UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Project in Logistics and Transport Management

Risk Management of the Supply of Rare Earth Elements: A Case Study of an Automotive Manufacturer

Charlotte Kjellberg and Fredrik Fejne

Supervisor: Catrin Lammgård
Master Degree Project No. 2015:52
Graduate School

RISK MANAGEMENT OF THE SUPPLY OF RARE EARTH ELEMENTS: A CASE STUDY OF AN AUTOMOTIVE MANUFACTURER
By Charlotte Kjellberg & Fredrik Fejne

School of Business, Economics and Law, University of Gothenburg, Vasagatan 1, P.O. Box 600, SE 40530 Gothenburg, Sweden

Contact: charlottekjellberg@hotmail.com or fredrik.fejne@outlook.com

Abstract

Increased focus on clean technology has increased the demand of the rare earth elements dysprosium and neodymium, which are materials included in wind turbines and hydro and electric cars. Today the supply of dysprosium and neodymium cannot keep up with the increased demand due to limited production sites, lack of effective substitutes and complex production and refinery processes. Furthermore, China has great power in the market of these rare earth elements due to big reserves, low regulations, low cost labour and the country owns the majority of the production sites. These factors makes China control the market and can increase the prices by implementing regulations such as export quotas or duties. Companies who are including dysprosium and neodymium in their product are exposed to price risks and sudden price increases that could impact the company considerably. There is no research covering how companies should handle these risks. The purpose of this thesis was, therefore, to investigate the risk management approach connected to commodity prices of rare earth elements for an automotive manufacturer. This was investigated by performing a qualitative case study of Volvo Car Group, with internal interviews at Volvo and an external interview with a first tier supplier of Volvo. Findings in this research show that Volvo has a high exposure to the price risks related to dysprosium and neodymium and possible mitigation strategies to reduce risk exposure, for the company, are: sharing price risks with suppliers, secure supply, reduce demand and recovery. This research could serve as a foundation for future research of the price risk management practise regarding rare earth elements in other industries or focus on the sustainability risks associated with rare earth elements.

Keywords: *risk management, commodity price risk management, risk mitigation, supply risk, supply risk management, supply risk of raw material, price volatility, commodity prices, price of raw material.*

Acknowledgements

First of all we would like to thank Volvo Car Group for making it possible for us to conduct this investigation. We also appreciation and are thankful for all the help we have obtained from Axel Edh, at the department of Environment and Fluid Dynamics. We want to thank him for the great support, useful inputs and professional guidance. Additionally, we would also like to thank the purchasing department at Volvo for the help with contacts and feedback when conducting the interviews. Great gratitude and appreciation goes to Catrin Lammgård for inspiration, guidance and feedback in the process of conducting this thesis. Finally we want to thank the interviewees, who took time to collaborate with us and shared their knowledge, making this investigation possible.

Charlotte Kjellberg

Fredrik Fejne

Gothenburg, 3rd of June 2015

Table of content

List of figures

List of tables

1 Introduction

The introduction will provide a description of rare earth elements, background information of its market, today's situation and the problematisation regarding this. The purpose, research questions, limitations and the outline of the thesis will also be presented in this chapter.

1.1 Background

Global warming is the biggest challenge of our generation. Since the industrial revolution, the average global temperature has increased by 0.8 degrees Celsius, of which two thirds occurred after 1975 (NASA 2015). The global average temperature fluctuates very little over time compared to local temperature, which change in the short-term depending on if it is winter or summer. Greenhouse gases in the atmosphere are the reason for increased temperature (NASA 2015), which is something that affects everyone on this planet. Carbon dioxide emission increases the global warming by encapsulating the globe and capturing the heat from the sun around the planet and causes the temperature increase. A warmer climate is damaging for the environment and enhances the risks of transmitted diseases, water shortage, increased natural disasters, and create difficulties in agriculture (NRDC 2015a). These consequences have caused increased environmental awareness and changed consumer attitudes, to demand clean energy from wind turbines and switch from petrol cars to hybrid and electric cars (NRDC 2015b; Habib and Wenzel 2014).

In the manufacturing of wind turbines as well as electrical and hybrid cars, rare earth elements are key materials (Habib and Wenzel 2014; Hoenderdaal *et al.* 2013). This is due to their lightweight, strength, resistance to heat and viability over time (Massari and Ruberti 2013; Habib and Wenzel 2014). The car manufacturing industry is characterized by a significant environmental impact and fierce competition (Global Intelligence Alliance 2012), which create challenges in being proactive and securing critical material supply. The industry is characterized by a high degree of outsourcing (Caniëls *et al*. 2013), which could result in a lower level of supply chain and raw material control. Higher pressure on reducing fossil emissions increases the demand of cars with lower environmental impact, to which neodymium and dysprosium are key rare earth elements.

Rare earth elements are not as rare as the name suggests, but they are hard to extract and separate from the earth crust (Campbell 2013). Because of the increased demand of clean technology the supply of the rare earth elements have become scarce since it cannot keep up with the increased demand. The annual growth in demand of rare earth elements between 2015 and 2020 is estimated to 10% (Gschneidner 2011) and at the same time, the supply is expected to be constant and might even diminish in the future (Massari and Ruberti 2013).

There are two key rare earth elements that are required in the technology of wind turbines and electric vehicles named dysprosium (Hoenderdaal *et al*. 2013; Habib and Wenzel 2014) and neodymium (Habib and Wenzel 2014). The minerals are typically used in magnets to enhance the magnetic strength (Habib and Wenzel 2014). Due to the increased demand of clean technology the demand of dysprosium and neodymium are expected to increase considerably in the future (Nieto *et al*. 2013). In 2013, the sales of electrical vehicles increased with 229% in the US (Shahan 2014) and demand forecasts of dysprosium and neodymium show that electrical vehicles seem to be the biggest consumer of the materials by 2050 (Habib and Wenzel 2014). The electrical vehicles sold in 2011 contained 20% of the global consumption of dysprosium (Hoenderdaal *et al* 2013). The car industry will use approximately 100 000 tonnes of neodymium in the form of magnets by 2020, where 20% will be used for electrical and hybrid vehicles (Stanford magnets 2015).

1.2 The market and supply risks for rare earth elements

The market of rare earth elements is characterized by a few producers, which are located mainly in China but also in Australia, Canada, South Africa, Brazil, Malaysia and India (Humphries 2013). China is the market leader due to big mineral reserves, low cost labour and the fact that mines in China tend to be unregulated and unlicensed (Hensel 2011). Rare earth elements were not a big concern for businesses until after the 1980s (Maull 1984). The strategic concern of the rare earth elements increased due to the uncertain availability and by 2000 their strategic significance has increased even further (U.S. Department of Energy 2010).

