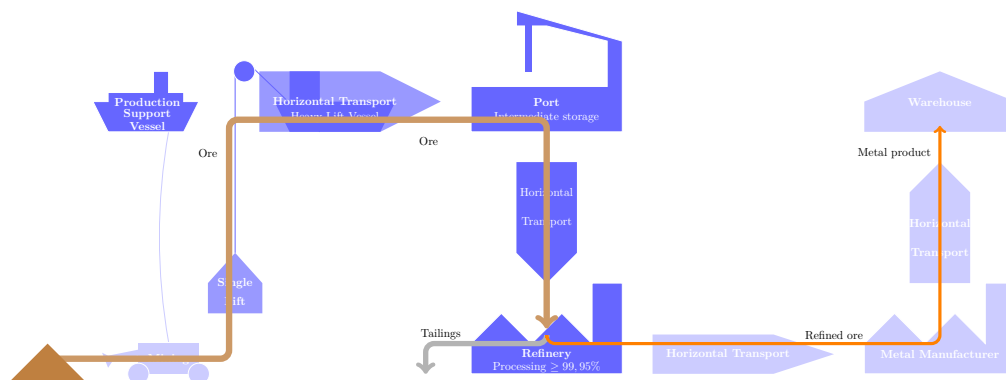


Figure 2.16: Material flow in concept 3 with a HLV for all transport



## Chapter 3

# Case study: concepts relation analysis

This chapter deals with the comparative case study. The aim is to analyze the relation between the concepts (input&output) that eventually lead to discovery of propositions to contribute to theory. Two cases are analyzed. The concepts are now officially called variables. The cases, or set of instances, determine the value of the factors that influence the relation between the variables. First, the Ogasawara back-arc is discussed and thereafter the Trans-Atlantic Geotraverse (TAG) region in the Mid-Atlantic Ridge (MAR).

### 3.1 Case study Japan: the Izu Ogasawara back-arc

This section discusses the case study of DSM of SMS deposits in the EEZ of Japan. The deposits are located 200 up to 1200km heading south off the coast near Tokyo. The situation is depicted in figure 3.1.

**Methodology** The Company internal research on national and international legislation and policy on DSM is used to establish the Japanese position on DSM. The same report also gives an overview on the level of corruption and the ease of market access for a foreign party. The calculation tool is applied on the case of Japan using the actual situational circumstances (set of instances). Logistics will be optimized by finding the balance between vessel size and available ports. Vessel size will not only depend on the calculation tool results but can also be related to the water depths in port. Larger vessels might provide EoS but will also limit the available ports, which could increase the travel distance.

#### 3.1.1 Case specific constraints

The Japanese government is an advocate of DSM. This has various reasons. For instance Japan wants to be less dependent from foreign resources (especially REE from China). Another reason is that Japan has one of the worlds largest capacity of MIPrc. These capital expensive facilities are best to be kept in use and therefore need resources. A legal framework for licensing and exploitation has been developed to attract companies that are interested in DSM.

**Japanese MIPrc location** Japan has three large copper processing facilities according to the United States Geological Survey (USGS) in a report on the risks of earthquakes after the Fukushima disaster in March 2011. Two of these plants are at the east coast and one is in the far northwest. The two on the east coast are marked with the black circles in figure 3.2. The

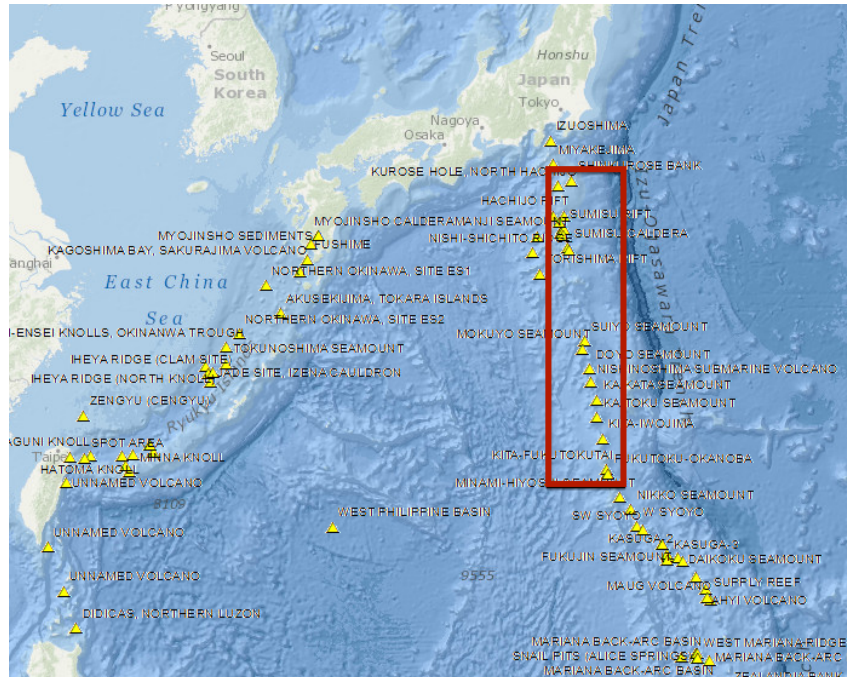


Figure 3.1: The Izu Ogasawara back-arc in the EEZ of Japan [3]

copper processing plant at Iwaki (upper circle) is close to the coast and has a port with dry bulk handling facilities and a water depth of 15 meters, while the second plant (Hitachi) only has a water depth of 11,50 meters. Ports with larger water depths are found in the Tokyo Bay, however there are no copper processing facilities located there. This is depicted in figure 3.3 showing the ports in the region with a water depth of 15 meters or larger and dry bulk handling facilities. This is derived from an on-line overview provided by Maritime Information Services Ltd. Iwaki is the port at the top of the figure.[33][30]

**Charter vessel capacity** The distance from the refinery at the port of Iwaki to the Izu Ogasawara back-arc region ranges from 300 to 1400km. Because the refinery is directly at the port, no intermediate storage costs or hinterland transport needs to be considered. Especially the larger vessels benefit from this, because these vessels would require much more storage capacity. However, since the port has a limited water depth only vessels similar to the Panamax vessels can enter the port. Larger vessels like the Capesize will not be able to enter this port since their draft is larger than 15 meters. Panamax vessels typically have a capacity of no more than 80.000DWT. This means that no larger vessels can be used in concepts 1&2. Concept 3, which would require the HLV to offload in port, is assumed to offload only in the port with the largest water depth. This is the port of Kawasaki (28m), which lies just south of Tokyo on the west bank of Tokyo Bay. This implies that hinterland transport and thus storage is required. Note that concept 3 has a different and closer destination (Kawasaki) than concepts 1&2 (Iwaki) and that concept 3 can also deliver to the refinery in Hitachi instead (over land). Concept 3 needs hinterland transport from the port of Kawasaki which is actually closer (on the same railway line) to Hitachi than to Iwaki. Both Iwaki and Hitachi are accessible via the Joban railroad line that runs along the east coast.

**HLV hoisting speed** The ridges close to Japan are situated at depths around 1300 meters. This is much less than the assumed 4000 meters in the previously shown capacity estimations

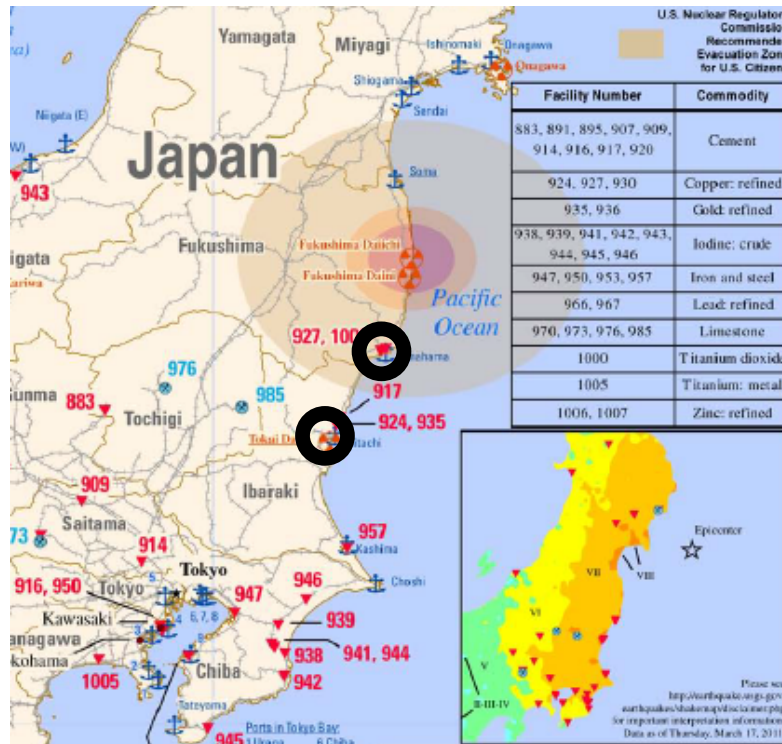


Figure 3.2: Locations of copper processing plants [33]

that represents SMS deposits in the deeper known deposit locations. This has a significant positive effect on the hoisting time of the HLV in concept 3. This can be increased from 2.800t/hr to 8.400t/hr. Hoisting time has a linear proportional relationship with the deposit depth when excluding handling time between descent and ascent and vice versa.

**Copper deposit grade** In the region, data on test samples vary from 0,8% up to 30% copper grades. Also, no research on deposit size is done and data consists of a few samplings only. So no information on deposit sizes is available that would allow to calculate a center of gravity for the region for example. Therefore, since not enough data is available, the Solwara1 low-average of 4% is applied, which has been assumed so far in the report.

### 3.1.2 Analysis of the Izu Ogasawara back-arc case study

The available ports and the water depths put constraints on the vessel capacity choice. Concepts 1&2 can both best use the largest allowable vessel in the port of Iwaki, which is the 80.000DWT vessel. Shipping to Hitachi, and thus using smaller vessels, is slightly more expensive (from a logistics perspective only). Concept 3 can only sail to Kawasaki where the ore needs to be further transported by rail transport to either the Hitachi or Iwaki refinery. This means that intermediate storage is required in the port of Kawasaki. Table 3.1 shows the values of the output variables, the KPI measurements in this set of instances. For both KPI a range is given which corresponds with the minimal and maximal distance from the deposits to the port. For concepts 1&2 this is 300-1400km to the Iwaki port and for concept 3 this is 200-1200km to Kwasaki port. Also the estimated KPI's of Barrick Gold Corporations copper mines are given as well as the estimated performance of Nautilus' Solwara1 project. The costs for refinement are derived from the calculation tool, also in the cases of Barrick and Nautilus. The results show that concept 3 is overall performing best, but is also the most influenced by the distance.



Figure 3.3: Ports with dry bulk handling facilities and a water depth  $\geq 15m$  [30]

Concept	KPI-1: C1-performance [\$ /t]	KPI-2: PC-competitiveness [\$ /t]
One	1.286-1.328	3.217-3.258
Two	3.379-3.385	3.841-3.847
Three	956-1.331	2.887-3.262
Barrick	3.300-5.000	5.200-6.900
Nautilus	766	2.666

Table 3.1: Case study Japan: KPI measurements



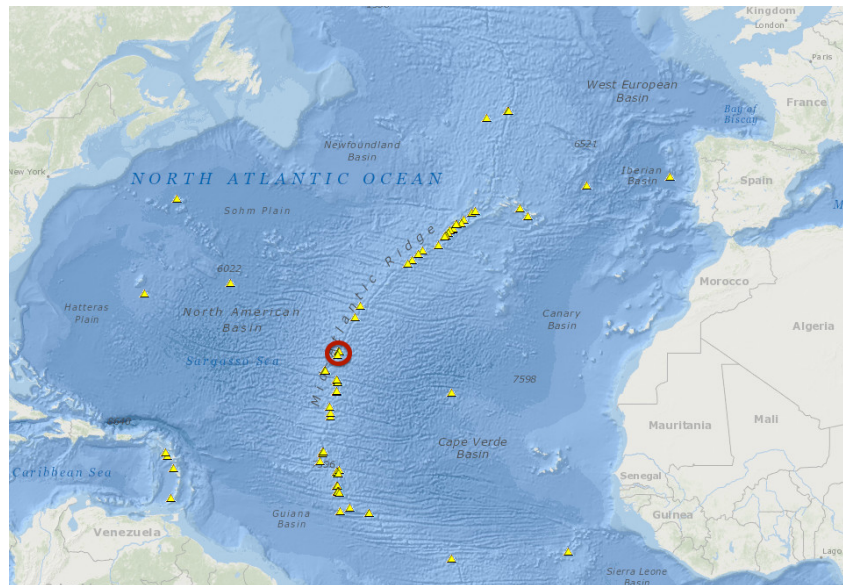


Figure 3.4: The TAG hydrothermal region on the MAR [3]

It should be noted however that these results do not include the rail transport from Kawasaki to one of the refineries in Hitachi or Iwaki. These costs will however not change the relationship between the variables. Concept 2 has the worst C1-performance, as expected since this includes OT while no processing at all is included in the other C1 calculations since it measures costs until delivery at the refinery. However, the processing effort off shore is not earned back in reduced logistical costs or reduced processing costs at the refinery. This results in overall bad performance of concept 2 compared to the other concepts. It is however still able to produce in the lower range of the Barrick C1-performance (3.300-5.000\$/t) and can therefore still be seen as a feasible alternative to conventional mining. But, from a logistical point of view, under these circumstances, concept 2 and OT are not favorable.

### 3.2 Case study Mid-Atlantic Ridge: the TAG region

This section discusses the case study of DSM of SMS deposits in the Area at the Atlantic Ocean. The deposits under consideration are located on the Mid-Atlantic Ridge. This is a hydrothermal region situated in international waters governed by the ISA, which is an UN subsidiary. The MAR lies at a distance of 3.100km of the US east coast and 5.300k away from Rotterdam. The situation is depicted in figure 3.4. The deposit of interest is encircled in the figure. Many of the deposits north of the deposit of interest are lying within an environmentally protected area such as the area around the Portuguese Azores. Deposits located to the south are currently under license by the French research institute IFREMER.

**Methodology** First, global statistics from the British Geological Survey [6] are used to establish which countries qualify to accept copper ore retrieved from the ocean floor. This is done by looking at the balance between their national copper production of mines and refineries and the national consumption. This gives an idea if a country is a net importer or exporter of copper ore and copper products and thus gives an idea if a country would be interested in importing copper ore/concentrate as a resource for either local demand, local copper processing industry or both. The assumption is that countries prefer to protect their current mining industry over

the lower costs DSM might offer. This assumption will only hold in the development stage of DSM, because eventually a cheaper product will outcast the existing one. This step leaves a small number of countries that could still be interested in importing copper products. Next, for these countries the locations of processing plants and available ports is mapped. This gives the required input to run the calculation tool with case specific constraints.

### 3.2.1 Case specific constraints

First all countries that are relatively accessible from the Atlantic Ocean are taken into account as potential destinations. This excludes for example Australia, China or Japan. This list is narrowed down by applying the following filters:

1. net copper importer,
2. copper refinery output of more than 100 kilotonne per annum (ktpa) (This output would require an input of 2,5 mtpa of 4% copper content ore, which gives security that the plants in this country have enough (spare) capacity to process the delivered ore.).

Countries with enough capacity that export copper originated from local mines are excluded because these countries are not likely to import ore from DSM while risking to harm their local mining industry. These filters cause Brazil, Canada, Chile, Mexico, Peru and USA to be excluded.

This leaves two destinations, both in Europe. One is the Aurubis operated copper production plant in Hamburg, Germany. The second is an Atlantic Copper operated plant in Huelva, Spain. Spain has some raw copper ore production. However, Germany has a significant refined copper output whilst not having any copper mines. Also, the operator Aurubis aims at having long-term relationships with their suppliers, specifically mentioning that no intensive, legal ties are favored from their perspective. A viewpoint which is generally shared by The Company, who treasures its own independent position. Furthermore Aurubis is internationally presented with locations in various regions such as Europe, China, Japan, Russia, Thailand, UAE and USA. Many of these locations are sales and distribution centers, which could benefit The Company in their operation. Aurubis does not control its supplies of copper through owned mines and there are no mines close to their European production plants. Therefore Aurubis could be interested in DSM.

### 3.2.2 Analysis of the TAG hydrothermal region case study

The Aurubis production site is located on the north-east end of the Hamburg port on the Norderelbe. The port authorities guarantee a depth of 15.10 meters. The port is located 120 km upstream at the Elbe river, which flows into the North Sea.

#### Logistical options

First the calculation tool is applied to investigate how logistics can be optimized. On such a large distance it makes sense to ship using the largest vessel, since this is generally the cheapest. The Aurubis plant is located in the port of Hamburg so storage costs can be neglected. A problem, however, is that these vessels often have a too large draft for many (inland) ports. An option is to use a large vessel for the long haul and then use a smaller vessel for the last part on the Elbe. However, this causes extra costs for handling. The four most obvious logistical options are (also see figure 3.5):

- a.) transfer in Rotterdam,

Option	transfer location	Distance to MAR [km]	Distance to Hamburg [km]	Port water depth [m]	Optimal vessel capacity [DWT]
a	Rotterdam	5.150	410	22,5	277.000
b	Wilhemshaven	5.500	155	19,0 (=max.)	200.000
c	-	5.655	-	15,0 (=max.)	80.000
d	Elbe entrance	5.500	120	-	287.000

Table 3.2: Logistical options MAR to Hamburg



Figure 3.5: The MAR logistical options overview

- b.) transfer in Wilhemshaven,
- c.) direct shipping to Hamburg,
- d.) floating transfer at the Elbe entrance (figure 2.10).

Rotterdam has the deepest waters (22,5m) of all ports under consideration. Which means that a Valemax vessel (400.000DWT) and the HLV can enter that port for instance. Table 3.2 shows the logistical options and the specifications. Concept 3 has less options than concepts 1&2 since the HLV can only enter the port of Rotterdam or use the floating transfer option at the outflow/entrance of the Elbe. For the transfer port locations, the distance to the MAR deposit and to the plant in Hamburg is stated. Also, for the transfer ports, the water depth is given. In the most right column the optimal vessel capacity, the capacity that results in the lowest shipping costs derived from the calculation tool, is written. Table 3.3 gives more detailed results on these options. Options a.) to d.) apply to concepts 1&2, because these concepts can vary in vessel size so that these concepts can ship to all ports with limited water depth. Concept 3 can only enter the port of Rotterdam (option a.)) and option d.), the floating transfer hub at the Elbe entrance.

Utilization (table 3.3) refers to what percentage of time a vessel is needed. 100% means that a single vessel is required to be full-time operational. In practice multiple vessels will be necessary, since vessels need maintenance for instance. This property is used to convert costs per cycle

Option	Utilization [%]	Shipping costs [\$/t]	transfer costs [\$/t]	Total costs [\$/t]
1a	24,9	124,99	9,31	153,55
1b	35,8	139,04	9,68	158,46
1c	88,4	214,81	-	214,81
1d	25,5	132,93	9,89	151,27
2a	3,3	16,67	1,24	20,47
2b	4,8	18,54	1,29	21,13
2c	11,8	28,64	-	28,64
2d	3,4	17,72	195	20,17
3a	38,5	2.078,20	15,59	2.113,05
3d	40,9	2.209,38	16,57	2.234,39

Table 3.3: Model results of logistical options

Concept	KPI-1: C1-performance [\$/t]	KPI-2: PC-competitiveness [\$/t]
One	1.420	3.327
Two	3.382	3.818
Three	3.028	4.959
Barrick	3.300-5.000	5.200-6.900
Nautilus	766	2.666

Table 3.4: Case study MAR: KPI measurements

(transfer costs for instance) into costs per time unit over a continuous operation. Than two cost items, shipping and transfer, are added together to calculate the total logistical costs. The costs for transfer are estimated at 0,02\$/t according to information on shipping provided in the course *CIE4840 - Freight Transportation*.

The findings of calculating the logistical options give close outcomes. Concepts 1&2 should both apply the option d.) where a floating transfer vessel is used as transfer location at the entrance of the Elbe. This means shipping between the mine and the floating transfer location with a capesize ore carrier of about 285.000DWT and than transfer to vessels with 80.000DWT to sail to Hamburg. Interestingly enough, the results for vessel capacity size optimization between concept 1 and concept 2 only differ 3,6%, while concept 1 ships about 7,5 times more mass of material compared to concept 2. Apparently, optimization of vessel capacity depends mainly on the shipping distance than that it depends on the total demand for transport. Concept 3 should use Rotterdam as a transfer hub.

### KPI measurements

The KPI measures of the three concepts are given in table 3.4. As previously mentioned, also estimates of Barrick Gold Corporations copper mines and Nautilus' Solwaral project are given. The optimal logistical setting from the MAR deposit to the Aurubis plant in Hamburg has been selected for each concept. This leads to options where intermediate transshipment is always part of, because shipping over these distances with smaller vessel, which could enter the port of Hamburg, is not economical. KPI-1, C1-performance, shows that regular dry bulk shipping is much more economical than the HLV. Concept 1 outscores concept 3. This extra costs for logistics, which were already shown in table 3.3, cause concept 3 not to be competitive

Concept \ Case	KPI-1		KPI-2	
	Japan	MAR	Japan	MAR
One	1.307	1.420	3.237	3.327
Two	3.382	3.382	3.844	3.818
Three	1.144	3.028	3.075	4.959
Barrick	4.150	4.150	6.050	6.050
Nautilus	766	766	2.666	2.666

Table 3.5: Case study: KPI measurements

with respect to the other concepts. This also holds in terms of KPI-2, where the concepts is performing closely to Barricks values. Concept 2 (and OT) is not competitive compared to concept 1, however it now outperforms concept 3 and it is competitive with respect to Barricks performance.