China produces approximately 97% of the world supply (Habib and Wenzel 2014; Wübbeke 2013), which makes them a powerful actor in the market. In 2010, the world got to experience the implications of the monopolistic power China possess, when the Chinese government implemented an export quota, reducing their exports of rare earth elements with 40% (WTO 2012). This became rather problematic since the world did not have many alternatives because rare earth elements have low recycling rates (less than one per cent) (Binnemans *et al*. 2013) and there is no effective substitute. Therefore, this action made the prices of rare earth elements increase considerably (Massari and Ruberti 2012).

As mentioned before, rare earth elements are not as rare as the name suggests but they are hard to extract and separate from the earth crust (Campbell 2013). The rare earth elements are extracted from bastnäsite ore and monazite ore and are dependent of mining together with other metals (Campbell 2013), which increases the complexity in the supply. The industry is a target for environmental regulation since when producing rare earth elements, toxic chemicals and nitric acid is needed in the purification processes, which are very environmentally damaging (O'Donnel 2015). Increased environmental regulations would improve the social and environmental situation but might hamper the production of rare earth elements and increase the supply risk.

1.3 Characteristics of dysprosium and neodymium

Rare earth elements include seventeen different materials (see overview of rare earth elements in Appendix A) and are referred to as a group because they are metallic and have chemical and physical likenesses regarding their characteristics. Rare earth elements are divided in two groups, light rare earth elements, heavy rare earth elements and scandium. Scandium is separated since it is not produced from the same deposits as rare other rare earth elements (European Commission 2014a).

Dysprosium
Dysprosium is categorized as a heavy rare earth element and has powerful magnetic strength characteristics even at low temperatures. Dysprosium is used in high performance magnets and found in various minerals in the earth crust. Dysprosium magnets are used in hard disc drives, automobiles, and motors and in wind turbines. (Moss *et al.* 2011)

Neodymium
Neodymium is a light earth element and known for, as dysprosium, its high magnetic characteristics in low temperatures. Neodymium is used to produce among the strongest magnets in the world, auto catalysts, petroleum refining and lasers. Smaller neodymium magnets are used in computer hard discs, microphones, loudspeakers and in-ear headphones. (Moss *et al.* 2011)

1.4 Problem discussion

The demand for rare earth elements is far from likely to decrease in the near future. Wind turbines, electric cars and other emerging clean technologies, which are dependent on rare earth elements, are projected to experience strong growth resulting in a mounting pressure on the supply (Habib and Wenzel 2014). Furthermore, rare earth are said to have unique properties, making them hard to replace. This combined with long start-up time for building new mines is making it difficult for the supply to keep up with a rapidly increasing demand resulting in structurally higher material prices. The supply also includes several inherent insecurities including China's dominant market position (Massari and Ruberti 2013) and arising concerns regarding the environmental aspects of the mining process (Wübbeke 2013). These issues have in the past resulted in severe supply disruptions and price fluctuations and no signs can be found, that this will go away in the near future. The Us Department of Energy (2010) have estimated the supply risk for neodymium and dysprosium by the factors: basic availability, competing technology demand, political, regulatory, social factors and co-dependence with other markets and producers diversity. This investigation estimated the supply risk of neodymium and dysprosium of 4 (5 being the highest level of risk) in the short-term and on a long-term basis; neodymium had an estimated supply risk of 3 while dysprosium had 4.

The issue with rare earth elements is not that the materials sources will be completely depleted and vanish from the market, but that there is a bottleneck in the supply, which makes the supply inflexible to changes in demand (Habib and Wenzel 2014). Mismatches of supply and demand makes the prices of rare earth elements volatile and could cause problems for manufacturers including them in their production. One should therefore not be worried for physical depletion of minerals but of the economic depletion, when the costs of producing minerals increase to a point where it is not affordable to use them (Tilton 2003).

Rising costs for input materials are of great concern for manufacturing companies since it has a direct, and in many cases, severe impact on the profit margin (Jusko 2006). The automobile industry is an interesting case due to its current and growing size, environmental impact and intense competitive pressure (Global Intelligence Alliance 2012). The combination of supply limitations and an increasing dependence have created a precarious situation for many car manufacturers using rare earth elements. The strong headwinds related to rising material costs are all piling up and increasing the pressure on the auto manufacturers to act. Some firms have already done this in different ways, most notably Toyota, who acquired a rare earth mine in Canada to ease its dependence on Chinese supply of rare earth elements (Halper 2012). How to act is a difficult question to answer due to the fact that general price risk management related to input material currently is a rather underdeveloped area (Fischl *et al*. 2014), where big improvements need to be done. Focus should be put on this issue because it is highly important for manufacturers to develop their own way to handle the increase uncertainties and price risks (Fischl *et al*. 2014). They need to employ effective strategies to be able to make decisions and mitigate the risk management processes (Colicchia and Strozzi 2012). Related to this, there is no fully developed framework on how to assess and tackle the risks associated with rising prices of rare earth elements. For one to be able to develop a framework, a profound analysis of company's usage and management of rare earth elements needs to be undertaken.

1.5 Purpose and research questions

The purpose of this research is to investigate possible risk management approaches connected to commodity prices of rare earth elements for an automotive manufacturer.

The focus of this research will be on the supply of the most important rare earth elements for automotive producers: dysprosium and neodymium. Answering the following research questions will fulfil the purpose.

1. What price risk exposure does an automotive manufacturer have of the supply of neodymium and dysprosium?

2. How can an automotive manufacturer mitigate the risks associated with the commodity price of neodymium and dysprosium?

To answer the research questions and to fulfil the purpose of this research, a case study on the company Volvo Car Group (hereafter referred to as `Volvo´) was performed. Compared to earlier studies this research will provide a framework, possible for actors in the automotive industry to use when mitigating supply risks of neodymium and dysprosium and possibly other rare earth elements.

1.6 Delimitations

This research was limited to investigate dysprosium and neodymium, because these were highlighted as highly critical in the study performed by Cullbrand and Magnusson (2012). Furthermore, dysprosium and neodymium have also been presented in earlier studies as important materials in electrical cars (Moss *et al.* 2013*)*, which is of high importance for the future environmental focus of Volvo (Volvo Cars 2015). This study will also be limited in not looking at the amount of neodymium and dysprosium that exists on earth because earlier studies have shown that there are relatively large amounts of these metals available in the earth crust (Humphries 2013). Therefore, this thesis has adopted the assumption that the supply will not be depleted.

1.7 The case study

Volvo is a Swedish car manufacturer, which is one of many actors in the industry facing the challenges of rare earth elements future supply. In 2014, Volvo sold 465 866 cars and had a global market share of 1-2 per cent. The company has 2 300 dealers in approximately 100 countries (Volvo Car group 2015) and they produces premium cars with a focus on safety, quality and environment. In 2013, the company employed over 25 000 people and their revenues were 122 245 million SEK (Geely Sweden AB, 2013). Since 2010, the Chinese company Zhejiang Geely Holding Group Co., Ltd is the owner of Volvo (Geely Sweden AB 2013) and the company´s top markets are China (16,8%), Sweden (13,3%) and USA (12,8%) followed by UK, Germany and Belgium (Volvo Cars 2014). The company is considered as a big company in Sweden but in the global market it is a relative small actor.

Strategy of Volvo

The new brand strategy of Volvo is called: *Designed around you* and aims to establish Volvo as a premium brand in the industry, by focusing on the human being (Geely Sweden AB 2013). The two most important functions in the process of becoming a premium brand are: the Drive-E powertrain technology and the SPA platform. The Drive-E powertrain technology is a technical engine solution, making it possible to produce high performance cars with only four cylinders and at the same time reduce emissions and carbon dioxide output (Geely Sweden AB 2013). The SPA platform is an in-house developed base structure, which is the base of where future models will be developed. In the process of electrification development Volvo is a leading actor on the market. The new SPA platform and drive-E are prepared for electrification, which makes it possible for Volvo to deliver smaller and intelligent powertrains that can provide performance levels comparable to larger combustion engines and still reduce fuel consumption and carbon dioxide emissions (Geely Sweden AB 2013).

Volvo includes dysprosium and neodymium in their cars, especially in their hybrid models (IMDS 2014). The rare earth elements in focus are also used in big amounts in high performance and advanced car models (IMDS 2014), which are products of great importance for Volvo when building its brand. If increasing production of these models in the future, even greater amounts of dysprosium and neodymium might be used. Volvo wants to be proactive in the area of how to handle the risks of rare earth elements in their supply chain. By evaluating the competence and the information within the company and externally with suppliers, a mitigation strategy could be helpful for the company to reduce the price risk exposure in the future.

Two investigations have been conducted before, for Volvo, about critical materials; one regarding identification of critical material in different car models (Cullbrand and Magnusson 2012) and the second about social responsibility when sourcing conflicts minerals in automotive supply chains (Gustafsson and Samuelsson 2014). Volvo wanted to improve their knowledge further about the critical materials and rare earth elements, which initiated the idea to investigate the subject.

1.8 Outline

To provide an overview of how this research is structured an outline have been created. Figure 1.1 shows the different focuses of the following chapters in this thesis.

Theoretical review	➢ Risk management ➢ Commodity price risks mitigation ➢ Own conceptual model of commodity risk
Methodology	➢ Research strategy and design ➢ Data Collection method ➢ Data analysis and research quality
Empirical findings	➢ Internal interview results ➢ External interview results
Analysis	➢ Discussions and analysis of the results and theoretical framework
Conclusions	➢ Answers of the research questions ➢ Recommendations to Volvo ➢ Implications and future research

Figure 1.1 Thesis outline

2 Theoretical review

The theoretical review is used together with the empirical findings to answer the research questions and fulfil the purpose of this research. The price risk framework of Zsidisin and Hartley (2012b) work as a starting point when creating a new framework of how a car manufacturer can mitigate price risk of the rare earth elements in focus. This framework will be complemented with other theories of the subject. In the end of this chapter a conceptual model from theory in the area is presented (see figure 2.3).

2.1 Risk definition

The notion of risk is in the modern literature applied to several different industries and practices including finance, supply chain management and decision theory (Heckmann *et al*. 2015). Risk could be defined as the interplay between exposure and uncertainty and there is, however, a great discrepancy between the academic and the operational meaning of risk (Holton 2004). Typically the notion of risk in its operational meaning is only focusing on the risk that can be perceived and to define this operational risk, it is common to use different risk metrics such as variance of return (Holton 2004). This is partly confirmed by Spekman and Davis (2004) who sets the broad definition of risk as "probability of variance in an expected outcome" (p. 416). This notion of probability theory has a long history but is still applicable to measure and apply to modern risk (Bernstein 2006). Furthermore, to be at risk, the subject needs to be self-aware. Thus, companies cannot be at risk, but only a way for its stakeholders to take risks (Holton 2004). It can be concluded that, for the stakeholders of a company to be at risk, it needs to have exposure to an uncertain event. Furthermore, to quantify the risk, one can use certain probability measures.

All companies are exposed to different kinds of risks and need to assess them to avoid negative consequences of their business. ISO (International Organization for Standardization) collected the opinions of hundreds of specialists in order to define risk. They agreed on the definition that risk is: ”Effect of uncertainty on objectives” (Purdy 2010 p.882). The uncertainties accrue from events, internal and external, which affect the organization to cause delays and problems and therefore not being able to achieve their objectives. These uncertainties are not completely controllable (Purdy 2010).

2.2 Risk in Supply Chain

Three types of risks associated with raw material, which makes them critical are; supply risk, vulnerability and ecological risk (Achzet and Helbig 2013). Risks related to a company's supply chain is a critical issue for companies to address due to its critical impact on the company valuation (Hendricks and Singhal 2005). To complicate it even further, supply disruptions are inevitable as long as the supply chain of a firm is complex and tightly coupled (Perrow 1984). Furthermore, there are several different views on risk in the supply chain and what it covers. Supply risk could be defined in a supply chain context to be "the variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective values" (Fischl *et al*. 2014 p. 484). Risks related to the supply chain could be grouped into product related, market related, supplier related and other risks (Ganguly and Guin 2013).

Absorbing, transferring or hedging risks force companies to deploy resources that otherwise could be spent on more productive projects (Banham 2004). Therefore, it can be concluded that it is of great importance for a company to deal with its risks in the most efficient way possible. One step in doing so is for the company to understand its risk tolerance. The risk tolerance, is according to Zsidisin and Hartley (2012b) related to how much risk the organization is comfortable to take on. The level of risk that is acceptable for the firm depends on several factors including the firm's philosophy, industry, experience and leadership. Typically, risk is related to the expected return of an outcome meaning that a risk adverse firm tends to make decision with low risk and return and companies with risk appetite vice versa (Zsidisin and Hartley 2012b). Commodity price risk is a major source of supply chain risk is, according to the authors and it needs to be investigated carefully.

2.3 Commodity price risk

The commodity markets are characterized by endless change and dynamism. Political, economic, social and climate events are all factors that are hard to predict and foresee and that affect the market as well as the prices (Kingsman 1986). The instability in commodity prices is caused by a mismatch of supply and demand, which increases the complexity of the purchasing process. Rumours about factors such as regulations and bad weather among others are affecting the companies who are afraid of shortage in the supply chain (Kingsman 1986). Furthermore, very few companies have any power over the commodity markets (Zsidisin and Hartley 2012b). This makes the commodity market unpleasant for a company to be exposed to even though small actors on the market tend to be hit worse than large due to a weaker bargaining power (Ni *et al*. 2012).