### 3.3 Relations between variables

To discover propositions for theory the relations between the variables in the cases is analyzed. The relation between the concepts (variables) refer to how the set of instances and its values for the factors in the calculation tool influence the relationship between the concepts. In other words, it is analyzed how and why the output variables react on situational changes that influence (factors) the input variables. The calculation tool results are analyzed to compare the output variables and the input variables and to determine if a relationship between the variables can be found. The results are also compared to Nautilus' and to Barricks C1-performance to see if DSM is economically feasible under the conditions of this specific set of instances. Table 3.5 summarizes the KPIs for both case studies. Sometimes averages are stated. When interpreting these figures, two general statements are good to consider:

1. Nautilus Minerals only considers a logistical distance of 50km shipping by barges in their C1-performance. This is the distance from Solwara1 to the hub in the Port of Rabaul and not the distance to the concentrator or refinery. This causes unrealistic good C1-performance.
2. It can be safely assumed that Barrick Gold Corporation is a profitable company. However, their KPI-2 approaches the market value of copper, while various cost items such as manufacturing, distribution, tax&royalties, overhead or costs for depreciation/CAPEX are not included in the KPIs. This suggests that Barrick is able to realize production and distribution for much lower costs than assumed in this report, because it is unlikely that the company can cover all these expenses with just the margin that is left when subtracting KPI-2 from the copper market value. Probably, a company like Barrick is able to bargain for better prices than are mentioned publicly in the industry. Both for logistics, processing and manufacturing. This report uses publicly available commercial prices that apply to the outsourcing of processes. While in practice large companies can cut costs through bargaining by agreeing on steady supplies under longterm agreements or by internalizing processes and cutting out the middlemen. These effects can not be predicted, but should be taken into account while interpreting the meaning of above-mentioned values.



### 3.3.1 KPI-1: C1-performance

Clear differences can be noticed between the two case studies and the relation between the concepts. The most striking is concept 3. Concept 3 uses the HLV for vertical and horizontal transport. The vessel is very expensive, but cuts back on the costs on the RALS (which is absent) and the PSV (which only controls the SPTs and does not come in contact with the ore). This causes the concept to have the best performance on the relatively close deposits and to perform much worse on the large distances. Concept 1 is thereafter the most influenced by this factor distance. This is because concept 2 has to ship approximately 7,5 times less material than concept 1 (under the assumptions of OT up to 30% purification and the possibility of DSTP) and therefore shipping cost in concept 2 are lower. Performance is therefore least influenced by increasing distance and increasing shipping costs. KPI-1 of concept 2 is not a very relevant measure because it includes a large cost item for OT. Processing will also increase the value of the material which is not found back in this measure, which makes it hard to compare to other concepts. All concepts remain competitive with respect to Barricks performance in both case studies, but are unable to reach the low production costs that Nautilus expects to realize on their Solwara1 deposit. Concept 2 is likely to be more competitive than concluded from KPI-1 since more value is added within the chain included in C1-performance.

### 3.3.2 KPI-2: PC-performance

KPI-2 shows that an increasing distance does not influence the PC-competitiveness of concepts 1&2 that much. It basically means that the costs involved with horizontal transport using dry bulk carriers are small compared to the costs for mining and processing. For concepts 1&2 distance is not likely to be the limiting factor when assessing the feasibility of a deep-sea mine. Concept 3 clearly shows decreasing competitiveness with an increasing distance. Note that the horizontal distance as well as the vertical distance changes in the same direction in terms of cycle time between the two cases. Concept 3 remains competitive compared to Barrick Gold Corporation.

### 3.3.3 Sensitivity analysis

To find other relations, a general sensitivity analysis is done on the calculation tool to see how the tool reacts on factors which are not changed in the case study. The sensitivity analysis shows to what extent situational factors affect the outcome of the calculation tool by varying all the factors separately. This means that all factors are held constant while one factor is changed with  $-10\%$  and  $+10\%$  to see what the effect on the outcome is. For each input concept, figures 3.6-3.8 show all the factors that have a significant effect on the total revenues. Revenues are calculated by subtracting KPI-2 from the copper market value, which is estimated at a 1-year-to-date average ( $7.192\$/t$ ; February 2014). The average over a longer period results in a higher average, while current copper prices are actually declining. The distance from deposit to the refinery is an important factor as shown in the previous analysis. However the sensitivity analysis shows that factors as deposit copper grade or copper market value have a far larger influence. Also, the impact of processing costs (treatment and refining) are important, where concept 2 is more heavily influenced by the treatment costs specifically since this cost item is higher offshore. Also, the mine production rate influences the total revenues a lot. Especially concept 1, since in the calculation tool OPEX for SPTs, RALS and PSV are not depending on the production rate (as they are based on the Nautilus production rate of  $3.700t/day$ ). Therefore, as production changes these costs do not change while costs for OT (concept 2) or vertical transport with a HLV (concept 3) do change with a changing production rate. Furthermore, concept 3 is

influenced by the characteristics of the HLV such as capacity, vessel speed and charter costs. The vessel characteristics in the other concepts are to a lesser extent of importance.

### 3.3.4 Conclusion

In general the following is discovered on the relations between the concepts:

- Concept 1 shows overall good performance.
- Concept 2 is not competitive over other concepts.
- Concept 3 performs best on a relative short distance.
- The distance from mine to port influence the economics of concept 3 the most and concept 2 the least.
- Logistical costs are a decisive factor for economics in concept 3. Economics of concept 1&2 mainly depend on other factors.
- OT is not economical. This should only be done if other influences than included in the research demand it.
- DSM is in general competitive w.r.t. conventional mining.

**Considerations** Concept 1 is the most robust PC concept to have an overall good performing PC. Concept 1 outperforms concept 2 in any case. External influences such as environmental regulations could force concept 2 to be necessary to execute. But that same environmental regulation would have to allow DSTP while imposing limits on what levels of contamination of the ore to allow to enter the ports, what would make OT necessary in the first place. This could be a conflicting policy, unless the government of the destination favors a Not-in-my-back-Yard (NIMBY) approach where all hazardous activities are kept as far from shore as possible while simultaneously trying to promote the project. Concept 3 performs well (even outperforming concept 1) on the short distances. However, this concept limits the operational flexibility since it is not profitable on a wide range of distances but only the relatively deposits. Also, the joint capacity of regular shipping as applied in concepts 1&2 is expandable as long as the berth capacity at the PSV and the port allow it, while the HLV has a fixed capacity. Furthermore, if concept 1 is expanded with OT equipment it is able to turn into concept 2 with relatively little adjustments. Table 3.3 shows the utilization rate of the vessels. Generally it is assumed that a vessel can reach about 2.000 annual operational hours. This corresponds with a utilization rate of about 23%. For regular shipping, when this percentage is exceeded, it means that an additional vessel is required. If maintenance scheduling is configured to maximize utilization this percentage can be increased, however to a certain maximum. A second HLV is not a realistic option since these vessels are expensive and not widely available in the market and/or owned by competitors. Concept 3 is therefore limited in flexibility. In terms of capacity per cycle and maximum capacity as well as operational distance and operational hours.

In general, the OPEX of DSM is competitive with respect to current conventional mining. Even the least profitable concept 2 will be able to compete since it has competing OPEX while adding more value to the chain and reducing refining costs in the latter part of the PC.



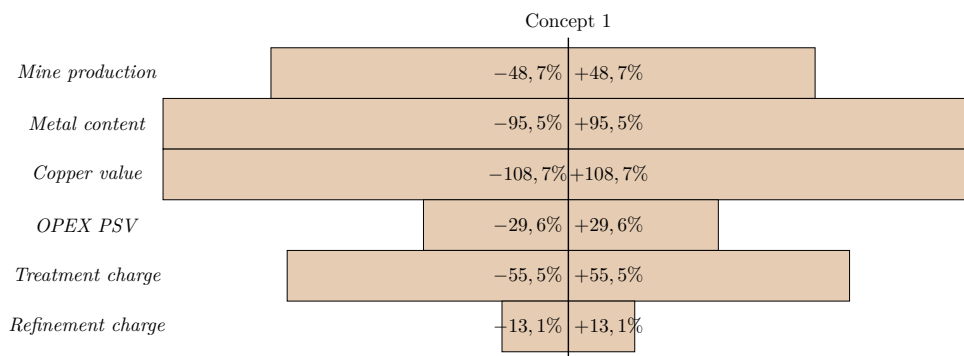


Figure 3.6: Sensitivity concept 1

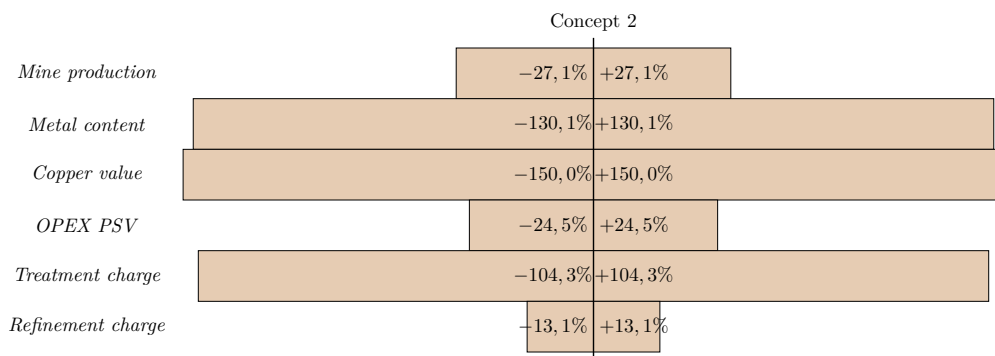


Figure 3.7: Sensitivity concept 2

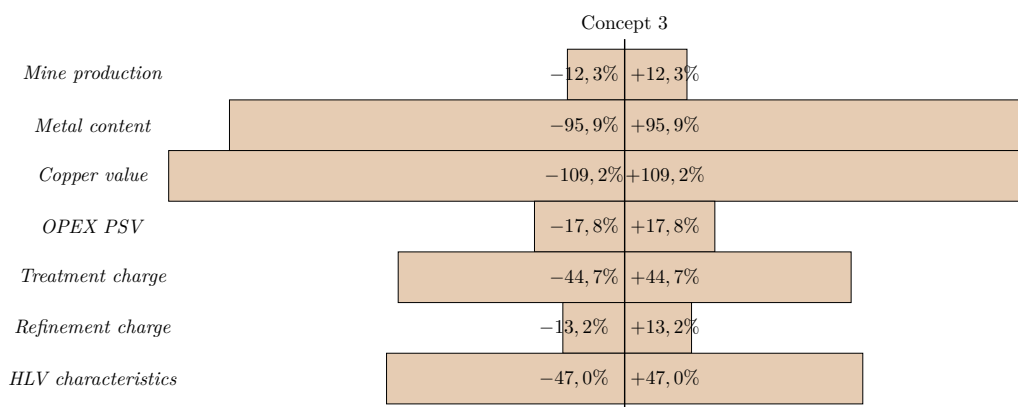


Figure 3.8: Sensitivity concept 3

## Chapter 4

# Scenarios for PC positioning

### Subquestion D: how should The Company execute the copper PC?

The conclusions of chapter 3 are put into practical use in this chapter. The aim is to find out if there is a general Road Map to find out how to execute the PC and if general statements can be found on the position and BP of The Company (contribution to practice). Ultimately, evaluation of the results lead to the composition of propositions (contribution to theory). For both cases it is simulated how The Company could be active in DSM. This is done for two scenarios where The Company positions in the market as:

1. mining company; operating the minimal BP as a contractor,
2. mining integrator; focusing on minimal BP, but possibly expanding the responsibilities.

To do this investigation, appendix E analyzes the actors involved and how to deal with them, possibly by strategic cooperative strategies. The possible strategies are discussed in appendix F. Appendix F shows that the options for cooperation mainly depends on two things: duration and intensity. In terms of duration there are three different parts to consider: (1) cooperation for the exploitation of a single field, (2) cooperation of exploration and exploitation of a region (such as the Izu Ogasawara back-arc region) and (3) a longterm cooperation for the development of DSM industry. Intensity determines to what extent resources, information and technology are shared with partners. The Company typically takes good care to keep in-house developed technology safe, however other knowledge such as exploration data can be shared with other parties. The options are visualized in figure F.2 on page F.2.

## 4.1 Scenarios in the Japanese DSM market

The case study has shown that DSM within the EEZ of Japan is most profitable using concept 3. The disadvantages of concept 3 are its limitations in applicability on larger distances, expansion with OT equipment and the limited shipping capacity (utilization rate). Only shipping capacity can pose limitations, however on the small distances this is not likely to occur. The maximum applicable distance and the absence of OT possibilities is not relevant in this case.

Japanese authorities can deny or withdraw licensing when the mining company exports minerals or applies strategic storage before the domestic demand satisfied. Also, a mining license must be effectuated so 'strategic storage' by postponing the actual mining is also not possible. Because of such regulations the possibilities of exchange platform trading are limited. When mining in Japanese waters, distribution is therefore aimed at the domestic B2B market. Furthermore, the Japanese government is not likely to promote OT while harming their domestic industry, so there is no reason to execute (the less competitive) PC concept 2.

Figure E.3 (page E.9) shows the actor analysis. The figure shows that close relations should be held especially with the national authority. The attitude and policy of the Japanese national authority is generally positive towards DSM, which is crucial in a developing industry where often little parties are unwilling to take the initial risk. Support from authorities can strengthen synergy which will benefit all actors in the PC.

#### 4.1.1 Scenario 1: The Company as mining company

The Company focuses on the minimal BP without the desire to expand responsibilities in the PC. This means that The Company will design and operate the mining equipment including vertical and horizontal transport without processing the ore. The product is *Offer DSM services*, while not being involved in exploration or licensing. This refers to the red boxes in figure 2.1, which shows that only equipment will have to be developed and that the client is a DSM operator. The client/integrator that hires The Company navigates through scheme C.1 (page C.2) from the origin (*acquire exploration license*) to the physical product it offers. In the unlikely case that the client is (the owner of) a refinery the most upward path is followed to the desired product. Most likely the integrator follows the path including *contract processor*. The Company fulfills the box *contract mine operator*.

##### Actors

The advantages of acting as a contractor is that most non-operational responsibilities are not within the scope of works. The actor analysis concludes that especially synergy is important in a developing industry. As a contractor The Company can contribute to this by making equipment concepts and test results publicly available to prove technical feasibility of DSM.

##### Partnerships

The company charged with the actual mining operation is likely to carry the largest investment costs which is a large risk. Therefore, guarantees on work availability are favorable to commence in development and manufacturing of the required equipment. Also, financial support (prepayment) from the client (mining integrator) can be considered. Therefore, longterm agreements with the mining integrator contribute to justification of the equipment R&D for a contractor. The duration of this agreement is long, but the intensity is low because little interaction of (physical) processes is necessary. Figure F.2 shows that *Supply Management* is the most suitable strategy for this situation. *Supply Management* aims at longterm agreements that lead to better performance of the chain while the sovereignty of each individual company is not compromised. Some advantages (figure F.3) are especially applicable:

- Through single sourcing greater business volume and thus lower cost prices are achieved (effect: integrator grants exploitation of other deposits to the current contractor).
- Demands on products and processes to be delivered are mutually defined (effect: client needs are better specified).
- The contractor is consulted about each further development (effect: contractors R&D anticipates clients plans).

#### 4.1.2 Scenario 2: The Company as mining integrator

In this scenario The Company functions as a DSM integrator including DSM itself and horizontal transport (concept 3) to the refinery; the costumer. The Company designs and operates the

minimal BP but seeks possibilities to expand responsibilities. Either in-house or by cooperation. As mentioned, all processing is focused onshore. Trading and strategic storage is restricted because of protectionism. Therefore, downstream responsibilities do not offer benefits to The Company. The expanded responsibilities are therefore similar to those of Nautilus Minerals (figure 2.3; page 28). The Company navigates through scheme C.1 (page C.2) from the origin (*acquire exploration license*) to the physical product *Sell Ore*. The Company has two paths to follow because the implementation of exploration is not defined. Either way, via the red box *operate DS mine* the product *sell ore* is reached.

The question that remains is now limited to the implementation of the exploration functionality. Exploration can be outsourced or developed in-house as a longterm investment. The Izu Ogasawara region is large with a multitude of deposits, furthermore exploration can be applied to other regions as well. Even as a service to others. However, when looking at figure 1.7 (page 7) it shows that all functions except for exploration fit within the Exploitation phase while exploration obviously fits in the Exploration phase. This suggests that exploration is rather a separate business unit than an expansion of the mining operation. Therefore, the investments in R&D of exploration should be justifiable independently of the justification for the investment in the minimal BP. This means that the exploration business unit should be financially healthy if it were an independent company operating it.

### Actors and partnerships

To contribute to synergy, The Company should take the initiative for licensing and exploration of the deposits. As discussed, exploration should only be internalized if the business unit could operate independently. Otherwise, exploration is executed by a contractor. The costumer is the refinery in Hitachi or Iwaki. The agreement is lengthy (duration), but the intensity is low, because little interface is needed between each others processes. This also leads to the *Supply Management* strategy. Additionally (to previous stated advantages) another advantage applies:

- Longterm blanket orders reduce total throughput time (effect: DSM downtime does not (immediately) disturb costumer relationship).

## 4.2 Scenarios for the MAR DSM market

Concept 1 is the favorable concept for exploitation of the MAR deposits. It performs better on the largest distances and offers flexibility in terms of capacity, expansion with OT equipment or the exploitation of other deposits in a different distance range.

Through the network of Aurubis the global market is accessed. When producing in Hamburg, the focus will be on the European market, however open market trading is not restricted. This means that public trade using global platforms and strategic storage is an option.

Figure E.2 (page E.9) shows the results of the actor analysis (developing DSM in the Area). An important element is that the international community, embodied in the UN subsidiary ISA has jurisdiction in the Area. Also, the ISA only allows exploratory or commercial activities to be undertaken with the support of a national authority. The figure shows that the ISA is very powerful and is following the developments closely. National governments have much less direct influence, other than that they have to provide support to DSM companies, if they are interested in securing steady resource supplies or offering a strong national export product such as DSM technology or equipment.

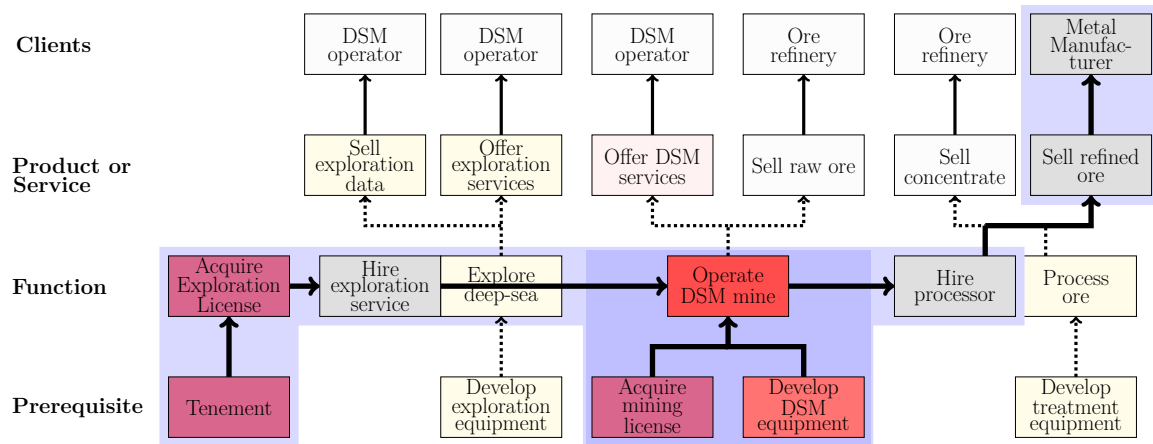


Figure 4.1: Function chain for The Company for the MAR TAG-region

#### 4.2.1 Scenario 1: The Company as mining company

This situation is similar to Scenario 1 of DSM in the EEZ of Japan. A difference is that concept 1 is executed instead of concept 3. Shipping is now executed with dry bulk carriers and shipping is outsourced under longterm agreements to reduce charter costs without owning the vessels. The considerations on actor management and PC strategy are also similar, and thus the *Supply Management* with the same advantages is proposed. Note that this is a partnership with the mining integrator and that this integrator decides where to process or sell the ore. As a contractor, The Company does not influence the PC and therefore the destination could differ from the Aurubis plant in Hamburg. However, all the mainland is located at distances where concept 3 is not competitive compared to concept 1 so the required set of equipment is not altered. The client/integrator that hires The Company navigates through scheme C.1 (page C.2) in a similar way as in Scenario 2 in the previous case.

#### 4.2.2 Scenario 2: The Company as mining integrator

The Company functions as a DSM integrator. As an integrator the responsibilities in the PC can be expanded from the minimal BP towards the upstream and the downstream side. The case study showed that OT does not add value to the PC and therefore concept 1 is executed and all processing is done at the plant of Aurubis in Hamburg. As an integrator The Company holds the licenses for exploration and mining. The previous reasoning whether exploration should be in-house developed is still applicable. Additionally, to receive the support of a national government (which is required for license applications) cooperation with or support from (nationally funded) marine research institutes (MRI) can help accessing this national governmental support. The question is also raised how, now The Company acts as an integrator, the relationship with Aurubis is designed. Unlike the Japanese domestic market, strategic storage and public trading is possible. To stay involved in this downstream part of the PC, the ore should not be sold to Aurubis because that terminates The Company's further involvement. Figure 4.1 shows how the package of functions look likes for The Company in the case of DSM in the MAR TAG-region. The lighter boxes show the functions that are included in the PC that is within The Company's responsibility. The darker box shows the functions that The Company is fully executing autonomously.

## Actors and partners

ISA policy requires The Company to be supported by a national authority. Since Aurubis is originally a German company and the ore will be processed in Hamburg, this is in the interest of German jobs, industry and economy in general. Therefore, it is in the German governments interest to support The Company. Furthermore, the German government has already shown interest in DSM through their support of joint research between universities and MRIs. In its turn, a MRI can be a partner for the exploratory activities to gain access to their network of reliable exploration companies (in case exploration is outsourced), their experience in dealing with the ISA and assistance in drafting of the EIA. And again, the German authorities are likely to support activities originating from their local companies and institutes and simultaneously working actively in securing metal supplies.

To conclude, the German government should be approached to be the national supporter of The Company's DSM project in the MAR region. The German based companies/MRI (exploration, if outsourced) and Aurubis (MIPrc, manufacturing & distribution) should be included in the PC.

## Partnerships

The relationship with Aurubis should be such that joint development of technology is possible so that methods for mining, transport and processing are perfectly aligned. Also, since The Company is interested in responsibilities in the downstream chain, this responsibility should be formalized. The Company can learn about the market and eventually decide to set up distribution autonomously. A *Virtual Organization* (see page F.4) gives these possibilities. A *Virtual Organization* is a structure that can be used for single projects between parties that have a longterm relationship. A *Virtual Organization* can be founded for each project, so that the allocation of responsibilities, obligations and revenues can be adjusted each project. A *Virtual Organization* is a product of a longterm (duration) and low intensity relationship, but on itself it is a short-term and high intensity form of cooperation. Through this cooperative form it is possible for The Company to be involved and learn from the practices in processing, manufacturing, distribution, warehousing and trading in the copper metal market, without compromising the sovereignty of their in-house processes.