Rising costs of input material have a direct negative impact on the firm's bottom line (Zsidisin and Hartley 2012b). Furthermore, for a company to maintain its competitive position, it is of great importance for companies to monitor the markets for input material, even for items deemed non-strategic (Ellram 2013). To deal with and to maximize the utilization of scarce resources, firms needs to consider the opportunity cost of material usage to a greater extent by consider alternative solutions (Hazy *et al*. 2008).

The price risks tend to be influenced by two forces, namely the market mechanism and market distortions. The market mechanism comprises the supply and demand of the market and creates market equilibrium that then is affected by distortions like speculation and barriers to entry. It is the interplay between these two forces that creates price changes and volatility on the market (Fischl *et al*. 2014). China's great power over the rare earth element supply has historically been a source of market distortions caused by regulations and quotas (Massari and Ruberti 2012). Evidence for highlighting the importance of monitoring rare earth prices, can be found in the fact that the price increases of neodymium and dysprosium is negatively correlated with clean technology companies share prices (Baldi *et al*. 2014). Valuations of companies are proven to be lowered during periods of increasing neodymium and dysprosium prices. The negative impact was particularly strong for European clean technology stocks, which were hit more severely by the price increases than its American, Asian and Oceania counterparts (Baldi *et al.* 2014). This is highly interesting for all users of rare earth elements in different industries competing on the same factor market (Ellram 2013).

2.4 Risk management

It is of great importance for companies to actively manage the risks that the firm is exposed to (Banham 2004) because putting the company at risk is costly for the firm that needs to tie up resources to handle the risk. Also, the notion that risks on the supply side is of particular interest to be mitigated adds further focus on the issue of rare earth elements (Wagner and Bode 2008).

Several authors highlight different, but interrelated and similar ways to monitor and reduce impact of supply chain disruptions. Key factors in risk management for companies is centralized market information and to employ people with risk management knowledge and the ability to be subjective (Ganguly and Guin 2013; Choi and Linton 2009; Datta and Christopher 2011). Additionally, it is of high importance to distribute the centralized market information though the company (Datta and Christopher 2011). To prevent future failures, the firm should also aim at reducing the tightness of the coupling and/or complexity of the supply chain (Perrow 1984). The former is done; by building in slack into the supply chain by increasing the degree of flexibility and redundancy by e.g. expands buffers. To reduce complexity there are two factors to view closer, the structure of the supply chain and the products (Perrow 1984). Furthermore, it is of high importance that the firm does not outsource too much of its operations to suppliers since that would increase the risk to miss changes in technology and market conditions. A high degree of market knowledge is of great importance for a company to know how to act and handle the risks they are exposed to (Choi and Linton 2009).

In the influential article *Purchasing must become supply management* (1983), Kraljic outlines several key parameters for diagnosing and mitigating risks related to procurement. The need for a supply strategy is said to depend on two parameters: strategic importance of the item and the complexity of the supply market. Based on these two parameters, a mapping can be done and conclusions can be drawn regarding the required level of sophistication in the procurement process. After completing the first phase of classification, a market analysis needs to be performed by assessing different aspects of the supply including supplier's capacity, uniqueness and the potential impact of a component shortage. Based on the market analysis and the classification of importance, the strategic positioning in the supply market needs to be considered. To assist this process, the Kraljic Purchasing Portfolio Matrix based on the two parameters from the classification phase should be drawn. Depending on the company's relative strength to the suppliers, a strategic position upon which concrete actions should be determined (Kraljic 1983). The work by Kraljic is, however, very focused on suppliers and components rather than commodities.

The conceptual frameworks focusing on commodity price risk is generally fairly underdeveloped and very focused on financial hedging (Fischl *et al.* 2014). Zsidisin and Hartley (2012b) do, however, offer a holistic framework to manage commodity price risk. Appropriately, this framework is adapted to the special circumstances of the commodity markets. Their framework consists of two parts; estimating risk exposure and creating a commodity price risk management strategy (see figure 2.1). The goal of the first part is to draw a risk matrix similar to the matrix drawn up by Kraljic (1983) but with Degree of Price Volatility on the Y-axis and Level of dependence on Commodity on the X-axis (see figure 2.1). The main difference of the commodity price risk adaptation is the focus on price volatility rather than supply risk that is a key parameter of the original one. Based on the level of risk exposure, the firm can then decide on how actively it should manage the risk. The volatility of the commodity is in this framework estimated by considering both historic data and forecasts of the future. To determine the dependence of the company on a commodity several factors such as amount of direct spend, amount purchased by upstream suppliers and the availability and viability of substitutes is considered (Zsidisin and Hartley 2012b).

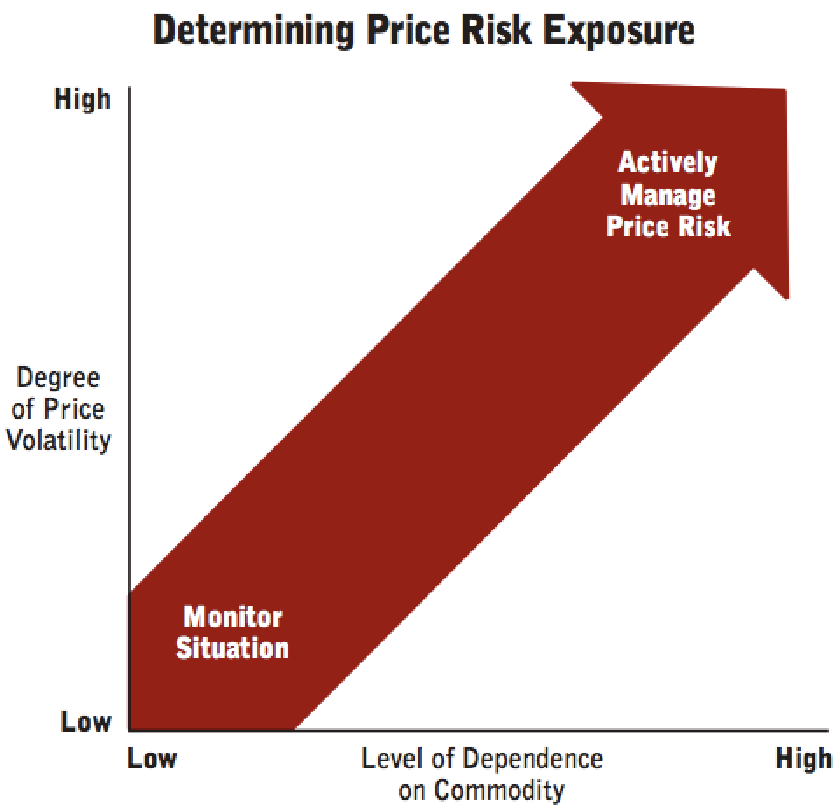

Figure 2.1 Determining price risk exposure (Zsidisin and Hartley 2012a)

The second part of the framework is devoted towards developing a risk management strategy (see figure 2.2). For this purpose, the authors have identified components to take into consideration when designing the strategy (Zsidisin and Hartley 2012b).

The different steps in figure 2.2 below should be seen, as a decision tool where *substituting*, when possible, tends to be the most preferable solution. If substitution is not a viable option, the strategist should move on down to consider *pass/share risk with customer*. If the second strategy is not possible the third alternative, *pass/share risk with supplier* should be considered. *Forward buy* is the fourth step in the decision tool and if this is not possible the company should investigate if direct markets exist, where the company could *hedge* against the commodity risk. An alternative if direct markets do not exist, the company should investigate substitute markets, referred to as *cross-hedging.* Finally if no of the above mentioned strategies are possible the final option is *absorb risk/reduce demand* (Zsidisin and Hartley 2012b).

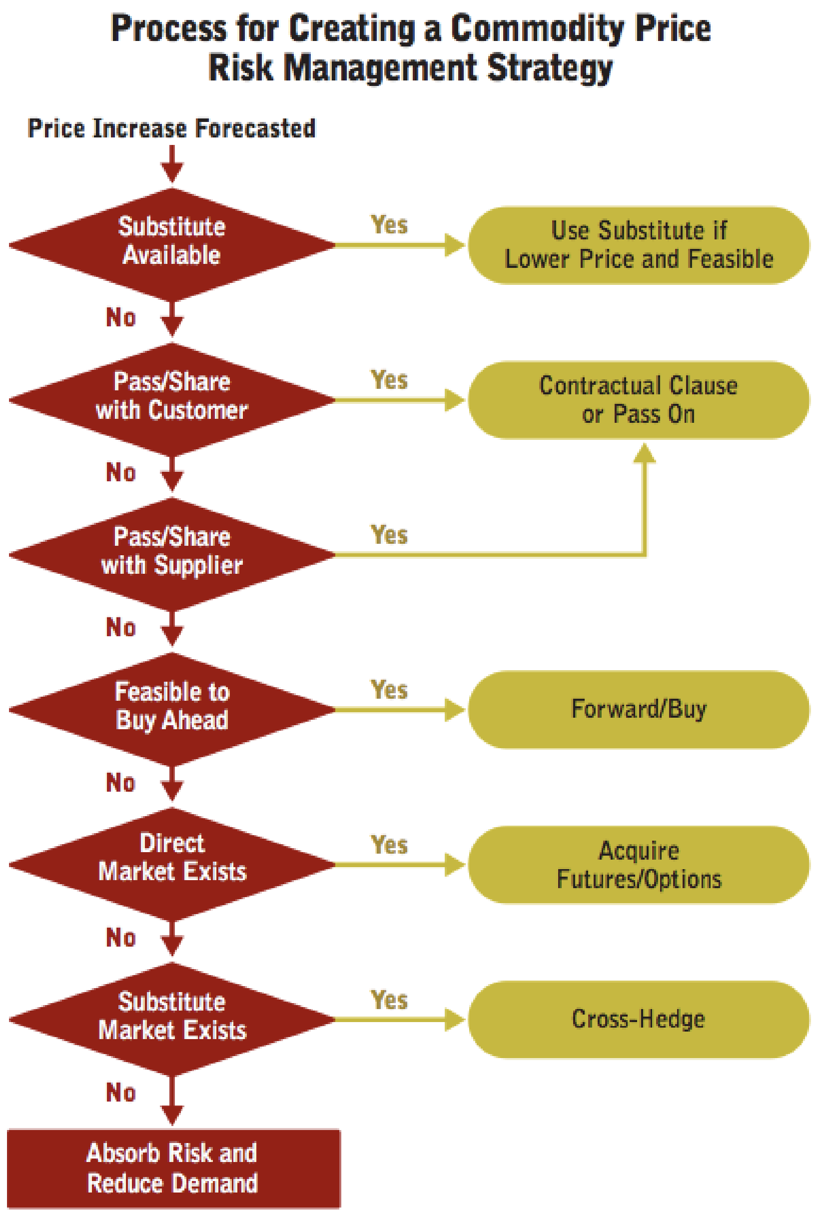

Figure 2.2 Decision tool for creating a commodity price risk management strategy (Zsidisin and Hartley 2012a)

Similarly to the framework developed by Zsidisin and Hartley (2012b), Slowinski *et al.* (2013) have identified four areas of actions to be taken by a firm facing shortages of critical materials. The first action is to identify critical materials and to assess the risks associated with them. Plotting the different materials into various adaptations of supply risk matrixes frequently does this. However, this might be hard for many firms with outsourced activities due to difficulties to oversee all tiers of upstream suppliers. The second action is to address the demand by reducing, recycling and reusing the concerned material. When reducing demand, it is important to consider different solutions depending on the properties of the used material since it is very hard to find a solution that fits all situations. The third action is to communicate the management and make them fully aware of the potential material shortage and its potential implications. This action is done best when the implications are quantified and communicated as a financial matter. The fourth and last action is to secure the supply. This is mainly done by backward vertical integration and to assume control over the supply by either taking part in a consortium or by acquiring a stake in a producer of the concerned material. An example relevant to this this thesis is Toyota's formation of a joint venture with a Canadian producer of rare earth elements (Slowinski *et al.* 2013).

In the same spirit, but more focused on the supply side and macroeconomics rather than the focal firm, Bell *et al.* (2012) offers a natural resource scarcity framework. For the situation of rare earth elements where the resource is non-renewable and globally scarce a discretion strategy can be employed. This risk mitigation strategy focuses on redesign of products to lower usage and an increased focus on recycling (Bell *et al.* 2012).

2.5 Risk Exposure

The first step in designing a strategy for managing commodity price risk is to look into the firm and assess its risk exposure. The level of risk exposure is determined by the interplay of two critical factors, level of dependence and price volatility (Zsidisin and Hartley 2012b). These factors could cover several of the different risk components of commodity prices such as diversity of supply and political risks (Slowinski *et al* 2013).

2.5.1 Price Volatility

Price volatility of key inputs is a great source of instability for a business and it needs to be assessed closely in order to determine a firm's price risk exposure. If historical volatility is low, usually it is enough to only monitor the situation rather than actively manage. Also, if past volatility is caused by accidental events such as natural disasters, the volatility can be overlooked (Zsidisin and Hartley 2012b). Hence, it can be argued that only structural sources of volatility should be considered when investigating the volatility of a certain market. The authors further state that, the simplest methods to measure the volatility of a commodity price are to compare the standard deviation or the high/low-range with the mean value. To perform a fundamental analysis, however, a more subjective approach is required to understand the underlying supply and demand (Zsidisin and Hartley 2012b).