A MRI has the knowledge for exploratory works and access to a network of important actors (ISA) and subcontractors. A MRI should be kept close to the operation, without harming its independent position. In that way, a MRI will be able to make a EIA and monitor the environmental effects for example without raising questions on their independent status. The ties between The Company and the MRIs will provide for confidence (or even support) from the authorities, Environmental Agencies (EAs) and the public society. The involvement of the government needs to be formal, because the ISA demands official support from a national authority. The supportive government should therefore be willing and able (legally) to officially support each *Virtual Organization*.

Figure 4.2 shows the structure of this *Virtual Organization*. The hatched areas represent the functions that certain parties have full responsibility for. In practice, in order to work together and to learn from each other, some overlap will be possible.

Because The Company's partners are not likely to be interested in developing DSM tools, The Company's own knowledge will be relatively safe. It should however be carefully negotiated how topics such as intellectual property rights and ownership of licenses are dealt with.

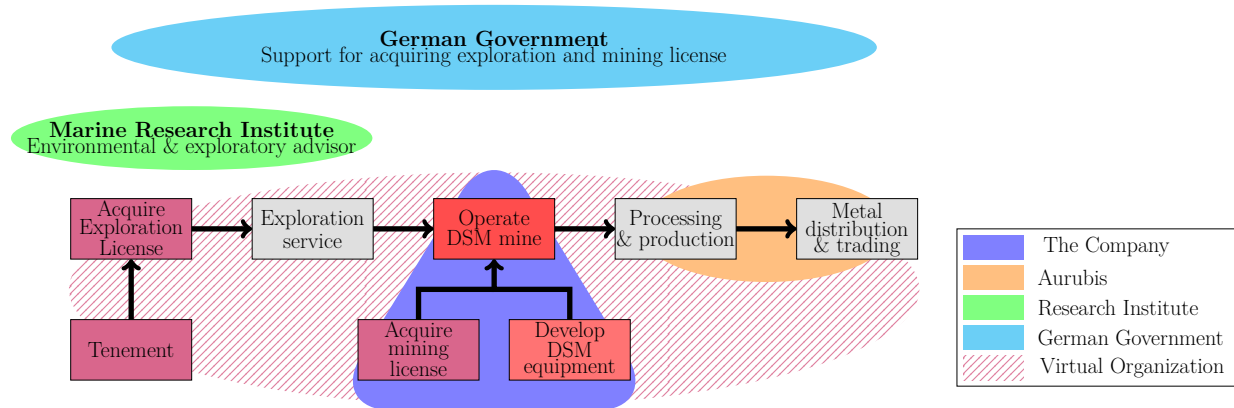


Figure 4.2: The *Virtual Organization* for DSM in the MAR TAG-region

## 4.3 Scenario evaluation and conclusion

**Conclusion to Subquestion D: how should The Company execute the copper PC?**

### 4.3.1 Contribution to practice

Evaluation of the scenarios show the following:

- competent authorities determine the BP range and the possible partners.
- strategy *Supply Management* secures reliable business volume.
- strategy *Virtual Organization* is suitable for more complex, intensive and longterm relations.

The approach of scenarios shows that to build a plan for DSM market entry the following basic steps are taken:

1. determine optimal PC concept.
2. determine if the minimal BP needs expansion.
3. use actor analysis to divide tasks in that BP over The Company and possible partners.
4. search for partnerships.

The considered scenarios for market positioning are actually two possible outcomes of the question-list that is proposed in section 2.2. To have a more general approach (instead of the two scenarios), this question-list is integrated in the above-mentioned steps. The question-list goes as follows:

*The initiative for development of a particular mine site can be:*

1. *with The Company. So that The Company actively searches for deep-sea mine sites. Either through in-house or outsourced exploration. Tenements & licenses are held by The Company,*
2. *with another party. The Company is hired to operate a deep-sea mine site. Responsibilities for licenses and procedures lie with the client.*



Mined ore can be (see figure 2.1):

1. sold to processor,
2. treated onshore or on-board,
3. treated & refined by The Company or by subcontractor.

Logistical trade-offs need to be made on:

1. how to transport the ore,
2. where to process the ore,
3. how to distribute the product.

This leads to a general Road Map to build a plan for DSM market entry:

- Step One: apply calculation tool to quantify KPI-1 and KPI-2 for all PC concepts.
- Step Two: use question-list to determine package of functions and range of responsibility.
- Step Three: apply actor analysis to divide functions over The Company and other actors.
- Step Four: evaluate possibilities for cooperation to streamline market entry.

The Road Map gives a general approach on what steps to take and what methods to apply to find an optimal execution for the DSM PC. The Road Map finds the range of the BP, possible partners and how to deal with them.

**Considerations** Governmental support and partners should be sought in countries with a metal resources deficit. Preferably a nation with a significant MIPrc industry, which guarantees processing capacity, processing experience and demand for resources.

Local circumstances determine to what extent the BP should be extended and what kind of strategy is optimal for that. In short, mining in the Area is restricted to some extent by ISA regulations, however it offers more downstream flexibility. There is a wider range to choose production locations and an open market allows for distribution against the best price as well.

### 4.3.2 Contribution to theory

Inspection of table 3.5 leads to the propositions to theory. The following propositions with the form of a *sufficient* condition are proposed:

**Proposition 1a:** long distances from deposit to refinery is a sufficient conditions for competitive C1-performance of concept 1.

**Proposition 1b:** long distance from deposit to refinery is a sufficient conditions for competitive PC-performance of concept 1.

**Proposition 2:** the distance from deposit to refinery is not a sufficient conditions for competitive C1-performance or PC-competitiveness of concept 2.

**Proposition 3a:** short distance from deposit to refinery is a sufficient conditions for competitive C1-performance of concept 3.

**Proposition 3b:** short distance from deposit to refinery is a sufficient conditions for competitive PC-performance of concept 3.

**Proposition 4:** DSM in the Area is a sufficient condition for worse C1-performance and better PC-performance for concept 1.

**Explanation to Proposition 1a**

Compared to other concepts, concept 1 is expected to have the best C1-performance when exploiting the same long-distance deposit.

**Explanation to Proposition 1b**

Compared to other concepts, concept 1 is expected to have the best PC-performance when exploiting the same long-distance deposit.

**Explanation to Proposition 2**

Distance is not decisive for the performance of both KPIs of concept 2.

**Explanation to Proposition 3a**

Compared to other concepts, concept 3 is expected to have the best C1-performance when exploiting the same short-distance deposit.

**Explanation to Proposition 3b**

Compared to other concepts, concept 3 is expected to have the best PC-performance when exploiting the same short-distance deposit.

**Explanation to Proposition 4**

Due to open market conditions for DSM in the Area, concept 1 is expected to have worse C1-performance (compared to a deposit in an EEZ) but better PC-performance.

## Chapter 5

# Conclusion and recommendations

This study treats the following main question:

**To what extent do production chain concepts influence the composition of The Company's business portfolio and its competitiveness in the deep-sea mining production chain in 2020?**

The first section presents the answer to the main question and the conclusions of the research and the second section gives the recommendations for further research and advised course of action.

### 5.1 Conclusion

#### General conclusion

The production chain (PC) concept of choice influences the competitiveness of the business portfolio (BP) and the PC, but it does not influence the composition of The Company's BP as that is mainly determined by constraints imposed by market conditions and by policies.

It is discovered that the distance parameter of deposits determines the choice between PC concepts 1 and 3. Concept 1 has high base expenses, however shipping is relatively cheap which causes the concept to perform better on larger distances compared to concept 3. Concept 3 has lower base expenses, however the Heavy Lift Vessel (HLV) is expensive in use. This impedes its competitiveness on larger distances. Also, the utilization rate of concept 3 increases with an increasing distance to levels where a second vessel is necessary, which will have large consequences on the investment costs. Because of this utilization rate combined with a fixed capacity of the vessel, the range in terms of transport capacity and applicable distance is limited compared to concept 1. But still, when distance increases, concept 3 shows competitive performance compared to conventional mining.

Concept 2 is also competitive compared to conventional mining, however offshore treatment (OT) has shown not to be competitive compared to concepts 1&3. Therefore, only other parameters than researched could provide the arguments to execute this PC concept. Offshore treatment can be required when:

- untreated ore degrades immediately during transport,
- untreated ore is banned from import.

**Subquestions** The report dealt with the following subquestions:

- A) What are the functions and opportunities in deep-sea mining (DSM)?
- B) What are the strategic considerations that determine The Company's BP?
- C) What technology is available for DSM, vertical transport, metallurgy and logistics?
- D) How is the copper PC for DSM optimally executed?

The Company is in the first place interested in the development of mining equipment. The Sea-floor Production Tools (SPTs) can not function without a Production Support Vessel (PSV). And to have a fully marketable service, vertical transport is included as well. These items form the minimal BP for The Company.

Exploration is the next function that is closest to The Company expertise, however to include exploration services does not offer a wider operational service but rather a new separate business unit. Exploration is an activity prior (in terms of a mine life-cycle) to exploitation. Both are executed under separate licenses. Offering both services to the market does not offer direct benefits, because both activities do not directly influence each other. Expansion of the BP should ideally cause operational efficiency so that lower costs are realized. If a single mine is considered, having both services available automatically means that if one is operational the other is not. Surely, when one is mining, exploration is already done. Business units and equipment should be fully utilized. Unless a role as integrator is pursued and tenements and licenses are also acquired and held by The Company, both elements must be seen as separate business units. Both are required in a mine life-cycle, but at different phases. It is therefore not directly a logical combination of services unless The Company desires to be involved over the entire lifetime of the mine as a mining integrator. In that case, to guarantee a continuous mining operations, to some extent continuous exploration is required as well.

Downstream services on the other hand, contain less interface with The Company's traditional activities and are already offered in the existing mining PC. But these functions can be offered as a direct expansion of the mining service. The relation with the mining operation is evident, however the relation to The Company is less evident. The Company has for example no experience with mineral processing (MIPrc) or the distribution of ore. This is where partnerships can be useful to learn from parties that have the experience on the downstream side, but do not pursue an adventure in mining the deep-sea themselves.

Concept 1 is the most robust PC concept to have an overall good performing PC. Concept 1 outperforms concept 2 in any case. External influences such as environmental regulations could force concept 2 to be necessary to execute. But that same environmental regulation would have to allow Deep-Sea Tailing Disposal (DSTP) while imposing limits on what levels of contamination of the ore to allow to enter the ports, what would make OT necessary in the first place. This could be a conflicting policy, unless the government of the destination favors a Not-in-my-back-Yard (NIMBY) approach where all hazardous activities are kept as far from shore as possible while simultaneously trying to promote the project.

Concept 3 performs well (even outperforming concept 1) on the short distances. However, this concept limits the operational flexibility since it is not profitable on a wide range of distances but only the relatively deposits. Also, the joint capacity of regular shipping as applied in concepts 1&2 is expandable as long as the berth capacity at the PSV and the port allow it, while the HLV has a fixed capacity. Furthermore, if concept 1 is expanded with OT equipment it is able to turn into concept 2 with relatively little adjustments. Generally it is assumed that a vessel can reach about 2.000 annual operational hours. This corresponds with a utilization rate

of about 23%. For regular shipping, when this percentage is exceeded, it means that an additional vessel is required. If maintenance scheduling is configured to maximize utilization this percentage can be increased, however to a certain maximum. A second HLV is not a realistic option since these vessels are expensive and not widely available in the market and/or owned by competitors. Concept 3 is therefore limited in flexibility. In terms of capacity per cycle and maximum capacity as well as operational distance and operational hours.

In general, the Operational Expenditure (OPEX) of DSM is competitive with respect to current conventional mining. Even the least profitable concept 2 will be able to compete since it has competing OPEX while adding more value to the chain and reducing refining costs in the latter part of the PC.

## Contribution to practice

Subquestion D is answered through the development of a general approach. Evaluation of the scenarios to build a plan for DSM market entry lead to the general Road Map:

- Step One: apply calculation tool to quantify KPI-1 and KPI-2 for all PC concepts.
- Step Two: use question-list to determine package of functions and range of responsibility.
- Step Three: apply actor analysis to divide functions over The Company and other actors.
- Step Four: evaluate possibilities for cooperation to streamline market entry.

The Road Map gives a general approach on what steps to take and what methods to apply to find an optimal execution for the DSM PC. The Road Map finds the range of the BP, possible partners and how to deal with them.

Governmental support and partners should be sought in countries with a metal resources deficit. Preferably a nation with a significant MIPrc industry, which guarantees processing capacity, processing experience and demand for resources.

Local circumstances determine to what extent the BP should be extended and what kind of strategy is optimal for that. In short, mining in the Area (high seas under UN jurisdiction) (Area) is restricted to some extent by International Seabed Authority (ISA) regulations, however it offers more downstream flexibility. There is a wider range to choose production locations and an open market allows for distribution against the best price as well.

## Contribution to theory

The following propositions with the form of a *sufficient* condition are proposed:

**Proposition 1a:** long distances from deposit to refinery is a sufficient conditions for competitive C1-performance of concept 1.

**Proposition 1b:** long distance from deposit to refinery is a sufficient conditions for competitive PC-performance of concept 1.

**Proposition 2:** the distance from deposit to refinery is not a sufficient conditions for competitive C1-performance or PC-competitiveness of concept 2.

**Proposition 3a:** short distance from deposit to refinery is a sufficient conditions for competitive C1-performance of concept 3.

**Proposition 3b:** short distance from deposit to refinery is a sufficient conditions for competitive PC-performance of concept 3.

**Proposition 4:** DSM in the Area is a sufficient condition for worse C1-performance and better PC-performance for concept 1.

The proposition formulate the general relations that have been discovered between the input concepts (concepts 1,2 & 3) and the Key Performance Indicators (KPIs).

## 5.2 General considerations

Considering this report and its conclusions, some notes should be made. Because of a limited time frame and limited access to reliable data, many assumption had to be made. This compromises the reliability of the conclusions drawn in the report. This leaves large spaces for uncertainties. This research would therefore best serve as a framework for future research and can be used as a guide to find strategies suitable for comparable situations. The Road Map and the calculation tool offer suitable tools to asses future DSM opportunities. The identified scenarios, principal questions, actor analysis and cooperative structures are ideally used to determine relative effects. The results and conclusion are thus considered to be correct in a qualitative manner and to be used as hypotheses for future research.

Uncertainties occur at:

- Data from the industry. Key figures on OPEX are based on reliable, however few, sources.
- Costs for services can refer to both in-house costs as market prices.
- The analogies made with the oil&gas industry is not a proven methodology.
- The research does not include Capital Expenditure (CAPEX) or costs for research and development (R&D).

## 5.3 Recommendations

First of all, this theory-building research required a comparative case study. The two cases that were analyzed in this research comply with this, however two cases is the absolute minimum for a comparative case study. Therefore, an unrestricted number of additional cases can be analyzed to improve the case study conclusions. This will also allow for testing and improvement of the Road Map that is developed in this study.

The calculation tool allows to differentiate in the parameter distance from mine to port. The sensitivity analysis showed that other parameters such as deposit metal content or production rate have significant impact on the results as well. Therefore, it is recommended that the calculation tool is expanded so that more variable parameters can be added. This will also allow for more extensive proposition testing and the discovery of new propositions to theory based on these new parameters. Furthermore, the costs used in the calculation tool should be continuously updated and improved. Also, the cost items can refer both to actual in-house costs as well as commercial prices, so more consistency would also improve the reliability of the results.

For each unit in the PC a more detailed representation of cost components (maintenance, labor, consumables) would allow for a better analysis in cost control. This especially applies on the costs for offshore treatment. The estimation on offshore treatment costs is based on an assumed

analogy with the offshore petroleum industry. A breakdown on various cost components, would allow for targeted improvement on cost control.

The PC concepts can be further developed. This is best done by researching the technical alternatives for vertical transport and mineral processing. Especially, the impact of varying water depth and the impact of varying metal content (ore density) is not or briefly discussed in this thesis. Also, the developments in the field of buoyancy techniques and synthetic cables, which can benefit the HLV alternative should be closely followed.

As mentioned, next to the minimal BP, The Company has the most affinity to expand the BP with exploration technology. However, this should be seen as an independent business unit. Therefore, to come to a conclusion on this, an separate feasibility study on this topic is required.





## Chapter 6

# Contact information

**Author:**

C.M. Rutgers van Rozenburg

E-mail : coenrvr@gmail.com

Phone : +31616312571

**Company**

The Company

Innovations Department

**Institution**

Delft University of Technology

Master Transport Infrastructure and Logistics

Faculty Transport Engineering and Logistics, Mechanical Engineering, 3mE Faculty

Faculty Transport and Logistics, Engineering Systems and Services, Technology Policy and Management

**Committee members, institution**

Prof.dr.ir. G. Lodewijks

E-mail : G.Lodewijks@TUDelft.nl

Phone : +31152788793

Faculty : 3mE

Ir. M.W. Ludema

E-mail : M.W.Ludema@TUDelft.nl

Phone : +31152781885

Dr. W.W.A Beelaerts van Blokland

E-mail : W.W.A.BeelaertsVanBlokland@TUDelft.nl

Phone : +31152786680



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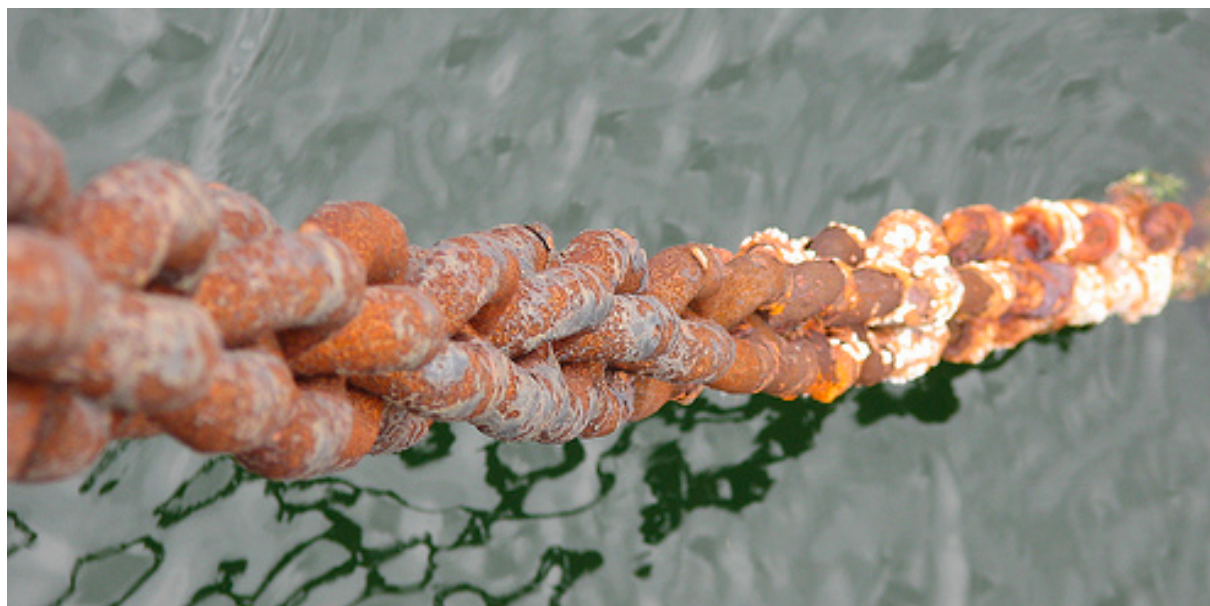
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# APPENDICES

## DEEP-SEA MINING: A ROAD-MAP TO POSITIONING IN THE PRODUCTION CHAIN





# Appendix A

## Copper market background

Section 1.4 discusses and schematized the life-cycle of a mine, the mining production process and the physical locations in the production chain (PC). This appendix provides insight in the global trends and mining market mechanisms.

### A.1 Demand and supply confrontation in the copper market

Table A.1 shows the largest processing copper countries in the world. The volumes are stated in metric tonne (t). The difference in production volumes is partly explained by recycling. Economics and market forces often have to do with demand and supply. For the copper market it is interesting to analyze how this works in practice. Based on data and literature some insight is given.

#### A.1.1 Demand and supply

Prices of commodities tend to fluctuate. Some research has been done, and theories have been developed to predict price fluctuations. However, the future and its economic development remain uncertain. Generally, it is accepted that prices are determined by demand, supply and what people are willing to pay for the product. But this knowledge still does not provide enough information to make a forecast on price levels, or on demand and supply levels. [15] Metal trading does shows to be more predictable than other commodities like agricultural products. Metals do not have a seasonal demand, except for small changes since construction

Country	Smelting	growth '07-'11	Country	Refining	growth '07-'11
China	3.080.100	45,9 %	China	5.197.100	48,5 %
Chile	1.364.200	-11,0 %	Chile	3.092.400	5,3 %
Japan	1.173.300	-17,9 %	Japan	1.328.300	-18,7 %
India	671.300	-4,3 %	USA	1.040.000	-26,0 %
Russia	652.200	0,4 %	Germany	708.800	6,5 %
USA	538.400	-14,6 %	Korea	595.400	5,1 %
Zambia	511.200	128,2 %	Poland	571.000	7,1 %
Poland	481.900	-7,6 %	Zambia	515.400	1,6 %
Korea	449.200	-4,6 %	India	525.000	4,7 %
Australia	441.000	10,5 %	Australia	447.000	7,9 %
<b>Worldwide</b>	<b>13.200.000</b>	<b>7,3 %</b>	<b>Worldwide</b>	<b>19.500.000</b>	<b>9,6 %</b>

Table A.1: 2011 Top 10 countries copper processing [t] [6]



Figure A.1: Copper price since 1983 [\$/t] [24]

is usually planned outside winter season. Metals are also not perishable or do not have a particular harvest season for example. And still, metal prices have gradually rose over the past decades and have shown large volatility, both throughout the years as on a daily basis. As emerging countries keep demanding more resources, the pressure on the supply side will keep rising. On the other hand, the current financial crisis has caused the prices to drop significantly but also recover to an all time high, breaking the records seen in '06-'07. Figure A.1 shows the development of copper prices since 1983. The copper price is stated in \$/t. Clearly the prices have gone up. Not just for copper actually, but the trend is similar for other metals and oil as well. The financial crisis in '08-'09 is clearly visual in the copper price, however a recovery to new record price levels can be seen as well. Figure A.1 also shows that copper prices historically tend to fluctuate significantly, however the general trend has been upwards.