When assessing price volatility it is also important to look into the future at the forecasted commodity prices. There are several organizations, including the World Bank and many private firms, offering market intelligence for commodities. It is only possible to develop own forecasts by performing either a technical or fundamental analysis. Fundamental analysis tends to be more long-term focused and based on the assumption that the interplay between supply and demand drives the market. The analysis aims at examining the underlying market forces of supply and demand and how it will affect the prices. The process of estimating a long-term price includes both a qualitative and a quantitative part and if there is a correlation between supply and demand, a regression analysis can be derived (Zsidisin and Hartley 2012b).

It is natural for critical minerals to experience boom and bust cycles on a regular basis making the prices very volatile (Rosenau-Tornow *et al*. 2009). Since the production of neodymium and dysprosium is highly concentrated to one country and the substitutes are limited, China can exert a strong bargaining power on the market. Even though there is no lack of geological resources of rare earth elements, the monopolistic situation where China controls the whole process from mining to separation pose a serious market risk (Golev *et al*. 2014). In 2010, China used its dominant market position and caused a 20-fold price increase in only a matter of months (Nieto *et al*. 2013). Even though the prices have declined since then (Golev *et al*. 2014), it can be seen, as an example of the impact China possesses on the market. Countries privileged with a high level market power are not very likely to stop taking advantage of their market power in the short-term (Massari and Ruberti 2013). This is particularly true for rare earth elements since they are to be viewed as one of the future key strategic resources in global trade.

Start-up mines across the globe provide potential for some much needed supply diversification and these projects could in a couple of years mean that the Chinese hegemony is over in the rare earth elements-sector (Golev *et al*. 2014). When the mining capacity that currently is developed will be operational, this could help increasing the non-Chinese rare earth market shares to satisfactory levels (Habib and Wenzel 2014). Despite the optimism, questions remain regarding the long-term profitability of these mines due to China's low cost level (Hensel 2011). For dysprosium, however, it is a bit more complicated than for neodymium, since China controls about 70% of the world's reserve. It is thus likely that China will maintain its dominant market position in the short to medium-term until recycling offers an alternative supply (Habib and Wenzel 2014).

Both neodymium and dysprosium are likely to experience a rapid growth in demand in the future, which will put pressure on the supply. This is should lead to significant market risk in the short-to-medium term according to Moss *et al.* (2013). There are obstacles in the production capacity for both materials and the investments made in new mines are only likely to impact the supply positively in the long-term (Moss *et al.* 2013). These limitations are, however, more severe for dysprosium than for neodymium. This is further supported by studies showing that the projected future output will not be enough to cover the aggregated demand for dysprosium and neodymium (Habib and Wenzel 2014; Hoenderdaal *et al.* 2013). The high market risk identified for neodymium and dysprosium is further increased by the political risks associated with China's great control of the production. All these factors have according to Moss *et al.* (2013) lead to very volatile prices in the last few years.

2.5.2 Level of Dependency

In most cases, organizations' offerings are highly dependent on the externally controlled resources, which make the company dependent on its suppliers. Therefore, extensive focus should be placed on the resources that are procured by the organization (Kraljic 1983).

The level of dependence on a commodity is based on three different factors; the amount of a commodity purchased directly by the focal firm, the amount purchased by upstream suppliers and the availability and viability of substitutes. The assessment of dependence begins with a spend analysis to map up how much, by whom and from where material is being purchased. It is highly important that the spend analysis also covers the materials embedded in parts purchased from suppliers since high volatility and rising prices will be passed on to the focal firm or lead to financial distress of the supplier. Substituting the commodity in question can serve as a buffer against rising prices and needs to be evaluated closely in order to estimate the dependence (Zsidisin and Hartley 2012b).

Dependence on rare earth elements is assessed by reviewing different alternatives to reduce the rare earth elements content, which is done by comparing the costs and benefits of the different alternative solutions (Nieto *et al.* 2013). For both dysprosium and neodymium, the main usage area is the electronic applications and more particularly in magnets. Neodymium is also commonly used for the printed circuit board. The amount of both neodymium and dysprosium used is highly affected by the electrification and equipment level of the car. This means that the hybrid cars uses a lot more of the two materials than the conventional ones and the usage of neodymium and dysprosium is approximately 2,5 and 4,8 times higher for a hybrid midsize car than a conventional one (Cullbrand and Magnusson 2011; Massari and Ruberti 2013). This holds true also for other companies' hybrid cars, like the Toyota Prius to which neodymium is vital (Hensel 2011).

2.6 Risk Mitigation Strategies

When the risk exposure of the company is mapped up, the next step is to develop a strategy to mitigate the risks (Zsidisin and Hartley 2012b). Mitigation strategies can involve several different actions but the key is to execute them successfully is flexibility (Zsidisin and Hartley 2012b; Slowinski *et al.* 2013).

2.6.1 Substitute

In times of material shortage, substitution of materials could serve as an efficient mitigation strategy (Joce 2013). Also, for a firm facing higher or volatile prices of a commodity, the firm can benefit from looking for possible substitutes. Substituting is therefore cited as the first mitigation strategy to consider when exposed to price risk (Zsidisin and Hartley 2012b). When doing so, it is important to assess both the cost of the materials and the costs related to switching to the substitute. Even when it is economically viable to switch materials, it is a major project to select and implement. Typically, the process requires involvement of several internal business units and supply chain partners and the involved business units usually include design, marketing, operations, purchasing and logistic. Of these, the design and marketing departments tend to have a very important role. The design department has a key role in ensuring that the substituted material does not affect the quality or performance negatively. The marketing department needs to ensure that the new material does not harm the customer perception of the product. On top of this, the supply management function tends to have the coordinating role of the task to introduce new substitutes (Zsidisin and Hartley 2012b).

In many industries, flexibility in the design stage helps organizations to switch the materials used depending on the current market situation. To be able to use two or more materials that intersect and preferably are negatively correlated can be highly beneficial in the effort to tackle price risks (Zsidisin and Hartley 2012b). For rare earth elements, a substitution strategy might, however, be tricky to achieve in the near term due to the lack of substitutes to the most commonly used rare earth elements (Golev *et al.* 2014). Rare earth elements, like neodymium and dysprosium do possess unique chemical and physical properties, making them difficult to replace (Habib and Wenzel 2014). In the long run, however, nanotechnology is likely to present the possibility of substituting the rare earth elements by emulating their properties. Nanostructured magnets could reduce the demand for rare earth elements and at the same time make the magnets stronger than the ones being used today (Massari and Ruberti 2013). This development lays, however, far into the future.

2.6.2 Pass/Share risk

If the organization has enough leverage over its customers or suppliers it can pass or share a larger portion of the risk to/with them. This is common practice in several industries such as trucking, where fuel surcharges are very frequent. Whether or not depends on different factors including degree of competition on both customer and supply market, the type of industry and the financial state of the counterparts (Zsidisin and Hartley 2012b).

To pass and/or share risks with customers receives support from the discovery that, for some segments, relationship with the seller is increasingly important for the consumer when making a purchase decision (Odekerken-Schröder 2003). By prioritizing relationship over price to a greater extent it could imply a chance for the auto manufacturer to pass on some of the increases in raw material prices to the customer. However, it should be noted that the automotive industry tends to be extremely competitive (Talay *et al.* 2014). Intense competition tends to lead to less bargaining power for the seller making it hard to pass on price increases (Porter 1979).

The automotive Original Equipment Manufacturer's (OEM) supplier relationship tends to be highly buyer-dominated (Lilliecreutz 1998). This implies that price increases and risk should be easy to pass on to the suppliers (Porter 1979). However, the financial situation of the supplier is a latent risk for the buying firm who needs to consider the total risk of the whole supplier base. This gives an incentive for the OEM, who tends to be the strongest part, to manage the total risk of the supply chain in some cases (Hofman 2011). The risk of financial hardship is one reason for a buying firm not to pass on risk or costs to its suppliers who might not have the capability or resources to manage price risks. This may deteriorate the relationship and cause supply disruptions in the future (Zsidisin and Hartley 2012b). The firm needs to consider the type of supplier relationship that will be the most beneficial, a relational or a short term focused. Which one of these, or if a combination, is to be preferred depends on different demand and cost parameters (Peleg *et al*. 2002). Relational contracts tend to be more long-term oriented and include more joint efforts and information sharing than a typical arm's length relationship. If the firm elect to pursue a relational relationship to a certain supplier, it is expected that burden and benefits is to be shared by both parties, (Wagner and Boutellier, 2002). This could limit the possibilities for an automotive manufacturer to let the supplier take the hit from price increases. A clearly defined way for sharing the commodity price risk is to insert a price escalator clause that adjusts the price of the products when the commodity price is changing. The clause typically includes a third-party reference for price increases, like a commodity index and clear instructions on how to share the risk (Zsidisin and Hartley 2012b).

2.6.3 Forward buy

Forward buying could be a suitable strategy for tackling future price increases (Zsidisin and Hartley 2012b). By increasing the safety stock of key products or material and share the costs of the increased stock reduces the risk of disruption (Lee 2002). It requires the firm to buy its commodities from the spot market and to have the capital to purchase and store large quantities of the commodity. Another deficit of the strategy is that it does not work with a lean supply chain since it ties a lot of capital. Furthermore, it does also add risk to the organization by taking on a risk of buying material based on forecast and increased of operational complexity due to increased storage (Zsidisin and Hartley 2012b). These drawbacks are partly confirmed by Manikas *et al.* 2007, who state that the main issue of the strategy is to balance out the profit and holding cost. To determine if the downsides are offset by benefits it is important to closely examine how and by whom the commodity is consumed (Zsidisin and Hartley 2012b).

2.6.4 Hedge/Cross-hedge

One way to handle supply risk is to share resources, which result in sharing and pooling the risk of supply disruption; this strategy is called risk-hedging strategy and by sharing the risk between several entities, each one of them become less vulnerable (Lee 2002). Manuj and Mentzer (2008) more specifically define hedging against supply chain risk as "a globally dispersed portfolio of suppliers, customers, and facilities such that a single event (like currency fluctuations or a natural disaster) does not affect all the entities at the same time and/or with the same magnitude" (p. 142).

By purchasing forward contracts rather than the physical goods, many of the drawbacks of forward buying can be offset. The forward contracts are highly standardized in terms of delivery, time and payment and the only variable is the price. For commodities the most trading is done on the Chicago mercantile exchange. Since the forward contracts are a type of financial instrument, the price is in most cases higher than the spot market price until the date of delivery. The forward contract market is, however, limited to the most common commodities and many commodities are therefore not possible to hedge against using forward contracts. The alternative is then to identify other commodities with an existing forward contract market that show a strong correlation with the commodity at risk. Once a strong positive correlation has been identified one also needs to analyse the fundamentals of the pair to ensure future correlation to be likely (Zsidisin and Hartley 2012b).

2.6.5 Absorb risk/Reduce demand

When none of the previously mentioned strategies to manage price risk is feasible, the only solution may be for the focal firm to absorb the risk. When doing so, the firm gets a chance to minimize the long-term exposure to the commodity. This strategy tends to have a large potential and requires extensive inter- and intra-firm collaboration and an early involvement in the design phase (Zsidisin and Hartley 2012b). Inter-firm collaboration with suppliers is cited as beneficial for a company to enhance the innovativeness of the firm. It does, however, require active management to exploit the full potential of these strategic type supplier-partnerships in the development phase. The supplier-buyer relationship could be distinguished depending on its time frame and deepness of integration. For instance, DaimlerChrysler tends to categorize its supplier-partners into four different categories depending on those two parameters (Wagner and Boutellier, 2002). Intra-firm collaboration may, however, be hard to perform due to the lack of cross-functional integration (Griffin and Hauser 1996). If departments such as R&D, marketing and manufacturing have a high level of interdependence and are very different this might result in conflicts regarding objectives, decision criteria and which approach that should be used in designing and producing new products (Griffin and Hauser 1992). Conversely, good communication between different departments improves the company's ability in new product development. Further complicating, the design changes is in itself a source of supply chain risk (Lin and Zhou 2011), exposing the R&D, production planning, information and organizational structure. Seen in that light, the solution with changing the design a bit paradoxical. This approach could also be called a discretion strategy since it is covering the redesign of products and an aim at recycling of the minerals (Bell *et al.* 2012). To focus on consumption reduction and recycling is further supported by the fact that being at risks tends to take focus from more important and productive tasks (Banham 2004).

Waste reduction, recycling and reuse are all potential measures to reduce demand of critical materials, including neodymium and dysprosium (Habib and Wenzel 2014; Moss *et al.* 2013). Technical difficulties to extract minerals from scrap, relatively low prices and the abundance of a primary supply has historically hampered the interest in recycling of neodymium and dysprosium. Despite these drawbacks, the interest in recycling has increased significantly as the markets has become more volatile (Golev *et al*. 2014). However, recycling of rare earth elements has a great potential to grow from today's low levels of 1%, despite technical difficulties. To realize the potential, new processes need to be developed due to the fact that the most common rare earth elements applications like magnets and alloys are very complex to reuse or recycle. Furthermore, since many magnets contain only small amounts and also different types of rare earth elements the waste needs to be treated individually (Binnemans *et al.* 2013; Moss *et al.* 2011). Involvement of different industries is further to be seen as a key action in developing new design and production processes adapted to rare earth recycling (Golev *et al*. 2014). In the short to medium-term, it will be tough to replace the demand for virgin dysprosium and neodymium by recycled materials. This is mainly due to the long lifetime of the typical products containing the material, which causes a long time gap before the products are scrapped. On longer sight, recycling could, however, play a significant role in matching supply with demand (Habib and Wenzel 2014; Golev *et al*. 2014).