Global figures on copper production and consumption show a growing trend. Table A.2 shows a growing production and a growing demand for the past years (in megatonne (Mt)). Also, discrepancies can be seen in three copper production processes: mining, smelting and refining. Smelting is only an optional part of the production since there are processing alternatives available. So that explains one of the discrepancies. The data shown in table A.3 suggests that refineries are depleting previously built inventories to fulfill the demand, however a secondary recycle inflow is more likely. Refineries seem to follow consumption quite well, while miners are producing much less than consumed (87.7% of consumption). The total average gap (between 2004 and 2011) between mined copper and consumed copper is about 12.3% (table A.3). This amount could be well explained by a recycle flow, however no clear data has been found to back this up.

### A.1.2 Storage

Storage is always part of a production process and supply-chain. Storage is known to be unavoidable, but since it is costly, for production efficiency reasons storage is always tried to be eliminated as much as possible. Inventory is usually not producing any money, while investment (procurement and production costs) and storage costs are already made.

In the mining PC it is cheaper to transport bulk solid material in large (bulk) quantities. This alone imposes necessary storage at the beginning and end of each separate production location,

Year	Mines	Smelter	Refineries	Consumption
2004	14,6	11,2	15,8	16,4
2005	14,9	11,8	16,6	16,2
2006	15,1	12,1	17,2	17,0
2007	15,5	12,3	17,8	18,0
2008	15,6	12,5	18,2	18,0
2009	15,9	16,2	18,3	17,0
2010	16,2	13,1	19,0	19,0
2011	16,2	13,2	19,5	19,8

Table A.2: World copper production [Mt/year] [5][6][18][13]

Year	Mines	Refineries	Mine-to-Consumer
2004	-1,2	-0,6	-1,8
2005	-1,7	0,4	-1,3
2006	-2,1	0,4	-1,9
2007	-2,3	-0,2	-2,5
2008	-2,6	0,2	-2,4
2009	-2,4	1,3	-1,1
2010	-2,8	0,0	-2,8
2011	-3,3	-0,3	-3,6
8y-average <sup>1</sup>	-2,3	0,1	-2,2
supply <sup>2</sup> [%]	87,1	100,7	87,7

1 stock is assumed to be held at the supply side

2 supply fulfillment to next production facility

Table A.3: World copper stock level movement [Mt]



Figure A.2: Copper warehousing typically costs 1,5% of the value per year

since the volume of at least a single transport unit (usually a vessel) is dropped off or picked up. These loads typically do not directly feed from or to the production line. Furthermore, storage is used to decouple different production processes in order to be less vulnerable if supply problems should occur. This is valid both inside a plant on a small scale as on a larger scale between production locations and companies.

A second reason for storage is a financial strategic one. The owner of the inventory might think the value of the inventory will increase. However, storage can be costly and large inventories can also cause the prices to drop instead of rise. In the case of strategic storage, inventory is actually considered to be able to create (more) value. Strategic storage can be a matter of days, however since metals do not deteriorate over time if stored correctly, this could take much longer as well.

### Storage costs

Literature on costs for stockpiling resources mentions a general figure for annual storage costs of about 4% of the inventory value. Research on the storage costs of the London Metal Exchange (LME) base metals has indicated some figures on storage costs for base metals in the LME warehouses across the globe. The article states a global average for 6 base metals (Aluminum, Copper, Lead, Nickel, Tin and Zinc) of 1-5% of the value per year of the stored material in 2011. For copper a 2011 global average is given of 0,367 \$/t/day. The 2011 average price of 3-month futures for copper was \$8824 per t. So when using these figures, the storage costs for copper are about  $\frac{(0,367\$/t/d \cdot 365d)}{8824\$/t} = 1,5\%$ . This source only included the LME approved warehouses, but these are very numerous in most regions where trade takes place, except for China. [20][19][24]

### A.1.3 Copper Push-market and decoupling point

Table A.2 and table A.3 show that when consumption was dropping in 2009 (and growth was stalling in 2008), this had hardly effect on mine output or refinery production. Especially in 2009 the refineries overproduced about 1,3Mt of copper. This suggests that the mining industry works with consumption forecasts, that obviously did not foresee the financial crises that caused the copper consumption to drop. It suggests a forecast driven PC, that pushes the products to the market and is not able to react on (sudden) current developments. The analysis has already shown that the products are collected in the warehouses ran by the trading platforms.

The warehouses show a clear decoupling point, where demand meets supply and movement of products is driven by customer needs instead of suppliers forecasting. This means, since The Company is not likely to engage in commodity trading itself, that The Company will only be active in a PUSH PC based on demand forecasts. Furthermore, copper, in all its forms, has characteristics that do not get outdated or become less desired by customers because of similar or improved products. This means that the product does not lose value because customers become less interested in the product. Also, market value of metals is volatile however products closer to the end-market are more valuable regardless the travel time or production time. The time element in the PC is therefore not influencing the revenues or costs, other than costs for stockpiling, warehousing and other time related logistical cost items such as travel time.

## A.2 Conclusion

The most interesting is that the copper industry produces and distributes copper to the warehouses close to the market based on demand forecasts. This suggests a PUSH-market with the decoupling point in the warehouses of the trading houses.

Also, literature shows that the storage costs in the LME warehouses are 1,5% of the value annually. This means that storage costs move with the market value of copper. So when prices drop and intuitively one wants to wait for better prices on the product, storage cost drop too allowing longer storage time. Similar it will be expensive to store metals when prices are high (because demand is high & inventory low). Consequently, as prices are high and suppliers are pressed to sell their products because of rising storage costs, prices stabilize again because suppliers put their stock on the market. This works in both ways.

From the analysis of market behavior and supply-demand confrontation in the copper metal market, the following can be concluded:

- The copper PC is a PUSH chain up to the warehouses. The warehouse is also the physical decoupling point where client orders influence the product movements
- The time element in the PC does not influence product revenues, because market prices fluctuate independently of the time-length of the PC
- The time element in the PC is only found back in costs for storage
- Warehouses and distribution locations are located at the selling markets





## Appendix B

# Nautilus Minerals

Nautilus Minerals is a company owned by several shareholders including large mining companies (incl. Mawarid Mining LLC, AngloAmerican and Metalloinvest). Nautilus explores the sea-floor and holds several tenements for the exploration and exploitation of offshore areas, mostly within the Economic Exclusive Zone (EEZ) of Papua-New Guinea (PNG). Nautilus is prospected to commence the mining operation at Solwara1 in the next five years. Nautilus is also involved in the development of nodule mining near Tonga through its wholly owned subsidiary Tonga Offshore Mining Limited. [35] An example of the deep-sea mining (DSM) process is described schematically by Nautilus Minerals in figure B.1. It shows the process as it is proposed by Nautilus Minerals for their Solwara1 project in the EEZ of PNG. The mining process has been visualized from mining of the ore to shipping the concentrate to the refinery. As mentioned, the term *concentrate* applies to treated ore with a concentrate of 20-60% content. In this case that is copper.

### B.1 Mining process

The mining concept is visualized in figure B.2. The production chain (PC) starts with ore excavating. Nautilus will use three Sea-floor Production Tools (SPTs) to do that. Sub-sea, and especially at increasing depths, human activity becomes a serious challenge due to issues such as high pressure, oxygen supply or the use of power tools. Also, combustion is challenging due to the absence of air supply for instance. Therefore, the use of remotely controlled (electrically powered) vehicles is required. The mining process consists of three SPT mining tools that are powered by a Production Support Vessel (PSV) via umbilicals.

The mining process starts with the *Auxiliary Cutter* (AC), that prepares the surfaces for the two other machines. Then the *Bulk Cutter* (BC) cuts the material and leaves it on the seabed for the *Collecting Machine* (CM) to pick up. Figure B.3 depicts concepts of the three SPTs. The machines are currently being build by Soil Machine Dynamics Ltd. (SMD). Figure B.4 shows the *Bulk Cutter* at their production facility in Tynesdale. [35][45] The *Collecting Machine* crushes the ore and pumps it via a flexible hose into the *Raiser and Lift System* (RALS).

### B.2 Vertical transport

Between the SPTs at the sea-floor and the PSV a vertical transport system is required to transport the ore to the sea level. The RALS is a vertical slurry pump system that pumps water and ore up to the PSV.

## B.3 Production Support Vessel

Inherent to the use of SPTs is the use of a PSV. SPTs need electrical power supply, monitoring and control from an external source. The PSV in the Nautilus' case, is responsible for power supply to and control of the SPTs and the RALS. Furthermore, it has initial ore treatment equipment. Next to power supply and control of the equipment, it also needs to be able to launch and recover as well as store and maintain the equipment. In this case, treatment equipment means dewatering equipment and water treatment equipment so it can be pumped back to the sea-floor. The treated water is pumped back to the sea-floor via a second, smaller pipe attached to the RALS. It is stated by Nautilus this will prevent contamination of the water column above, which is a rich fishery source for the local community. The PSV also has handling equipment to load the ore onto the transport barges.

## B.4 Horizontal transport

Horizontal transport is done by barges. Because barges can be put aside the PSV and be picked up when filled by a tugs, the PSV needs minimal storage space, since it can offload in a barge continuously.

The Nautilus' concept seems to be focused on a fast throughput and low storage levels. The RALS is the first proof of that. This is a continuous system, keeping storage at the input size to a minimum, provided that the mining SPTs have a continuous output. Using a pipeline for vertical transport requires the material to be crushed to optimal particle sizes on the seabed. The PSV dehydrates the ore and then ships it by relatively small barges (high frequency, low capacity&storage) to the nearest port, minimizing the required storage capacity at the PSV. At the port ore is stored again in higher volume and shipped to a concentrator. This shipping is over a longer distance, using larger vessels and thus with a lower frequency. These choices made by Nautilus are specifically for this situation.

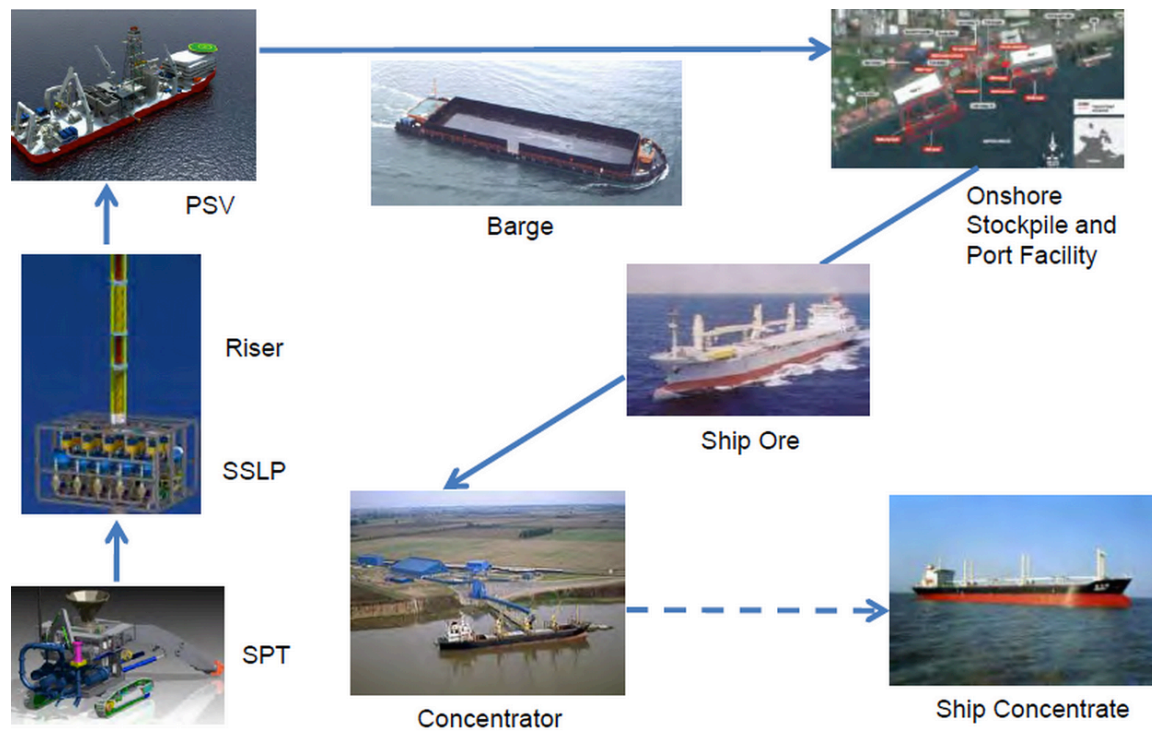


Figure B.1: Nautilus Minerals' DSM PC overview [35]

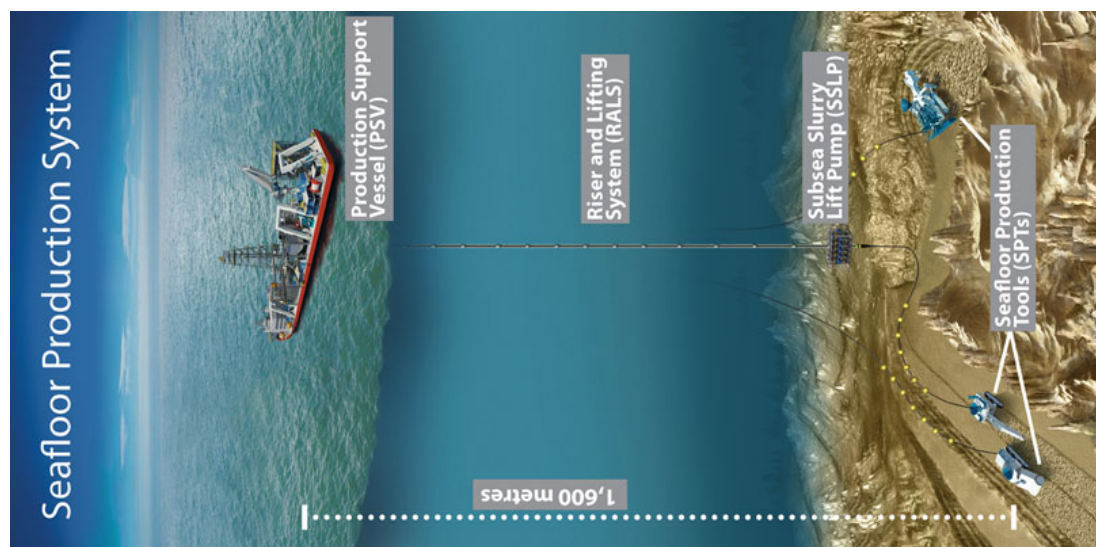


Figure B.2: Nautilus Minerals' DSM concept for Solwara 1 [35]



Figure B.3: Nautilus Minerals' SPT; top to bottom: AC, BC, CM [35]



Figure B.4: Nautilus' *Bulk Cutter* at SMD production site [45]

## Appendix C

# Functional analysis

This appendix contains the function analysis of the deep-sea mining (DSM) production chain (PC). After describing the methodology, the first section starts with some products and services that can be offered to this industry. Furthermore it states what functions relate to these products or services and what the preceding steps are to meet the requirements for fulfillment of these functions. It is also made visual what functions can easily be combined with other functions. For instance because of similar requirements. The second section analyzes the functions using several analysis tools. It results in advantages and disadvantages of (combinations of) functions so that the options can be compared. The conclusions are discussed in the main text in chapter 4.

**Methodology** The PC analysis in chapter ?? has already introduced the main functions in the (deep-sea) mining PC. These functions and the underlying processes are further investigated and captured in diagrams. These diagrams show the functions and the products that can be offered to the industry. Furthermore these diagrams show how the development of these products is realized and what other products can be offered simultaneously because of a similar approach and set of requirements.

### C.1 Identification of business opportunities

This section uses various diagrams to visualize the products and services that can be offered to the DSM industry and the functions that relate thereto. Furthermore it shows what steps need to be taken in advance before this product can be offered to the industry and what other products have a similar stepwise approach. The diagrams show what choices need to be made and what the consequences of these decision can be.

First an overview of products and functions is given together with the development tree that shows what is needed to realize the products. From this diagram several breakdowns are made that give a more detailed view on product categories or a backwards analysis is shown to see what developments are required for a particular opportunity.

#### C.1.1 The DSM market product range

Figure C.1 is a diagram that captures the primary products and the underlying functions in the DSM PC. The process of any DSM product (or service) is assumed to start with the acquisition of an exploration license (or a tenement of that area). Being the owner of a exploration license provides certain rights to the owner. These can be sold or used. Being the explorer or the holder of the exploration license grants an advantage when applying for the following mining license,

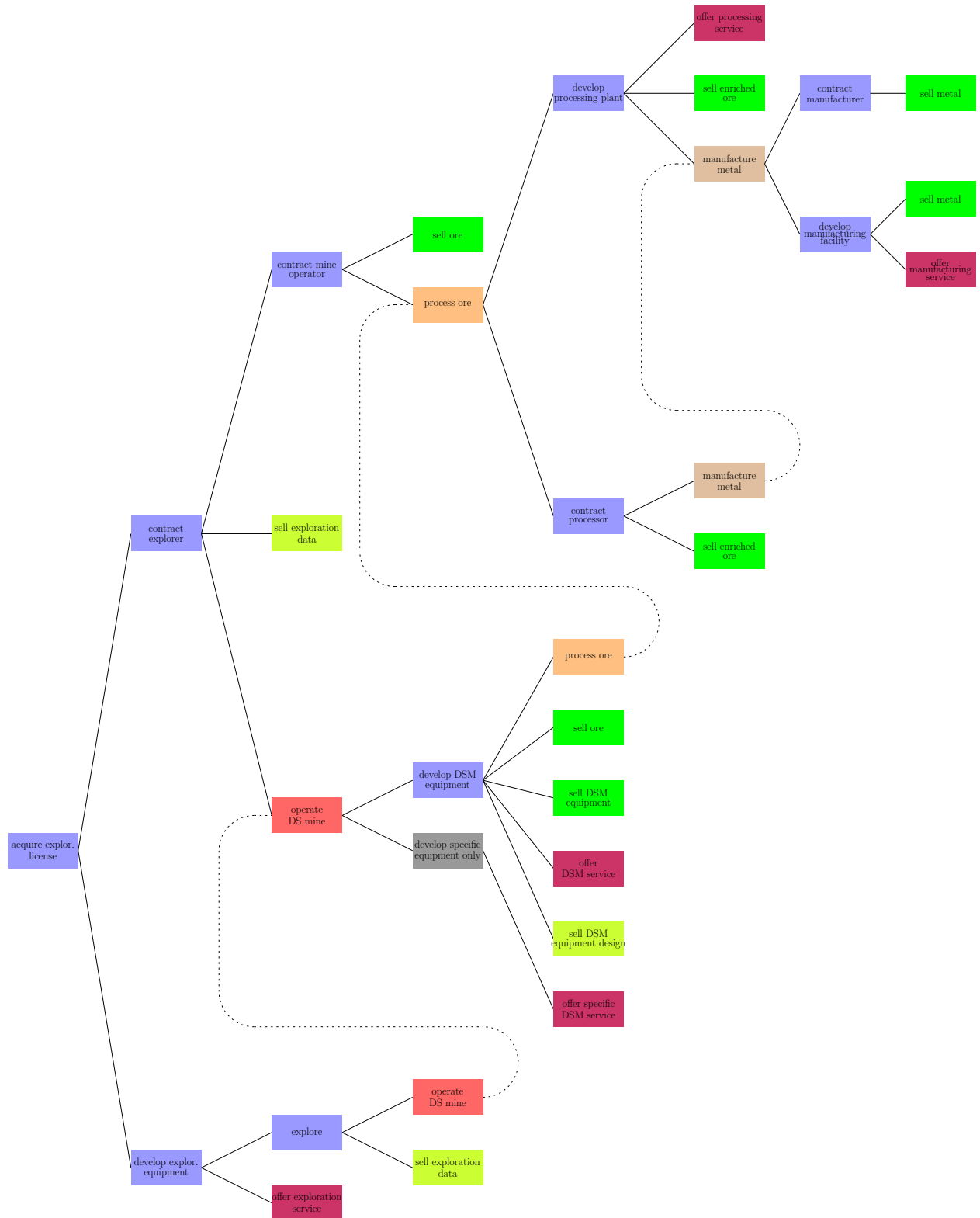


Figure C.1: Overview of marketable products and the development process

in case a potential exploitable deposit is found. So if the desire is there to mine, acquisition of tenements and exploratory licenses is a good start.



To read the diagrams properly, the following explanatory notes are relevant:

- **Blue block:**  
An activity and a decision point for the next step
- **Green block:**  
A physical product that can be offered to the industry
- **Purple block:**  
A service that can be offered on a contractor basis
- **Lime block:**  
An incidentally marketable product such as *exploration data* or *equipment design*
- **Gray block:**  
The activities that lead to *partial DSM equipment* development
- **Orange block:**  
The activity *process ore*. A key decision point that occurs on multiple places in the decision tree
- **Red block:**  
The activity *operate DS mine*. A key decision point that occurs on multiple places in the decision tree
- **Brown block:**  
The activity *manufacture metal*. A key decision point that occurs on multiple places in the decision tree

This diagram shows for example all the possible routes towards sales of *enriched ore*. It also visualizes what other products are relatively easy to offer 'along the way' of bringing enriched ore to the market. If for instance the most upper *enriched ore* is selected as main product, this figure shows that offering *mineral processing* service makes good sense because the activity *process ore* is required anyway. And from a strategic point of view this also makes sense because now efficiency, and thus the profitability, of the processing plant is decoupled from the companies own ability to supply the plant with sufficient ore, since third parties now supply ore as well. And before this goal of selling processed ore is reached, *ore* and *exploration data* will have been possible, temporary sources of income to finance the development of the processing plant. Furthermore, if for instance the decision is made that operating a deep-sea mine (the red block) is the main activity it is quickly seen that there are two routes to take. One while hiring an explorer and one by developing exploration services in-house.

This diagram does not include the possibilities of buying (or acquiring otherwise) the necessary resources (knowledge, equipment or supplies for instance) to acquire a position and skipping some stages at the left-hand side of this diagram. It therefore assumes The Company to be rather an upstream (exploration & mining) focused company than a downstream company. However, the diagram still suits its purpose even when acquiring preceding steps differently than stated in the diagram.

Figures C.2 to C.5 are derivatives of figure C.1. The figures use the same colored blocks and can be read in a similar way. Figures C.6 to C.9 are also derivatives but show the same process backwards, thus not taking the *exploration license* but the marketable product as the starting point.

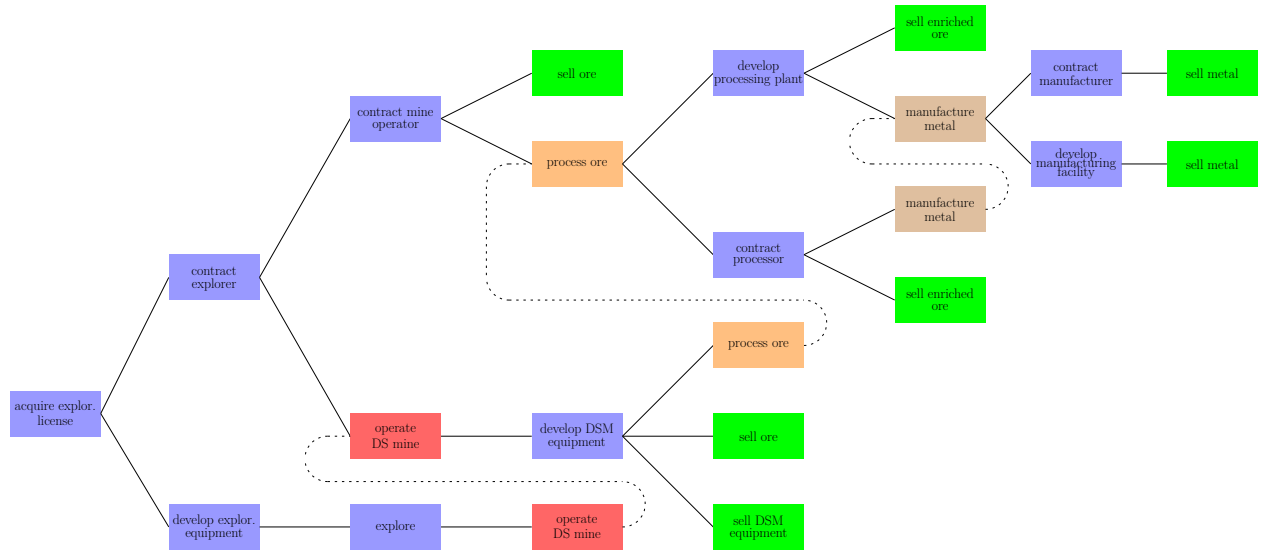


Figure C.2: Development process towards sales of physical products

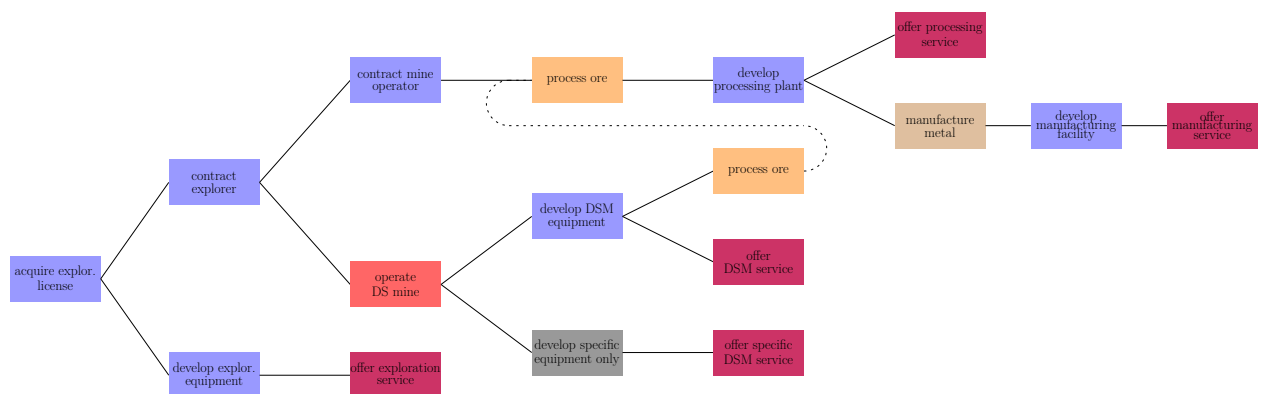


Figure C.3: Development process towards sales of services

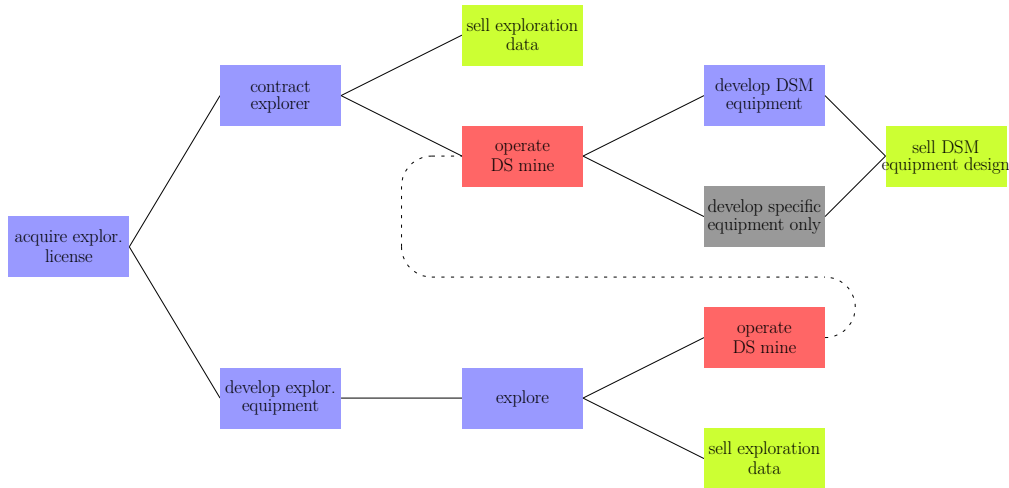


Figure C.4: Development process toward sales of knowledge and data based products

### C.1.2 Decision process towards different products and product types

Figure C.2 shows the activities and decision points that lead to all the physical products that are included in figure C.1) that can be offered to the industry. It is basically a simplified tree that only considers the products *ore*, *refined ore*, *metals* and *DSM equipment*.

Figure C.3 only shows the activities and decision points that lead to services that can be offered to other DSM companies directly active in the primary functions, such as exploration, mining and mineral processing (MIPrc).

Figure C.4 only shows the activities and decision points that lead to sales of *exploration data* and *DSM equipment design*. These are products that are not likely to be produced on a large scale. In a sales deal it will probably be demanded by the buyer that the knowledge will remain confidential between the seller and the buyer. And the buyer of knowledge usually only needs it once. However, there are situations possible where a long-term relationship is possible. For instance when many modifications of the equipment design are necessary when new fields are developed. And also exploration data can be processed or assessed by the company so that different products are created that can be sold to different parties with different interest. The sales of data can easily lead to new data set requests.

Figure C.5 show examples of the activities and decision points that lead to feasible combinations of products and services. It can be wise to offer a combination of products and services. For instance because some products can be offered in a early stage or maybe it makes other processes more efficient because of larger throughput volumes for instance.

### C.1.3 Reversed approach of the business opportunities

Figure C.6 shows a backward approach taking the sales of *metals* as the starting point. Bringing *metals* to the B2B market is the farthest downstream step that is considered here. The other three physical products (*ore*, *refined ore* and *DSM equipment*) are also depicted as intermediate starting points. The required activities and decisions required for each product are visualized. Figure C.7 shows a backward approach of how to realize the services that can be offered to companies active in the primary functions of DSM. The required activities and decisions required for each service are visualized.

Figure C.8 shows a backward approach taking the sales of *exploration data* and *DSM equipment design* as starting points. The required activities and decisions required for each product are

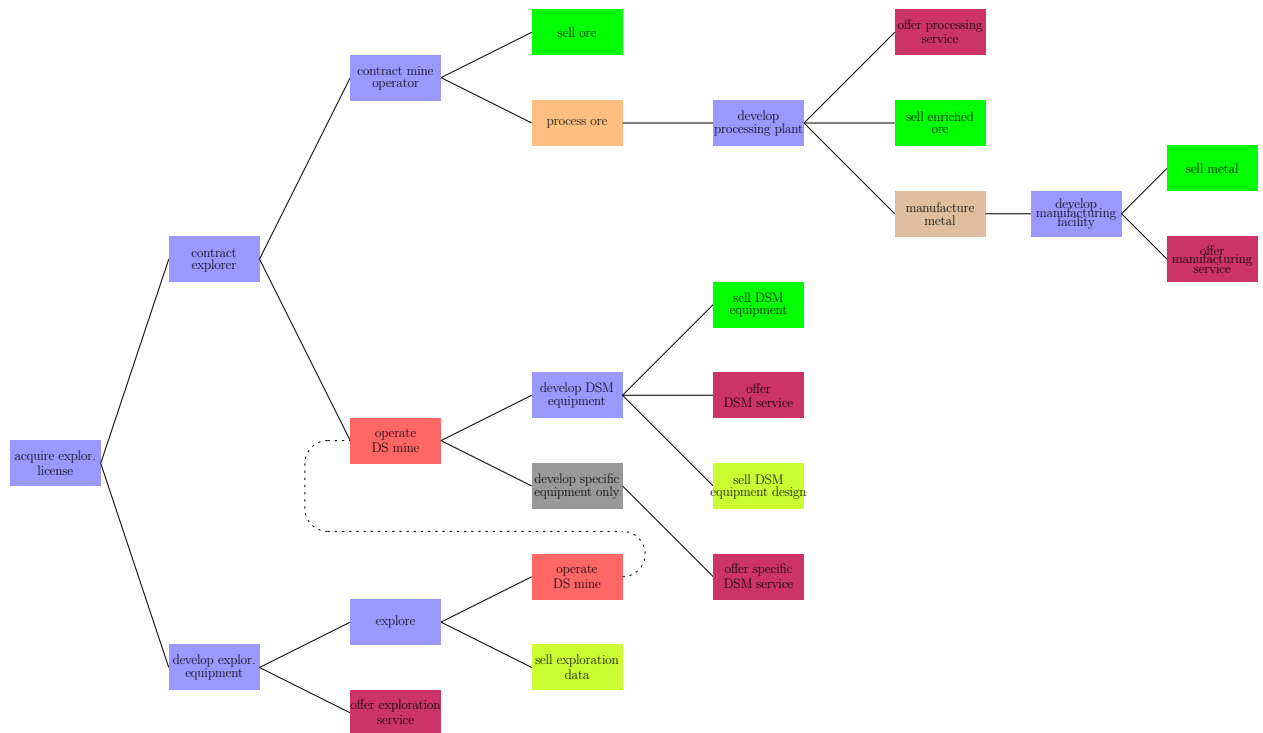


Figure C.5: Overview of development process toward sales of multiple product types

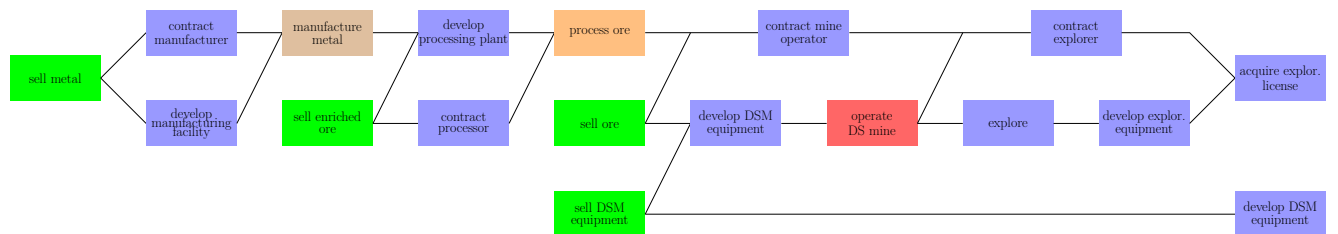


Figure C.6: Backward development process toward sales of physical products

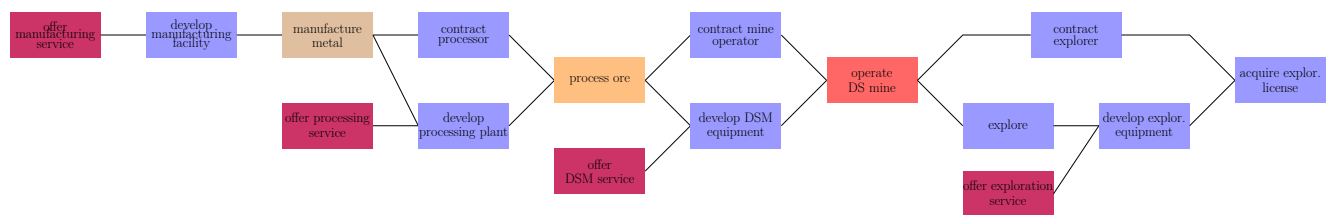


Figure C.7: Backward development process toward sales of services

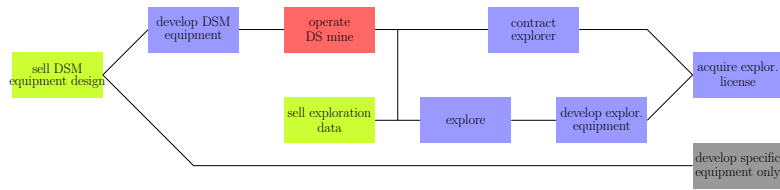


Figure C.8: Backward development process toward sales of knowledge and data

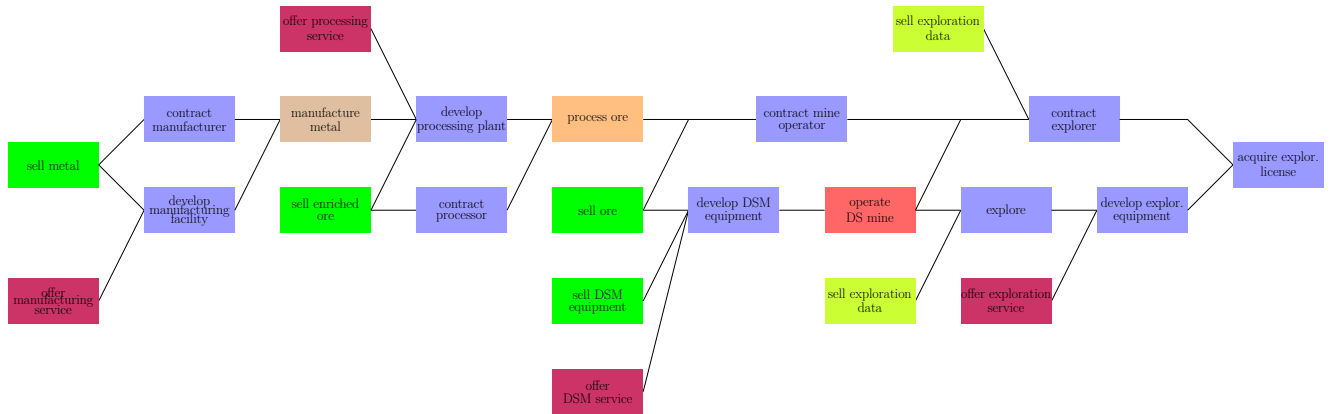


Figure C.9: Backward development process toward sales of multiple product types

visualized.

Figure C.9 shows a backward approach of how to realize some examples of feasible combinations of products and services. The required activities and decisions required for each product and service combination are visualized.

## C.2 Analysis of business opportunities

This section evaluates the information captured in the figures shown in the previous section. Each activity or function is discussed as well as the decisioning it involves and the products and services it enables.

### C.2.1 Products & services

The following physical products are considered:

1. ore
2. refined ore
3. metals
4. DSM equipment

The following services are considered:

1. exploration service
2. DSM service
3. specific DSM service

4. ore processing
5. metal manufacturing

The following incidental products are considered:

1. exploration data
2. DSM equipment design

**Ore** Ore is the material that is mined. Ore remains ore as long as it contains minerals that are going to be extracted for commercial purposes. If it no longer contains something of value to the company it turns into waste material or tailings in mining industrial terminology.

Figure C.2 shows that there are three routes to bring ore to the market. The first decision is how to obtain a mining license. This can be done through in-house exploration or by outsourcing exploration. Afterwards it is decided if the mine is operated in-house or that an operator is contracted to do so. Either way, the mined ore will become the companies property. In-house exploration and mining requires equipment and personnel. Obviously, this requires much more investments of time and money. However, this way the operation will be more independent. To outsource activities it also requires a party that offers those services. Equipment, exploration data and licenses can also be acquired by procurement or cooperation with other companies. When ore is brought to the market, the PC could end for a mining company. However, that same ore can be processed by the mining company as well.

**Enriched ore** Enriched ore (concentrate) is ore that has been processed. The content of the material(s) of interest, the metals that can be sold, is increased. This can be done through various (chemical) processes. Typical grades of ore can be below 1% (outer rings of land mines) or up to 15% (in the case of rich deep-sea deposits). Enriched ore grades can be up to 99.95% (refined ore) for instance, which means it is ready for metal manufacturers to use.

The sales of this product appears six times in figure C.2. That is because there are basically three decisions to make concerning in-house development or outsourcing. These are exploration, mining and processing. All three activities need each other but for each function separately it can be decided to outsource or not while keeping the control of the entire production process and remaining ownership of the materials flowing through the processes. However, all functions can be performed all together or separately without owning the material and offering the services to other parties.

Instead of selling the enriched ore, the enriched ore can be processed further as well into metal products.

**Metals** The production of metals suitable for the business-to-business (B2B) market is assumed to be the final product that can be delivered to the market. Therefore, this product requires the most preceding steps and has the most different routes to delivery. It appears 12 times as a end-product, because for each way towards enriched ore (which appeared 6 times) there is the choice again between in-house development or outsourcing.

**DSM equipment** Instead of the primary mining products like ore and metals, mining equipment can also be delivered to companies that operate mines. It is not included in figure C.1, but in fact this applies to every other function such as processing ore for instance. However, since The Company is rather a upstream focused company, these options are not included in the overview.

The possibility of selling the equipment follows from exploration etc. However if just the sales of the equipment is the companies focus, these steps are not required. Only the development of the equipment will be required to sell these products. But if the sales of equipment is a secondary product next to in-house operating of deep-sea mines for instance, than the left-hand side of the decision tree is applicable (figure C.6).

**Exploration services** Exploration service is the service of deep-sea exploration to search for deep-sea deposits that are adequate for commercial exploitation. Exploration can be offered as a service on contract basis (this actually does not even require that the license is obtained by the company itself) or to collect data. This data can be used for own use (DSM development) or it can be collected and processed and sold as a data set for specific applications (deep-sea mining, research, petroleum industry).

**DSM services** Instead of owning the material that flows through the production process, it can also be decided to offer services for that production. For instance DSM services. It actually only requires the development of DSM equipment if this is the core business of the company. However, if it is a byproduct of DSM development for instance, the left-hand side of figure C.1 is required to pass.

**Specific DSM services** Instead of offering all the DSM services it can be decided to specialize in a particular aspect, such as vertical transport.

**Ore processing** Ore processing can also be offered as a service to owner of ore. It can be seen as core business (which will not require the left-hand side of figure C.1) or it can be seen as a byproduct of the private operated processing plant. In both cases, (new) methods to effectively process the deep-sea mineral ore will have to be developed.

**Metal manufacturing** Similar to ore processing metal manufacturing can be offered as a convenient byproduct or as core business. However, it is not likely that The Company will only be involved this far along the production process (in the case that metal production is the core business). Nevertheless, it should be considered as a possibility.

**Exploration data** see *Exploration services*.

**DSM equipment design** see *DSM equipment*. Instead of the equipment only the design is sold. This can in principle only be done once. However, the knowledge is still in-house so clients will have to return for modifications etc.

## C.2.2 Functions

The following functions are the functions that can be developed or operated in-house. For each of these functions there is a similar outsourced function. When something is developed and operated in-house it is of course possible that external companies have been consulted in the development and design of specific aspects.

1. explore
2. operate DS mine
3. process ore



#### 4. manufacture metal

**Explore** Exploration is the search for potential mining sites. It can also be used to gather additional data that can be of interest for other parties. Exploration requires an exploration license. Exploration can lead to a data set that can be sold or it can be used to identify mining sites for own development. In that case, being the holder of the exploration license gives great advantage in acquiring the mining license as well. Exploration services can also be offered on a contract basis. And exploration data or exploration services can be purchased as well if outsourcing is favored over in-house exploration.

**Operate DS mine** Operating a deep-sea mine includes all activities necessary to get and keep the mine running. This includes development (or other ways of acquiring) the necessary equipment, personnel, supplies, licenses, budget etc. This can be outsourced or developed in-house. Operating a deep-sea mine will produce ore that can be sold or further processed. If the necessary equipment and knowledge is developed, this can be offered to the market as well. The equipment itself, the design or the mining can be offered as a service. These products actually can be developed and offered independently of operating a deep-sea mine.

**Process ore** Ore processing is the next industrial step after the ore is mined. It basically includes similar considerations as for operating a mine.

**Manufacture metal** Metal manufacturing is the next industrial step after the ore is processed. It basically includes similar considerations as for operating a mine and processing the ore.

To conclude, there are three basic strategies to operate in the market and a combination of the three.

1. **Material Owner:** at some point the material (or license to obtain the material) is acquired and at some point a product is sold. All the processes in between are outsourced. Income is generated when the products are sold.
2. **Process Owner:** at some point the material (or license to obtain the material) is acquired and at some point a product is sold. All the processes in between are developed and operated in-house so that the material that flows through the processes and the processes itself are fully controlled by the company. Income is generated when the products are sold.
3. **Process Contractor:** all or some processes are offered to Material Owners. Income is generated through payment for a provided service.
4. **Combined strategy:** many scenario's are possible that cause strategies to end up at a mixture of the three roles stated above.

## Appendix D

# Copper processing value chain of mineral processing

Each production step along the production chain (PC) should add value to the product. Analysis on processes, process costs and added value is called the value chain analysis. The value chain for copper enrichment is analyzed according to data collected from Ironoreteam.com [46] that collects data on metal transactions across China. This data provides daily figures on transactions including copper for different copper grades. Because this is data on spot prices and actual transaction, it excludes all the external effects included in pricing acquired from trading houses like the London Metal Exchange (LME). Through calculations this data is converted into a ratio that shows the mineral processing (MIPrc) costs for different copper content ranges. And since the Chinese market involves about 40% of the world market, these values are considered to be representative. The assumption is that price differences for different copper contents directly reflect on the MIPrc costs involved with the increase in copper content. This means that any other cost items such as labor costs, energy prices, taxes and procurement costs for supplies are assumed to be stable. Figures D.1-D.3 show examples of the data provided by Ironoreteam.com on January 29, 2014. Analysis has been done on data on January 27, 28 and 29 of 2014, to evaluate daily fluctuations. September 16, 2013 was included to have an end-summer benchmark to account for any seasonal fluctuations and January 4, 2013 for a year round dataset. Data similar to figure D.1 has been collected for the other dates mentioned

Copper Ore & Concentrate Prices in China on Jan 29, 2014			
Copper Ore CNY/MT(Metric Ton)(China market prices)			
Specification	Price	Origin	Remark
Cu=5% As<0.5%	1310	China	17% VAT not included
Cu=10% As<0.5%	2800	China	17% VAT not included
Cu=15% As<0.5%	4500	China	17% VAT not included
Copper Concentrate CNY/MMT(Metal Metric Ton)(China market prices)			
Specification	Price	Origin	Remark
Cu=25%	40800-40986	Inner Mongolia	17% VAT included
Cu=25%-27%	40848-41790	Shaanxi	17% VAT included
Cu=19%-20%	38124-39312	Hunan	17% VAT included
Cu=20%-25%	40406-41086	Liaoning	17% VAT included
Cu=20%-25%	40718-43236	Yunnan	17% VAT included

Figure D.1: Different copper grade transaction in China [46]

Spot prices of 1# refined copper in China on Jan 29, 2014				
Specification: Standard Copper Cathode, conforming to GB/T467-1997, Cu <sub>Ag</sub> >=99.95%				
Date	Regions	Price (CNY/mt)	Average	Change (CNY/mt)
2014-01-29	East China	50700-51100	50900	100
2014-01-29	North China	50900-51150	51025	10
2014-01-29	South China	51000-51100	51050	-50

Notes:

1. Price in east China: mainstream transaction prices in Shanghai and Shandong regions;
2. Price in north China: mainstream transaction prices in Tianjin region, with prices in its neighboring areas as a reference;
3. Price in south China: mainstream transaction prices in Guangdong region, with prices in its neighboring areas as a reference;

Figure D.2: Refined copper spot prices in Chinese regions [46]

Transaction prices of copper in China on Jan 29, 2014				
Date	Regions	Price (CNY/mt, tax included)	Average	Change (CNY/mt)
2014-01-29	Standard-grade copper	50700-50900	50800	130
2014-01-29	High-grade copper	50900-51100	51000	50
2014-01-29	Hydro-copper	50680-50780	50730	170
2014-01-29	Guixi brand copper	50950-51100	51025	65

Notes:

1. Standard-grade copper:  
Imported: Chile (CCC-P), Poland (small plate), Korea(ONSAN), Zambia, Philippines, USA, Brazil, Norway, Belgium, Kazakstan, India  
Domestic: Dajiang (Daye Nonferrous Metals Co., Ltd.), Shangye, tiger (Shanghai Dachang Copper Industry Co., Ltd.), Jinchuan, Honglu (Baiyin Nonferrous Metal (Group) Corporation), Ningbo Jintian, Datong, Zhongtiaoshan, Huludao, Sanjian (Penghui Copper Industry Company), Xiangguang
2. High-grade copper:  
Imported: Chile(CCC, ENM, AE), Poland (large plate), Japan(MITSUBISHI, OSR, SR), Peru  
Domestic: Guiye (Jiangxi Copper Company), Tiefeng (Yunnan Copper Company), Jintun, Jingchuan (high purity), Copper Crown (Anhui Tongdu Copper Stock Co., Ltd.)
3. Hydro copper: Chile (CDA, CMCC, MB, MV, QB), Peru (SPCC), Australia (ISA)

Figure D.3: Transaction of different high-grade copper [46]

Copper content	5%	10%	15%	23%	99,95%
29 Jan '14	4330	4627	4958	5753	7196
28 Jan '14	4330	4627	4958	5753	7187
27 Jan '14	4365	4795	5071	5756	7181
16 Aug '13	4346	4738	5011	5688	7266
04 Jan '13	4686	5071	5349	5586	7892

Table D.1: Chinese prices for copper ore grades [\$/Mt]

Content[%]	5>10	10>15	15>23	23>99,95	5>99,95
Content increase ratio	2,00	1,50	1,53	4,33	19,99
Added value ratio	1,08	1,06	1,11	1,31	1,66
Normalized value ratio	14,3	10,7	19,6	55,4	100,0
Cost effectiveness	0,54	0,71	0,72	0,30	
Normalized cost effectiveness	0,56	0,42	0,42	1,00	
Effort distribution [%]	23,2	17,6	17,4	41,8	100,0

Table D.2: Copper processing ratios

above. The prices in the first three rows (5, 10 & 15%) in this table relate to the value of a metric tonne (t) copper content and not to the batch size of the actual ore. So in the case of a 5% copper content for instance, to compare this to the prices given in the lower part of the table and the tables in figures D.2 and D.3, these prices need to be divided by 0,05 to retrieve the value of a t of ore. Next to that the values need to be converted from the Chinese currency Renmibi (RMB) (or CNY) to United States Dollar (\$) according to the exchange rate on that specific date for comparison to LME prices. Also, some prices are presented including a 17% value added tax (VAT) and need to be converted to net prices for reasons of comparison. So dividing the values by 1,17 to calculate the net value at 100% excluding VAT. Furthermore, the information from the lower part of the table in figure D.1 is averaged into a price for a 23% copper content. Also, all prices from figures D.2 and D.3 are averaged to have one price relating to common high-grade certified refined ore, which means a copper content of at least 99,95%. Rearranging and converting the available data, has led to the information given in table D.1. The transactions at all of the dates allow for value chain analysis. For all dates the ratio of content increase is calculated. This is simply dividing the new content by the previous content grade. So  $\frac{10\%}{5\%} = 2,00$  and so on. This is the same for each date since the grades presented in the data are equal for each date as well. The value increase ratio is calculated by dividing the new value of the ore with the higher content by the value of the lower grade ore. This has to be separately calculated for each date and for each grade increase. The findings are evaluated for disturbances and then averaged and presented in table D.2. By calculating the average results, first the results from 27<sup>th</sup>, 28<sup>th</sup> & 29<sup>th</sup> of January 2014 are averaged and then averaged with the other two dates. This way, the data from January 2014 will have equal influence on the final result as the other data. The ratio for value increase is divided by the ratio for content increase and that provides us with a dimensionless number that relates the value increase to the content increase within a certain content range. For this data these ranges being 5%-10%, 10%-15%, 15%-23% and 23%-99,95%. This value increase ratio can be called the cost effectiveness of copper processing under the assumption that profit margins are constant and all other fluctuations influencing production cost are considered constant as well. In that way the relative value increase can be directly related to the production costs. The cost effectiveness ratios in table D.2 show that processing is most expensive in the highest range. This is explained because

the required methods become much more sophisticated when higher content grades need to be met and quality control of the process becomes much more crucial. It is striking that the first range, that of 5%-10%, is more cost consuming than the two middle ranges, 10%-15% & 15%-23%. This is most likely to be explained by the lowest range of processing including size reduction steps that require enormous amounts of energy. The two middle processing ranges do not include size reduction while increasing the copper content is relatively easy compared to the latter range.

The cost effectiveness ratio is then normalized to ease further calculations and an effort distribution is calculated. This shows for instance that in the first range only 8% value increase (14,3% of the total value increase) is reached while spending 23,2% of the processing budget.

These figures provide insight in how the cost of processing behave, however copper ore from the deep-sea mine often contains higher grades, but would still need size reduction for further processing. Therefore, the costs for size reduction will shift to the higher ranges, if the ore extracted from the seabed already contains ore grades over 10%.

CRU, a global consultant for the mining and metal industry, provides data on global averages for Treatment Charge (TC) and Refinement Charge (RC). TC is the costs for initial processing of the ore. CRU considers processing up to a 30% content to be treatment. Refining then includes the processing up to standardized minimum of 99,95% content grade. This is a much more intensive process and that is seen back in the RC. Over 2011 CRU states an average TC of 58,83 \$/t and RC of 130,74 \$/t. [47][2]

## **D.1 Costs for offshore treatment**

To determine the costs for offshore treatment (OT), first the cost for regular MIPrc is determined. Because it is needed to relate these costs to the ratio's earlier mentioned, the data is collected from China as well. To determine the costs for OT the costs are assumed to be directly convertible from China's refineries. A disadvantage of OT could be the loss of the economies-of-scale (EoS) effect where large volumes cause the production cost per unit to decrease. The advantage is that after processing the total size to be transported will be decreased. However a greater tailings flow will be created simultaneously. So the total logistical costs are assumed to decrease, while the logistical cost for processing (supply of consumables, waste disposal) will increase.

The United States Geological Survey (USGS) reports in their mineral's yearbook 2010 on China [48] a combined output of the 21 largest copper refineries of 4,83 megatonne per annum (mtpa). This gives an average output of 230 kilotonne per annum (ktpa) per plant. The USGS also mentions an average refinery charge of 157\$/t over the years 2009-2011 between BHP billiton and one of the largest Chinese refineries TNMG.

### **D.1.1 Floating Production, Storage and Offloading vessels (FPSOs)**

FPSOs are vessels that can be used for the processing of oil and gas instead of production platforms at offshore oil or gas fields. This is for example favorable for deep-water oil wells. In the case of a common oil reserve, the production aspect includes the separation of the substance into natural gas, crude oil and water. Three basic components of any oil reserve. The gas is sometimes used to power the vessel, but this requires expensive equipment suitable for this. FPSOs are usually equipped with the typical flare installation that is seen at refineries to torch the excess of low-value gases. Because the vessels are more mobile, the lifetime can be expanded since the vessels can service multiple fields in different areas. Furthermore, a FPSO can be preferred in areas with harsh weather conditions such as an increased risk of cyclones.

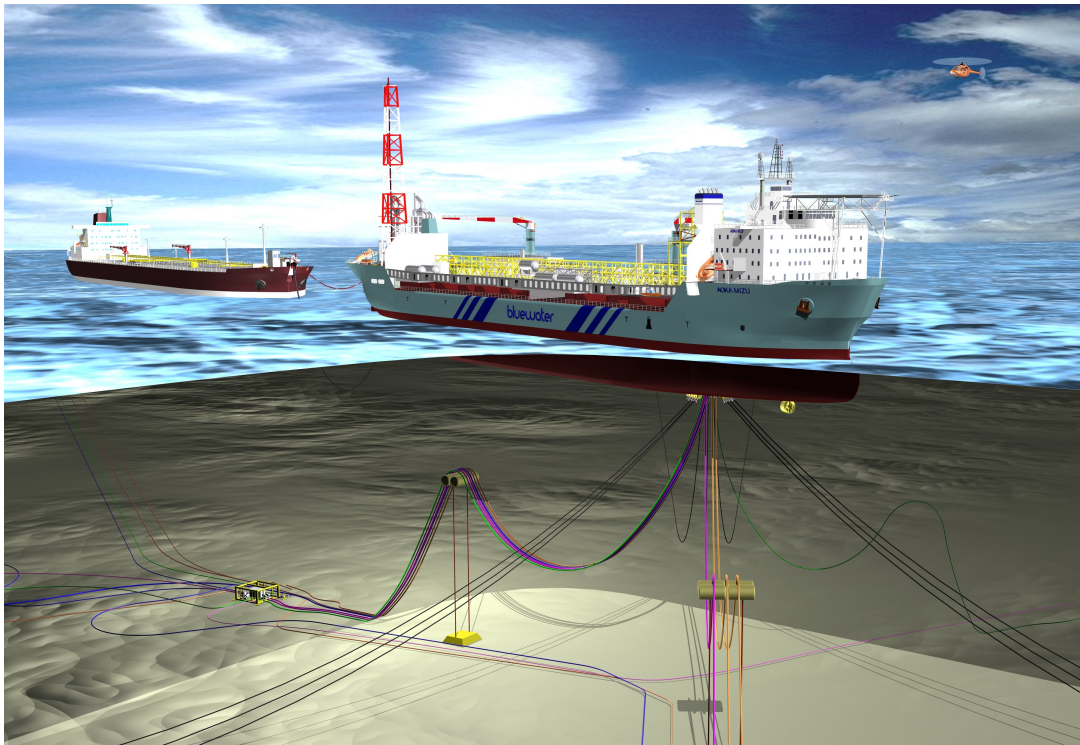


Figure D.4: Typical FPSO setup [4]

This is because a FPSO is equipped with a separate turret that is connected to the wells and thus if the vessel disconnects with this turret, weather conditions no longer threaten the system as a whole. The vessel is also able to rotate freely around the turret so it can always position itself in the optimal direction with respect to wind and wave conditions and the vessel will not damage the riser systems or umbilicals. Figure D.4 shows a typical FPSO setup. The FPSO is connected to the seabed with risers and umbilicals that connect to its turret. A loading transport vessel is also depicted, however FPSOs typically have large storage capacity in the range of several months up to over a year of their production capacity. Figure D.5 shows an example of a turret construction inside a FPSO. The turret is also often located at the bow of the vessel outside the vessels hull. These are usually the FPSOs that are converted from oil tankers. Both turret designs have similar function for the vessel, namely full freedom in the horizontal plane for the vessel around the turret, some freedom to move with the waves and the possibility to disconnect entirely when weather conditions demand it. The developments of FPSOs is used to make analogue comparisons to estimate costs for running an OT.

### D.1.2 Comparison OT to the oil&gas industry's FPSOs

Moving the MIPrc offshore is a similar development the oil&gas industry has undergone and is still undergoing in the development of FPSOs and more recently the Floating Liquefied Natural Gas production vessels (FLNGs). Therefore, this existing industry is looked at for assessing the additional Operational Expenditure (OPEX) for running an OT. OPEX typically include the extra costs for labor, logistics, environment, insurance etcetera. The similarities are present, however this data can only be used as a guideline.

The International Energy Agency (IEA) publicized a report in September 2012 on oil refinery margins estimates. The production costs varied from as low a 1,40\$/standardized oil barrel (bbl) in Thailand to 5,59\$/bbl on the US West Coast. According to the analyzed data, production in





Figure D.5: Example of a in-hull turret [12]

Europe is most expensive on average (4,0\$/bbl), followed by Central & North America (3,3\$/bbl) and then Singapore with a relative OPEX of 3,0\$/bbl. [1]

Data on FPSOs and FLNGs are hardly available, since this is such a case sensitive matter. Reasons to choose FPSOs over land based refineries or seabed-fixed solutions such as platforms or semi-submersibles are not always technical. Technical reasons are weather&wave conditions, field size or water depth. It often also has to do with tax regimes onshore, environmental regulation or national economy protective measures which has kept FPSOs out of the Gulf of Mexico for instance for a long time due to US regulations. Some data has been collected [38] which can be compared to the data of IEA. The Kraken FPSO (Bumi Armada operated) for example operates in the North Sea producing 80.000bbl at a relative OPEX of 6,0\$/bbl, while the same company operates a FPSO near Nigeria for 3,75\$/bbl. A Statoil FPSO is specifically mentioned because its break-even point rose to 7,0\$/bbl after a change in Norwegian tax regimes. This shows how the economics of a FPSOs are very case sensitive. However, if the European cases are compared a factor of 1,5-1,75 would be applicable when assessing additional OPEX of moving a production offshore. This factor could then be used to estimate the OPEX of an OT facility on the Production Support Vessel (PSV). This is an allowable comparison because FPSOs only take care of initial separation steps which is comparable to the initial processing, treatment, that can be done in OT. So up to a maximum of 30% concentrate and excluding the smelting step required for achieving higher concentrates.

Applying a factor of 1,7 would suggest that table D.2 in combination with the information from CRU can be converted into table D.3. The highest concentrate range reachable offshore is assumed to be 30% to avoid the use of smelting processes. This is shown in table D.4.

Content [%]	>30	30>99.95
Onshore costs [\$/t]	58,83	130,74
Offshore costs [\$/t]	100,01	-

Table D.4: Processing costs referenced to 2011 CRU TC and RC



Content [%]	5>10	10>15	15>23	5>23
Content increase ratio	2,00	1,50	1,53	4,60
Added value ratio [%]	1,08	1,06	1,11	1,27
Normalized value ratio [%]	14,3	10,7	19,6	
Cost effectiveness	0,54	0,71	0,72	
Normalized cost effectiveness	0,56	0,42	0,42	
Effort distribution [%]	23,2	17,6	17,4	58,2

Table D.3: Offshore processing ratios

It should be kept in mind that these are only indicative numbers. The ratio is based on the 2013 spot trading prices in China. This is quite reliable since China is 40% of the world market and spot prices do not relate to exchange prices such as LME prices. Exchange prices are not only established by the copper market, but react on many external (speculative) market forces as well.



## Appendix E

# Actor Analysis

This appendix shows the actor analysis of the deep-sea mining (DSM) industry. The analysis is done according to research into the current mining industry and the Nautilus Minerals case in Papua-New Guinea (PNG). It assumes a variety of six situations. One variable is that for DSM two phases are considered: (1) the development of DSM and the (2) operation of a deep-sea mine. The development of DSM means that technology has to be proven and that the prerequisite paperwork (licensing, insurance etc.) has not yet been acquired. The other situation is when the development of DSM is well underway and a certain mine has to be kept operational. So for each of these two phases, three locational cases are distinguished so that a total of 6 different situations can be identified. The first location for a deep-sea mine is the Area (high seas under UN jurisdiction) (Area). The other situation is an intended mine within the Economic Exclusive Zone (EEZ), or even closer to shore within the 12-mile zone. This case can be subdivided into countries that have strict environmental legislation (EL) and countries that have loose EL, like PNG.

Nautilus Minerals provides the most concrete information on how a DSM production chain (PC) could look like. The Nautilus Minerals case corresponds the most with a deep-sea mine in the EEZ of a country with loose EL. The PNG has shown to be less strict with controversial activities such as Deep-Sea Tailing Disposal (DSTP) (see page ??) and also by the exploration licenses provided in an early stage to Nautilus Minerals. Current land based mining activity in the PNG would not be possible in countries with stricter EL and labor condition regulation. This is allegedly also caused by corruption.

**Methodology** On the basis of the PC analysis the actors and their standpoint is analyzed. The first section discusses the actors in the mining market. It then states the actors that are introduced with DSM. Some actors slightly change when DSM is introduced or become more specialized. Research institutes interested in mining will turn into more specialized research institutes for DSM for example. This consolidated list is used to perform an actor analysis. This analysis is based on the method of Enserink (TPM, TU Delft) and the *Stakeholder Analysis Toolkit* offered by the Manchester Metropolitan University (MMU). [8]

The MMU provides a four-step process:

- Identify the stakeholders
- Create a Stakeholder Map
- Identify Stakeholder Allegiance
- Create a Stakeholder Management Strategy

These steps include the steps taken by the method of Enserink, however the presentation tends to differ. In this appendix only the first step is done for the mining industry and the first three steps are done for the DSM industry. That means that first the actors of the mining industry are identified and then the changes and additions for the the DSM industry are identified. This increases the chance on a complete list since many mining examples are available and only the Nautilus Minerals case as a example for DSM.

## E.1 Identify the actors

The first actors to mention are the authorities. Three types are distinguished. It depends on the situation what the relationship between the different layers of authorities is. Conventional mining is always on land in some sovereign state. This makes the national authority (Nat.Aut.) the responsible authority. The international community has no direct jurisdiction, but can lobby through the United Nations (UN), agreements, political pressure or even a boycott. For DSM this is very different since mines can be located in internationally governed Area.

**Authority** contain all the agencies and institution that have a governmental base. So this includes departments that are responsible for economics, environment, infrastructure, public health & safety or employment & education for example. It is important to realize that both the departments responsible for licensing and the institutions charged with advisory tasks are included in this group. **International authority** is responsible for international agreements on environmental issues, research or trade & transport regulations. The authority can refer to multiple organizations, usually within the UN. For DSM this usually is the International Seabed Authority (ISA) that is charged with the regulation of the Area. That is the 200 nautical mile (as long as no conflict with other nations occurs) wet area outside a nations borders that economically belong to that nation. The national law applies, however it physically is international water. The ISA is a product of the UN initiative United Nations Convention on the Law of the Sea (UNCLOS) which forms an important base for international sea law. The UNCLOS has been recognized by many nations and has an own court of law to handle disputes. International regulation can influence regulation or procedures in national jurisdiction as well. For example, for guidelines on environmental goals or rules for public tendering. **National authority** refers to the governments of the countries where the mining PC is operating in. Typically the Nat.Aut. welcome commercial activity because this could boost economy, labor and education for instance. In the case of mining, infrastructure is usually boosted as well. However, the authorities primarily have to look out for the interests of its subjects and environmental effects are also part of that. Mining generally does not benefit the environment, and unless regulation and agreements dictate otherwise, mining companies do not always share their profits with local communities. And because the mining market is a global market and most companies operate in many countries, the profits related to a specific value-adding activity, like mining or mineral processing (MIPrc), often does not flow back to the region the activity takes place, despite the fact that the local community could be greatly affected by pollution for example. Nat.Aut.s are usually the owner of their land and mostly the law states that all resources belong to the the Nat.Aut.s as well. This places mining activity under direct control of a nations government when mining within national jurisdiction. **Local authority** refers to the authorities of the local region where the mining related operation takes place. It is assumed local authority (Loc.Aut.) represents the local community well, so that the interests of the local community is covered by the Loc.Aut. hence explaining the communities missing from the listed actors. The interests of the Loc.Aut. can differ from the Nat.Aut.. Especially when it comes to local effects like pollution or the lack of beneficial effects. On the other hand, local population

can benefit greatly from increased industrial activity. Local population and businesses are represented by the Loc.Aut. and increased activity can result in positive effects on local suppliers and the employment rate. The Loc.Aut., and the community it represents, has proven to be of substantial power to forestall projects initiated by mining or offshore companies. Loc.Aut. is can influence activity directly by local policies and licenses, however Loc.Aut. can be overruled by Nat.Aut..

**Non-Governmental Organization (NGO)** is subdivided into environmental agencies (EAs), human right agencies, labor unions and consultancies that perform Environmental Impact Assessment (EIA). **Environmental Agency (EA)** look after the protection of the environment. Mines and the affiliated industry generally cause pollution. **Human right agency** look after the health and the safety conditions of employees. Especially mine workers in underdeveloped countries, or countries that lack regulation and supervision, can be at serious risk during their work. All large mining companies mention their effective safety programs, that reduce but still contain significant numbers of annual fatalities. **Labor union** is an organized group of employees within the industry that negotiate with companies for better/safer work environment, improved conditions of employment such as shift length or retirement plans or higher wages. Their ultimate weapon is a strike of their members, often including most workers. **EIA consultancy** is an independent consultancy that can be hired by any party to investigate and report on the environmental impact of an intended activity. To apply for licenses an independent EIA is usually mandatory.

**Research institute** are interested in the mining industry. At least specific ones. Universities, and other research institutes interested in mining and MIPrc, can add to methodological innovations and deposit exploration. For their funding they sometimes rely on cooperation with companies from the industry and in that case the institutions answer to specific market needs. Research institutes are interested in all (scientific) aspects, this includes technology, earth characteristics and environment or environmental effects.

**Mining industry** discusses the companies in the mining market. This concerns for a large variety of actors, where some of them are potential roles for The Company. Generally, companies within the same industry depend on each other and benefit from a growing market in total. However, some companies are competing for market share as well. **Mining integrator** is usually the largest company in the mining industry. It integrates a variety of functions in the PC and in some cases owns and controls the PC from mine to market. Some of the actors/functions mentioned below can in some cases be included in the mining integrator, such as the logistical service provider or the mining contractor. Examples are GlecoreXstrata, BHP billiton or Arcelormittal. **Mining contractor** is the company that is directly responsible for the actual mining operation itself. It is hired by an integrator to mine the ore. It is responsible for the equipment and methodology, but not for licensing and logistics for example. **Mineral processor** is the company responsible for the processing and refining of the ore. **Manufacturer** is the company that receives the ore from the mineral processor and turns it into metalliferous products. **Supplier** is a collection of companies that offer products and services to the mining industry. The products can be equipment, maintenance, consultancy or exploration for instance. **Trading platform** supervises (public) product transactions and price establishment. An example is the London Metal Exchange (LME). **Logistical service provider** is responsible for all shipping, handling and storage related activity. **Private investor** provide the necessary cash for a project, usually in return for shares. Especially, in an early stage banks tend to find a project to risky and so for initial funding parties rely on private investors.

**Finance and insurance sector (F&I-sector)** are the companies that provide the cash and securities for development and on-going processes. Insurance companies also bare the risk in case of accidents, disasters or such. Generally, these companies are open to new opportunities however tend to be risk avoiding. Unless proper research has been performed or practices have been shown to be safe, companies as these will not be very supporting.

The total list for the mining PC considered in this analysis is shown here:

1. Authority
  - a. International authority
  - b. National authority
  - c. Local authority
2. Non-Governmental Organization:
  - a. Environmental Agency
  - b. Human rights agency
  - c. Labor union
  - d. EIA consultancy
3. Research institute
4. Mining industry
  - a. Mining integrator
  - b. Mining contractor
  - c. Mineral processor
  - d. Manufacturer
  - e. Supplier
  - f. Logistical service provider
  - g. Trading platform
  - h. Private investor
5. Finance and insurance sector

### **E.1.1 Identify the actors in the deep-sea mining market**

DSM is very different from conventional mining, however many of the type of actors will remain the same or change a little bit into a similar but differently specialized actor. The actual people/institutes/companies acting as an actor however can differ significantly. By taking a look at the PNG and the DSM company Nautilus Minerals. The following list is presents the adjusted DSM actor list considered in this analysis.

1. Authority
  - a. International authority
  - b. National authority
  - c. Local authority
2. Non-Governmental Organization

- a. Environmental Agency
  - b. Human rights agency
  - c. Labor union
  - d. EIA consultancy
- 3. Research institute
  - a. Marine research institute
  - b. Mineral processing institute
- 4. DSM industry
  - a. DSM integrator
  - b. DSM contractor
  - c. Mineral processor
  - d. Manufacturer
  - e. Supplier
  - f. Logistical service provider
  - g. Trading platform
  - h. Private investor
- 5. Finance and insurance sector
- 6. Fishery & other affected industries

### Main differences with the mining market actors

The Company intends to enter the DSM industry, but not necessarily the mining industry. However, the role of The Company in DSM has yet to be determined. According to chapter ?? (page ??) The Company could represent one or more of the actors in the DSM industry. There are some differences in the mining and DSM PC and so it is good to have separate actor lists. However, since both PCs and markets are interconnected as the product moves closer to the end-market, these cannot be seen separately. Generally it can be assumed that the PC will meet at the MIPrc phase after shipping from the mine. The changes in the actor list are now discussed.

**Authorities** **International authority** becomes more important since DSM can, unlike mining on land, take place in international waters. International waters, and also EEZs to some extent, are controlled by the international community via institutes such as the ISA. **National authority** always keeps sovereign control over its national waters and EEZ. However, within the UNCLOS there is room for regulation that also applies to national waters if the specific country has committed itself to this clause or the UNCLOS as a whole. At the same time countries can be excluded from the exploration and DSM activities itself if the activity is outside their national waters or EEZ. However, when activity moves closer to shore, both **national** and **local authority** will feel more affected due to the risk for pollution or effects on tourism for instance.

**Human rights agency** focuses mainly on the health and safety of mine workers. Considering DSM, where it is safe to say the actual mining will be done using Sea-floor Production



Tools (SPTs), the human rights agencies will have less to worry about. However for the **EAs** DSM is even a larger concern than land-based mining. This is because the deep-sea is seen as (one of the) last untouched parts of the earth. Many formerly unknown species already have been found and are expected to be found, surviving under harsh environmental circumstances making it an interesting area for research and also for protection.

**Research institutes** is changed into **marine research institutes (MRI)** for DSM. But for instance the MIPrc of the ore can change significantly because of different ore types that contain multiple metals. This will still need the involvement of the conventional institutes that are involved in the regular metallurgy. However, these institutes will have the same principal interests and perspectives from a actor analysis point of view.

**DSM industry** includes the functions/actors from the mining industry that are still involved in the DSM industry. The function remain the same, but some titles have been specialized into DSM.

**F&I-sector** represent banks and insurance companies. These are companies that provide the initial cash for development and act as third party to effectuate trading and other ongoing processes that require cash in-advance. Insurance companies also secure the assets of a company and will therefore not only have to be convinced of the profitability of a project but also of the safety of the process. **Fishery & other affected industries** represent the fishery market that operates in the proximity of DSM activity. It can also represent other industries such as tourism. Generally, the fishery will be satisfied as long as their own business is not affected negatively. This means that there fishing area is not decreased and that the water quality is not affected in a negative way for the sea life. However, financial compensation will satisfy other industries as well.

### Positioning of the DSM actors

Now the position of the actors will have to be clarified. Two situations are distinguished that need a separate analysis.

1. in Area (table E.1)
2. in EEZ (table E.2)

When discussing these situation only the DSM operation itself is considered so that DSM in the Area actually remains in the Area. In reality the PC will at some point always enter national jurisdiction. But then the results of the analysis of operations within EEZ apply. Table E.2 shows the changes with respect to table E.1. Most of them concern a change in competent authority since the activity moved to an EEZ.

## E.2 Actor Map

The actors are mapped in a graph for each situation, so adding up to six graphs (figures E.2 - E.7). The graphs show the interest or dedication of an actor and the power or influence that actor has. It provided a graphic overview of all actors' positions and the interrelationships. An actor is dedicated when for this actor DSM is seen as a prioritized topic. Their influence or power is also visualized and that is especially interesting in the different jurisdictional cases. When interpreting these graphs, it should be mentioned that non-critical actors (low power and interest) should never be neglected or ignored, because when many non-critical actors unite, problems will still occur.

There are six situations considered:

Actor	Stake in the project	What is needed from them?	Perceived attitudes/risks	Risk if they are not engaged
<b>1</b>				
a	supervise and stimulate R&D	licenses & tenements	balanced interest in DSM & environmental protection	no DSM
b	attract industrial activity	no opposition	worries for pollution	lobby at ISA
c	attract industrial activity	no opposition	worries for pollution	lobby at Nat.Aut.
<b>2</b>				
a	protect environment	no opposition	environmental damage	lobby at ISA
b	protect human rights	no opposition	health & safety risks for employees	lobby at ISA
c	negotiate employee rights	agreement	bad employee rights, pension plan etc.	strike
d	independent research	independent judgment	none	no EIA
<b>3</b>				
a	general interest into the deep-sea	research	environmental disturbance before research	no independent research
b	interested in DSM MIPrc	MIPrc technology	no funding	insufficient technology
<b>4</b>				
a	responsible for operations	DSM initiative	engage if profitable	no marketing
b	executing DSM	DSM equipment	engaging alone is too risky	no mining
c	executing MIPrc	MIPrc facility	DSM volumes too small	disrupted PC
d	manufacture metal	interest in DSM ore	DSM is not of quality	disrupted PC
e	supplier of goods	specialized products	DSM industry too small	high R&D costs
f	exec. transport & storage	specialized handling equipment	industry too small	high R&D costs
g	enable trade	branding	DSM is not of quality	private trade only
h	enable R&D	initial funding	DSM not promising	no funding
<b>5</b>	enable ongoing processes and securities	funding and insurance	DSM not profitable and too risky	DSM initiative too risky
<b>6</b>	protect interests	no opposition	DSM has negative effects	lobby at ISA

Table E.1: Actor identification; situation 1.

Actor	Stake in the project	What is needed from them?	Perceived attitudes/risks	Risk if they are not engaged
<b>1</b>				
a	influence Nat.Aut. policy	no opposition	national policy mismatch	lobby at Nat.Aut.
b	-	licenses & tenements	-	no DSM
<b>2</b>	-	-	-	lobby at Nat.Aut.
<b>6</b>	-	-	-	lobby at Nat.Aut.

Table E.2: Actor identification; situation 2.

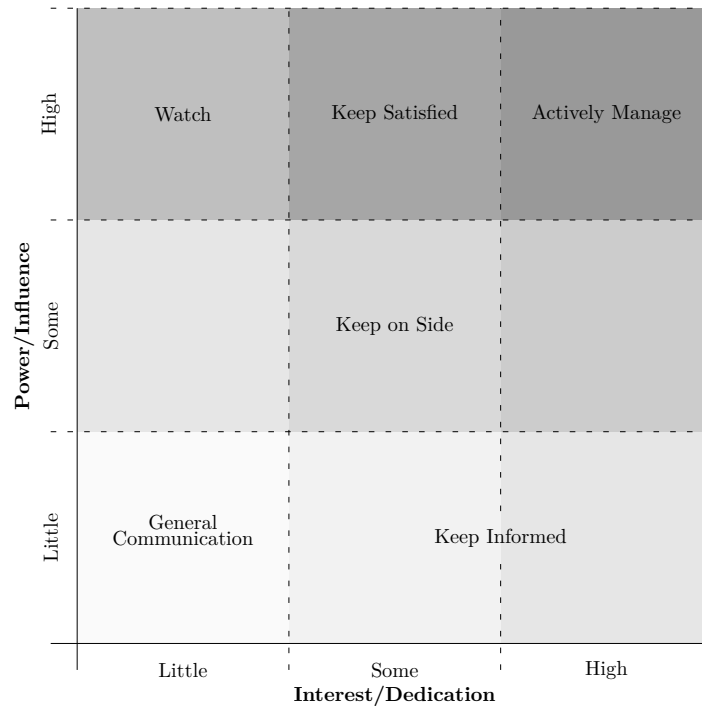


Figure E.1: General actor mapping

1. development of DSM
  - a. in Area
  - b. in EEZ; strict EL
  - c. in EEZ; loose EL
2. operational of DSM
  - a. in Area
  - b. in EEZ; strict EL
  - c. in EEZ; loose EL

Some comments are necessary to clarify the figures. The international community is very powerful since it both makes the rules and enforces them. However, when DSM develops further, licenses and tenements have been provided which will decrease their influence on operations. As the industry needs less stimulation, their interests will decrease as well. For DSM in EEZs their influence can be substantial through political channels for instance, however this will have more impact on Nat.Aut.s that already have strict EL (assumed that this reflects on their general

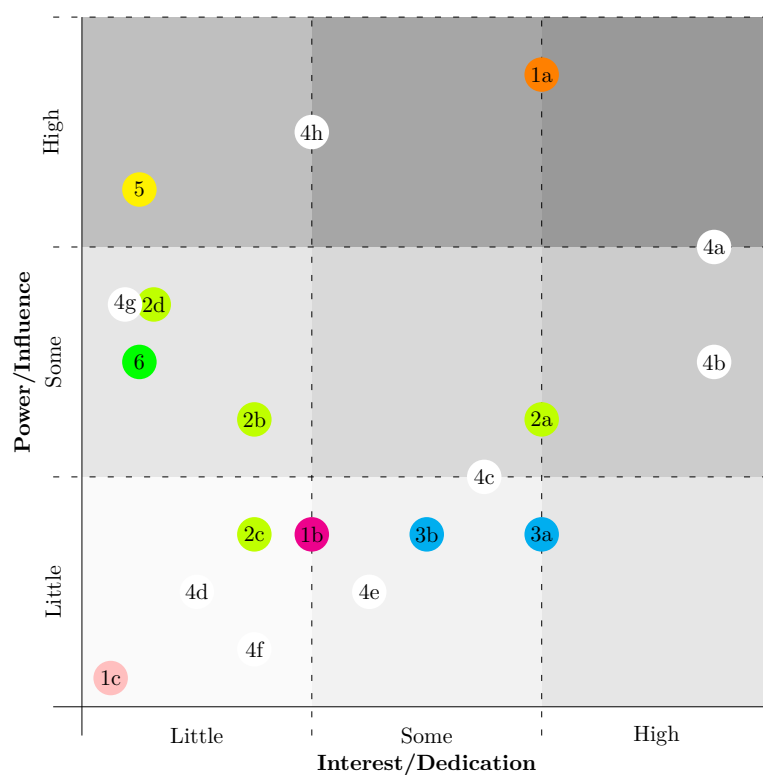


Figure E.2: Actor map DSM development in Area (1a)

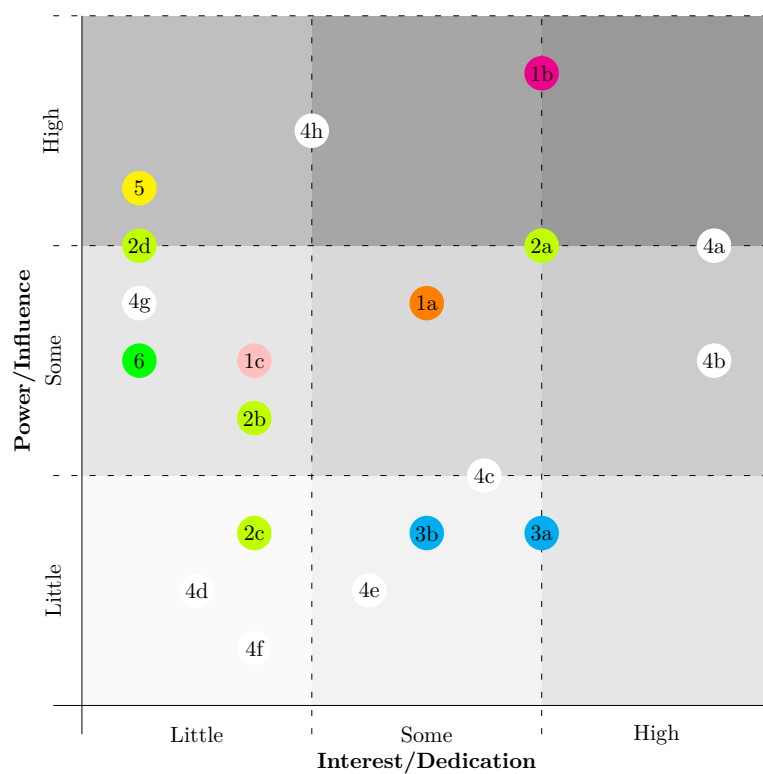


Figure E.3: Actor map DSM development in EEZ with strict EL (1b)

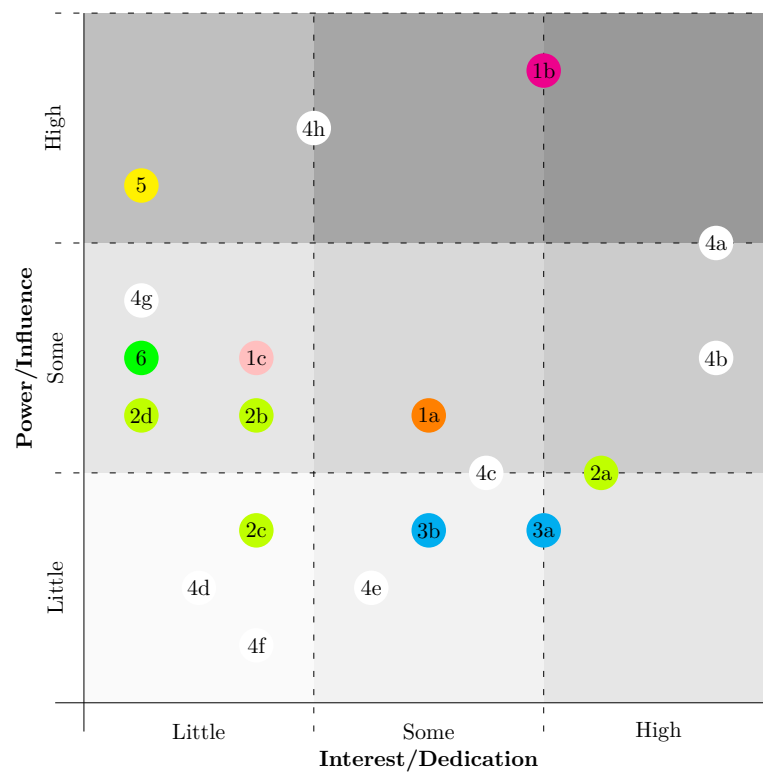


Figure E.4: Actor map DSM development in EEZ with loose EL (1c)

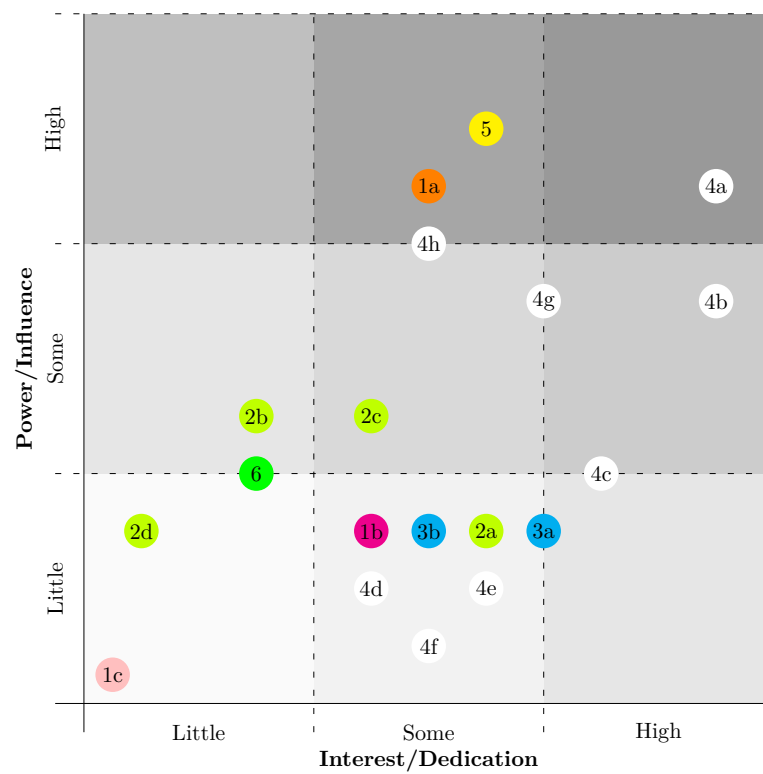


Figure E.5: Actor map operational DSM in Area (2a)

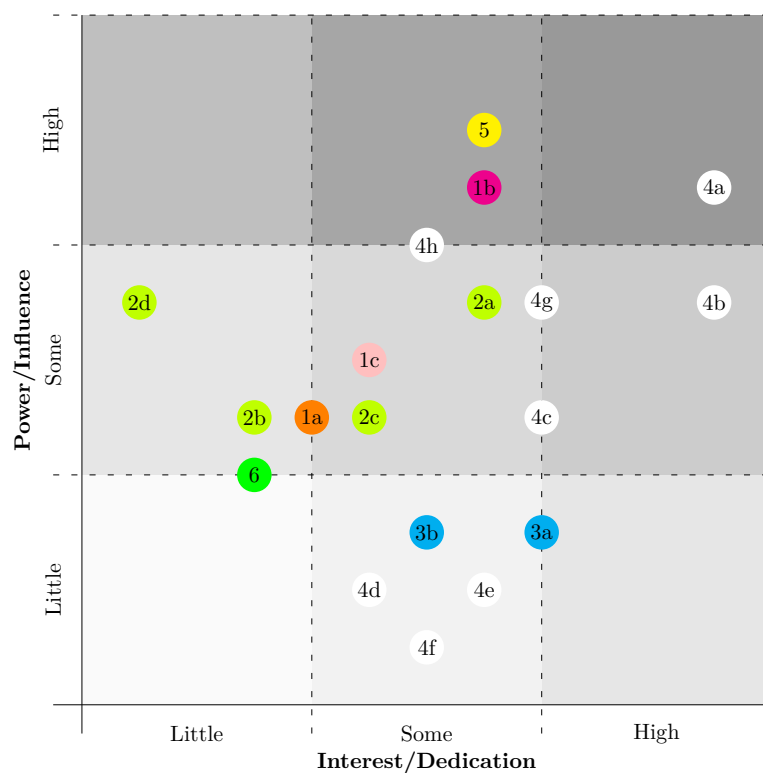


Figure E.6: Actor map operational DSM in EEZ with strict EL (2b)

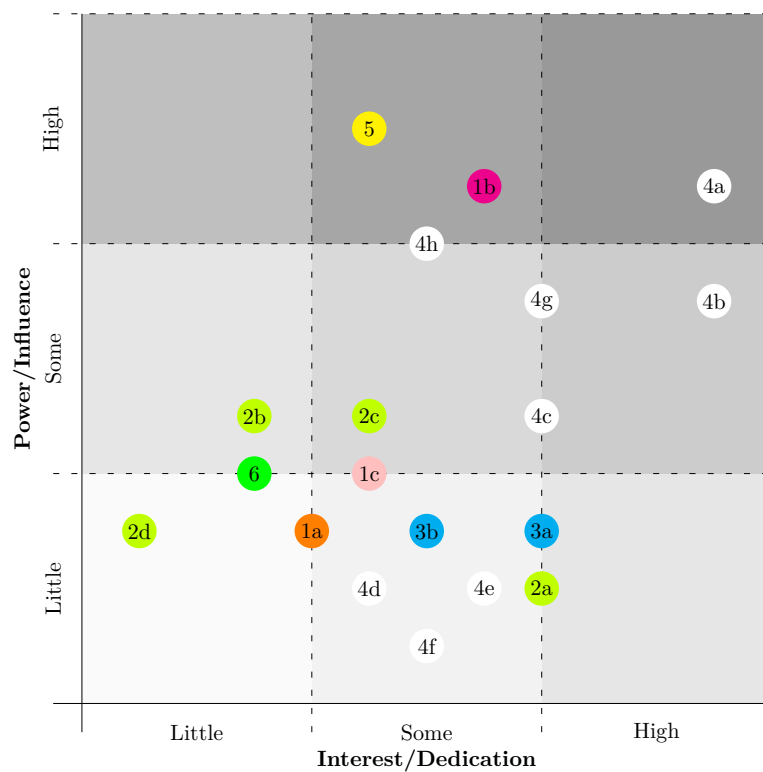


Figure E.7: Actor map operational DSM in EEZ with loose EL (2c)

level of development).

Nat.Aut.s follows a similar path where both interest and power decrease as development of the industry increases. Also, for DSM in the Area Nat.Aut.s will keep an eye out to attract economic activity towards their borders and will also be able to influence regulations at the ISA through political channels.

Loc.Aut.s have no power or interest for any DSM in the Area. DSM in their own country will receive more attention since economic activity should benefit them as well, however this will mostly become clear as the industry is already advancing in their proximity. That is also the point where Loc.Aut. will keep a look at environmental threats. Because stricter EL is assumed to represent a stronger rule of law, the Loc.Aut. will have more influence on national policy level as well, hence the higher power in situation 2b (figure E.6).

EAs have more political power in strict EL in EEZ than on ISA. In looser EL states their worries (interest) grow larger, but (and because) their influence is much lower. When DSM is operational their influence and thus their interest decreases since the licenses for DSM are assumed to be legit and so there is less ground for protesting.

Human right agencies will have similar, general interest in all cases.

Labor unions will gain power as the industry develops, because their members and thus the employees and thus the industry will have to grow.

EIA consultancies are not committed at all, but do have large power through their independent judgment on the environmental impact. This power will decrease as the effects become more visual and the methods become more advanced. Also, for an EIA to be important the EL will need to be strict first, so their power differs between the EEZ cases as well.

Research institutes will have similar interests and influence throughout the entire development process since the need and research for innovations is always present.

The DSM integrator and contractor itself, have the initiative and thus the influence for development of DSM. This does not relax over time. The other industrial player (4c-4f) become more interested as the industry involves, since the risks of entering decreases and opportunities have proven to be there.

Trading platforms will be suspicious, but once they have approved their interest is very high. Through their branding and warehousing regulations, their power is very high. This only applies if public trading is desirable.

Private investors are initially powerful because their funds are required, however when the industry evolves regular banks will step in to bare the decreased risk. Also, operations in less developed countries is less attractive for investments than developed countries. This is reflected through the strict and loose EL.

Finance and insurance companies are very powerful but have enough other opportunities to be very interested as well. When the industry is up and running and methods have proven to be safe and profitable, the insurances and funding will come as well for further development.

The affected industries like fishery, cannot do much as long as DSM is not operational. But as soon as negative effects occur, their possibilities to intervene will have decreased. These parties are expected to be one step behind.

### E.3 Actor Allegiance

Table E.3 shows the position of the actors for each situation. Especially the *blockers* are interesting, since this category is not necessarily against DSM but need to be convinced since they can be critical to the development of DSM. *Blockers* can become *Advocates* or *Opponents* depending on the success of the actor management efforts by the initiators. *Opponents* are hard



to deal with and active management is required so that this category behaves more like the category *Indifferent*. Figure E.8 shows the general approach how to deal with the categories (according to MMU).

Assessment	Definition	How to Manage
<b>Advocates</b>	<ul style="list-style-type: none"> <li>• Only group driving the change or project</li> <li>• Active communications, keep regularly involved</li> </ul>	<ul style="list-style-type: none"> <li>• ‘Internal’ champions and sponsorship</li> <li>• Input to key milestones and decisions</li> <li>• Use for internal promotion of objectives and benefits</li> </ul>
<b>Followers</b>	<ul style="list-style-type: none"> <li>• Have a low understanding of project aims and objectives</li> <li>• Increase their understanding for future benefit</li> </ul>	<ul style="list-style-type: none"> <li>• Support the project and tend to “go with the flow”</li> <li>• Keep informed and positive</li> <li>• Avoid the temptation to exploit</li> </ul>
<b>Indifferent</b>	<ul style="list-style-type: none"> <li>• Individual or groups yet to take a definitive position on the project</li> <li>• Identify gaps in knowledge and seek to fill them</li> </ul>	<ul style="list-style-type: none"> <li>• Seek their views on key issue and address concerns</li> <li>• Have a medium understanding and medium agreement</li> <li>• Be careful not to make them opponents</li> </ul>
<b>Blockers</b>	<p>Shows resistance to the project or its aims. Principally due to having a low understanding and low agreement. This can be driven by:</p> <ul style="list-style-type: none"> <li>• Proactive communication</li> <li>• Interview and meet</li> <li>• Explain and overcome fears</li> </ul>	<ul style="list-style-type: none"> <li>• Use conflict management techniques</li> <li>• A lack of communication</li> <li>• Seeks views once understanding starts to develop</li> <li>• A (perceived or actual) loss from project</li> <li>• Knowledge of error in project assumptions</li> </ul>
<b>Opponents</b>	<ul style="list-style-type: none"> <li>• Has high understanding but low agreement to the project</li> <li>• Initiate discussions and understand reasons for low acceptance</li> </ul>	<ul style="list-style-type: none"> <li>• Will potentially ‘lose out’ in some way from the activity</li> <li>• If the loss is perceived but not real, then convert using facts and data</li> <li>• Counter the reasons for low acceptance</li> </ul>

Figure E.8: Actor category management [8]

## E.4 Conclusion

The Company, if anything, will form one of the actors within the DSM industry. Making the development and operation of DSM a success synergy will be very important. This means that especially the DSM integrator has an crucial role in uniting the different actors needed to complete a DSM PC. If this integrator is for instance an existing mining integrator this would even mean that the hard to acquire funding might be available within the industry as well. Creating

Assessment	Case 1a	Case 1b	Case 1c	Case 2a	Case 2b	Case 2c
<b>Advocates</b>	UN/ISA DSM integrator DSM contractor	DSM integrator DSM contractor	DSM integrator DSM contractor	UN/ISA DSM integrator DSM contractor	DSM integrator DSM contractor	DSM integrator DSM contractor
<b>Followers</b>	Labor union MRI MIPrc institute	Labor union MRI MIPrc institute	Labor union MRI MIPrc institute	Labor union MRI MIPrc institute Manufacturer Supplier	UN/ISA Loc.Aut. Labor union MRI MIPrc institute Manufacturer Supplier	UN/ISA Loc.Aut. Labor union MRI MIPrc institute Manufacturer Supplier
<b>Indifferent</b>	Nat.Aut. Loc.Aut. Manufacturer Supplier Logistical Provider Trading platform	Loc.Aut. Manufacturer Supplier Logistical Provider Trading platform	Loc.Aut. Manufacturer Supplier Logistical Provider Trading platform	Nat.Aut. Loc.Aut.	Nat.Aut. Loc.Aut. Private Investor Trading platform	Nat.Aut. Private Investor Trading platform Private Investor
<b>Blockers</b>	Private Investor F&I-sector Fishery & others	Nat.Aut. Private Investor F&I-sector Fishery & others	Nat.Aut. Private Investor F&I-sector Fishery & others	Nat.Aut.	Nat.Aut.	Nat.Aut.
<b>Opponents</b>	EA	EA	EA	EA	EA	EA

Table E.3: Actor allegiance

synergy requires cooperation and some openness of developments. Especially in an early stage, even competitors might be necessary to reach a large enough platform to convince the public for the need and benefits of the project.

Synergy can also be reached through cooperation with authorities or research institutes. Having these actors on the pro-DSM side can be extremely beneficial for the development of the industry.



# Appendix F

## Cooperative structures

This appendix will give some background on the history of supply-chain cooperation and possibilities of cooperative structures between companies within a production chain (PC). It is discussed according to the paper *With Agility and adequate partnerships strategies towards effective logistics networks* of P. Schönleben. [41]

A suitable definition of supply-chain is: *A supply chain is the network of all the individuals, organizations, resources, activities and technology involved in the creation and sale of a product, from the delivery of source materials from the supplier to the manufacturer, through to its eventual delivery to the end user.* [51]

### F.1 The traditional customer-supplier relationship

After the Second World War suppliers of manufacturers were generally powerful players in the PC because shortages were in the order of the day. Because of increasing industrial performance the market became more saturated in the mid '70s, and the demand in the PCs started to decrease. The power balance quickly shifted towards the customers in the supply-chain and this also caused a general price reduction. This power shift allowed producers to build strategic relationships with their suppliers. These agreements included standards for price and quality. This system is depicted in figure F.1. The figure comes with a definition:

*The Traditional Customer-Supplier Relationship is defined by the law of supply and demand. Suppliers are chosen on the basis of low prices. Cost reductions are achieved as suppliers play off against each other.*

To cut costs the suppliers could keep low stock for instance. This strategy has proven to have some risks:

- Reduced quality
- Longer delivery times
- Poor delivery reliability

These risks occurred in the early '80s and caused shortages and a decrease in service level. Therefore, new strategies were required. These new strategies are now discussed. Generally, partnerships have two main dimensions:

- Duration
- Intensity

- **Quality:**
  - The supplier is responsible for meeting the customer's quality specifications.
  - The customer is responsible for the acceptance and must check the meeting of the specifications.
- **Cost:**
  - The customer chooses a supplier, where quality is sufficient, primarily according to the lowest prices, following the law of supply and demand
- **Delivery:**
  - The customer awards a contract stating desired product, quantity and delivery due date.
  - Safety stock is necessary in order to avoid the problems caused by delivery delays.
- **Flexibility:**
  - The customer aims for multiple sourcing through finding new suppliers.
  - If transaction costs become too high, a make-decision is made.
- **Relationship between the companies in a logistics network:**
  - Starting from raw materials and standardized parts, it is the customer who develops all products and processes in the logistics network.
  - The customer delegates the manufacturing of semi-finished goods or parts of the manufacturing process to suppliers. The customer controls the quality particularly of first deliveries.

Figure F.1: The traditional customer-supplier relationship [41]

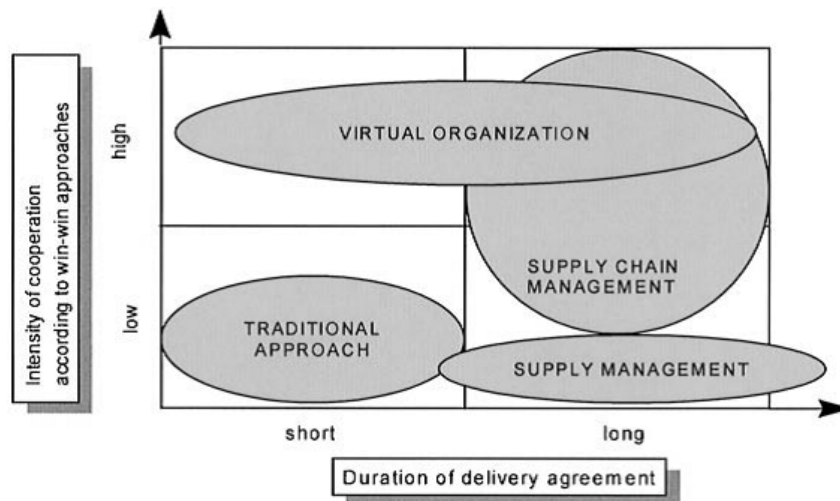


Figure F.2: Ordering of various strategies of cooperation in a logistics network [41]

In figure F.2 three different types of partnerships are shown. The two main dimensions determine the type of partnership that is compatible with the wishes of the partners. The Traditional Approach is also mentioned in the overview. The three different types of partnership strategies will be separately discussed in the next few subsections.

## F.2 Supply Management

The given definition is as follows:

*Supply Management is a strategic and long-term reduction of the number of suppliers to achieve fast and easy operational order servicing. The choice of a supplier is made in view of total costs, i.e., under consideration of all opportunity costs.*

The relationship is build on long-term cooperation, but the intensity is low. There is little entrepreneurial cooperation and the cooperation is limited to reducing friction caused by order

• Quality:
<ul style="list-style-type: none"> <li>• The supplier achieves a minimum level of quality (according to its own quality control, external certification).</li> <li>• In order to control the quality of the supplier, the customer has access to its production facilities. Both parties mutually improve quality in a logistics network.</li> </ul>
• Cost:
<ul style="list-style-type: none"> <li>• Through single sourcing greater business volume and thus lower cost prices are achieved.</li> <li>• (Long-term) blanket orders allow intermediate stores to be reduced.</li> <li>• The choice of a supplier is made according to total costs, that is, in consideration of opportunity costs.</li> </ul>
• Delivery:
<ul style="list-style-type: none"> <li>• (Long-term) blanket orders reduce total throughput time (supplier and customer).</li> <li>• There is now direct delivery on demand to the production facilities of the manufacturer.</li> </ul>
• Flexibility:
<ul style="list-style-type: none"> <li>• Single sourcing also provides for a replacement supplier.</li> <li>• As to the rest, the buyers' market secures the robustness of the approach: transaction costs are small, and it is relatively easy to secure a replacement supplier (buy-decision).</li> </ul>
• Entrepreneurial cooperation in the logistics network:
<ul style="list-style-type: none"> <li>• Demands on products and processes to be delivered are mutually defined.</li> <li>• The supplier is consulted about each (further) development.</li> </ul>

Figure F.3: Strategies of supply management [41]

negotiations. The relationship has to be under constantly evaluation to determine its validity. Otherwise the following risks may become reality:

- Wrong choices when reducing the number of suppliers
- Changes in crucial conditions on the part of suppliers
- Unexpected shift to a sellers' market

Figure F.3 shows the strategies that are valid using Supply Management.

## F.3 Supply-Chain Management

As the duration of a partnership becomes longer, transaction costs are likely to decrease. Therefore outsourcing anything but the core competence becomes more likely. To ensure fast innovation, entrepreneurial cooperation is necessary since all parties in the chain are sticking to their core competence and not to the entire (range of) product(s). This asks for trust, long lasting relationship and close communication. Therefore technology on this part was essential (fax, ISDN, internet). Figure F.4 shows the strategies that are complementary to the strategies already shown in figure F.3. The given definition:

*Supply-chain Management is the coordination of strategic and long-term cooperation among co-producers in the total logistics network for the development and production of products, both in production and procurement and in product and process innovation. Each co-producer is active within its own area of core competence. The choice of co-producer is made with chief importance according to its potential towards realization of short lead times.*

Because of the closer cooperation and information sharing the following risks occur:

- Abuse of the knowledge gained from cooperation with co-producers in order to enter business relationships with their competitors
- Investiture by co-producers which - due to brief cooperation periods - is not profitable

<ul style="list-style-type: none"> <li>• <b>Quality:</b> <ul style="list-style-type: none"> <li>• Each co-producer <i>feels responsible</i> for the satisfaction of the end user.</li> <li>• Quality requirements are developed and improved mutually.</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Cost:</b> <ul style="list-style-type: none"> <li>• All advantages of supply management are maintained. This leads generally to lower transaction costs.</li> <li>• Sharing of methods and know-how among co-producers reduces costs.</li> <li>• Each co-producer is active in its area of core competence. This yields the best possible return from the resources implemented (including time).</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Delivery:</b> <ul style="list-style-type: none"> <li>• The same logistics are necessary for all co-producers (same operational procedures, documents, etc.).</li> <li>• Planning and control systems are linked (for example, via EDI).</li> <li>• The choice of co-producer depends with chief importance upon speed, that is, the co-producer's contribution to short lead times.</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Flexibility:</b> <ul style="list-style-type: none"> <li>• All co-producers give impetus towards product development.</li> <li>• Once again, the buyers' market guarantees that the approach be robust: transaction costs are low, and replacement suppliers may be arranged relatively easily (buy decision).</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Entrepreneurial cooperation in the logistics network:</b> <ul style="list-style-type: none"> <li>• All co-producers are involved in product and process development from the start.</li> <li>• All co-producers are involved in planning and control.</li> </ul> </li> </ul>

Figure F.4: Strategies of supply-chain management [41]

## F.4 Virtual Organizations

The virtual organization is usually a temporary solution of a partnership with a long duration for a short-term opportunity. It is used for temporary ventures. For instance, a non-repetitive product for a specific situation of a client. Legally the Virtual Organization is not a company but it is a joint venture of departments of different companies to perform this specific task. This form of cooperation is only possible when a long-term relationship and mutual trust is realized. Figure F.5 tries to visualize this phenomenon. Again as a complementary set of strategies, figure F.6 shows the strategies involved for a Virtual Organization.

To use Virtual Organization, the companies involved must be flexible so that the organization can be formed rapidly when necessary. This is a key necessity for the Virtual Organization to be effective since it is meant to be able to react efficiently on a unforeseen changing demand of a client. The definition is as follows:

*A Virtual Organization is a short-term form of cooperation among legally independent co-producers in a logistics network of long term duration of potential business partners for the development and manufacturing of a product. This is true for procurement and production, as well as for product and process innovation.*

The risks of the Virtual Organization are:

- Lack of competition with regard to potential partners in the network means that certain orders cannot be taken on
- Legal problems (loss and gain distribution, copyrights and rights of ownership)
- The volume of business is too small to justify the long-term expense involved

## F.5 Relation to The Company and deep-sea mining (DSM)

The Company could decide to be active in the DSM industry. If so, the content of the business portfolio (BP) is not determined and can be implemented in various ways. Furthermore it is



<ul style="list-style-type: none"> <li>• <b>Quality:</b> <ul style="list-style-type: none"> <li>• Each co-company carries <i>extensive responsibility</i> for end-user satisfaction.</li> <li>• Action guidelines, structures and processes of the virtual organization are developed mutually, as is the basic network of potential partners.</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Cost:</b> <ul style="list-style-type: none"> <li>• All advantages of supply chain management are maintained. This leads to lowest costs.</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Delivery:</b> <ul style="list-style-type: none"> <li>• The logistics network for a specific order is formed rapidly.</li> <li>• The same operational procedures, documents, etc. are prerequisites.</li> <li>• Identical information systems allow a maximal exchange of information during mutual product development and production.</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Flexibility:</b> <ul style="list-style-type: none"> <li>• Criteria for the choice of a co-enterprise are 1) its flexibility to enter as a partner into a logistics network 2) its innovative power, that is, its flexibility in creating customer value and 3) the extent of shared value orientations.</li> </ul> </li> </ul>
<ul style="list-style-type: none"> <li>• <b>Entrepreneurial Cooperation in the logistics network:</b> <ul style="list-style-type: none"> <li>• All potential partners form a long-term network. One has the role of a broker, in order to put together the virtual organization according to a concrete demand.</li> <li>• All co-producers supply product and process development and planning and control from the start. They share mutual involvement and responsibility for success or failure.</li> </ul> </li> </ul>

Figure F.5: Strategies of a virtual organization [41]

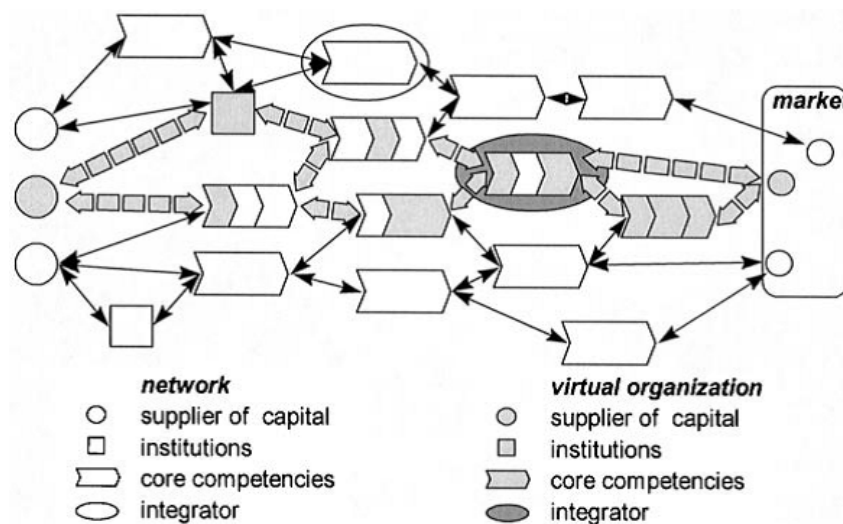


Figure F.6: The virtual organization and underlying network of potential partners [41]

unknown to what extent the entire BP, whatever this may include, is developed and executed in-house or that any of the structures mentioned in this appendix can be practiced to meet the requirements of a specific set of tasks The Company, or collaborating group including The Company, wants to offer to this industry. The two determining factors are intensity, which deals with trust and to what extent parties are willing to share information, and duration, which deals with the length of the project(s). This appendix shows some options that will be considered in the discussions in the main text of the report.