2.6.6 Secure Supply

A firm can offset a competitive disadvantage by participating in direct investments and thereby get access to critical resources (Honglin Zhang 2009). This has been done to mitigate the risk of soaring material prices; some companies has stepped away from its core businesses and engaged in mining activities. The engagement can be done in different degrees of involvement and typically it means a pure financial investment in an existing mining company or the formation of a joint venture between the two firms. These investments are often a large business undertaking and demand a very long-term focus to solve the supply shortage (Slowinski *et al.* 2013). It is also a shift of focus away from the core competencies of the companies, which in most cases of industrial firms can be assumed not to be mining activities. It is of great importance for firms to focus on core competences and not doing so could potentially be harmful to the business (Prahalad and Hamel 1990). An alternative for a single firm to make an investment alone is to form a consortium with other actors in the same position. This solution helps sharing the risk and financing burden of the often long-term and highly insecure projects of new mining development (Slowinski *et al.* 2013).

Toyota has applied the strategy of securing rare earth supply by forming a joint venture with a Canadian rare earth miner. In the agreement, the Canadian firm is responsible for fully develop the mining activities and Toyota commits to purchasing 100% of the mining output (Slowinski *et al.* 2013). This strategy could potentially be replicated in Europe in order to secure the supply of neodymium and dysprosium (Moss *et al.* 2012).

2.7 Summary of the literature review

It is of high importance for companies to understand different risks the company is exposed to and how these could be handled in an effective way. Many companies are highly dependent on resources that are externally controlled. Therefore, creating a commodity price risk management strategy is of great importance. In figure 2.3, an overview of the literature review is illustrated. In risk management the factors centralized information, communication of management and market knowledge are identified as high important when engaging in risk management. Additionally, a framework of how to mitigate commodity price risk was identified and complemented with one more mitigation strategy called secure supply.

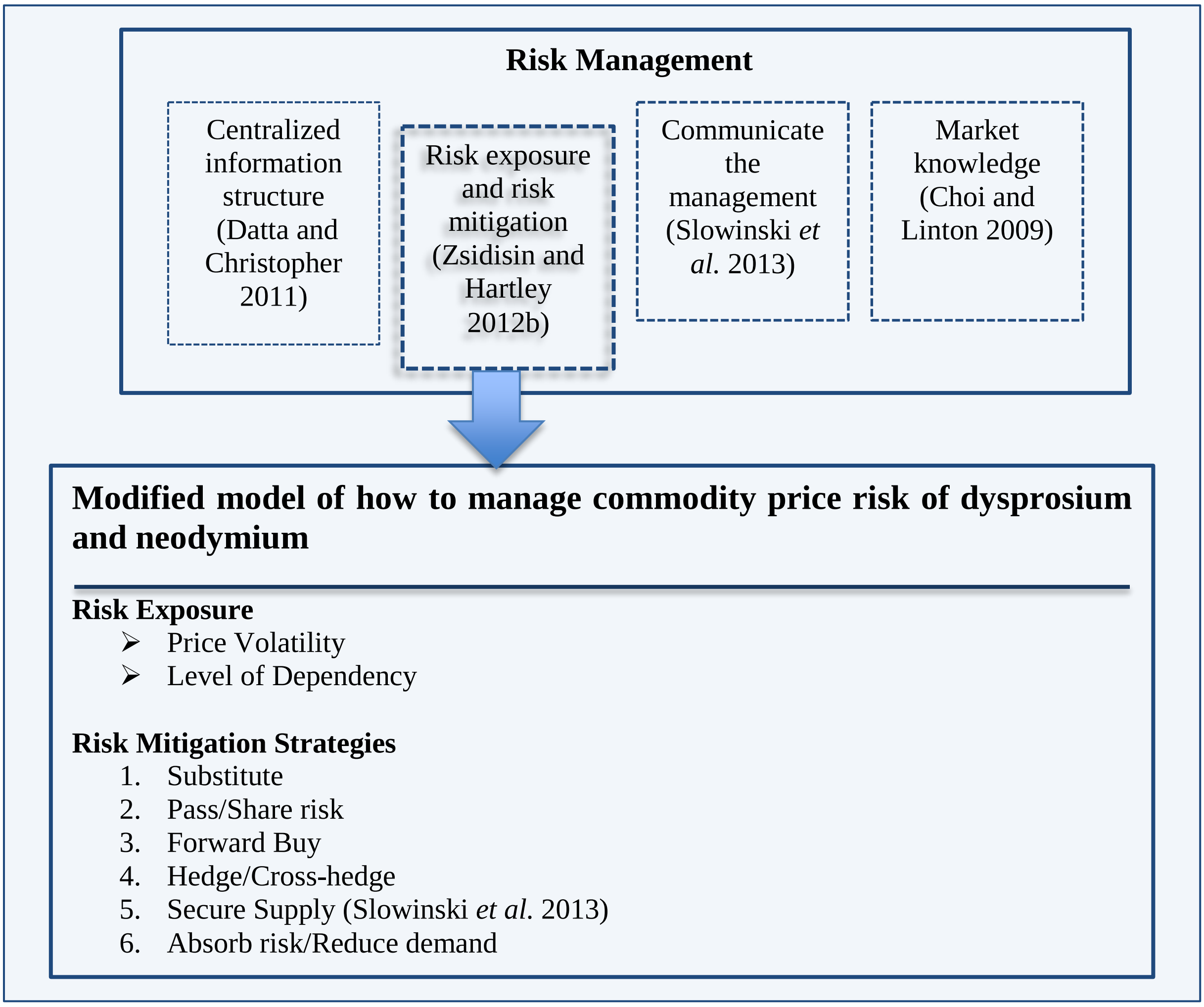

Figure 2.3 Own conceptual model based on the theoretical review

Companies who are including dysprosium and neodymium in their supply chains need to monitor the price volatility of these materials in order to evaluate the **risk exposure** of the company. Furthermore, the dependence on the materials is crucial when deciding which actions that need to be taken. The interplay between price volatility and level of dependency defines the firm's exposure to risk and when this does not match risk tolerance of the company, something has to be done. Furthermore, information sharing in the supply chain and a high degree of market knowledge is of high importance when handling risk in a company.

A couple of **mitigation strategies** are highlighted in the literature review, where substituting is one of the most important ones. By finding a substitute for dysprosium and neodymium, companies including these materials in their productions could reduce their dependence on the materials and reduce the price risks. Passing risk to or share risk with suppliers and customers has been merged mainly due to the fact that the literature gives little support to the opportunity of passing risk to customers. To succeed in passing or sharing price risks, the actor exposed for the risk, needs to have the capabilities and resources to handle the risk.

No research have been found, that forward buy is not possible as a mitigation strategy for reducing risk exposure for dysprosium and neodymium, and will therefore be included in the modified model. Hedging and cross hedging has also been merged since they can be considered complementary and due to limited support in the academic literature. Hedging is included in the modified model due to it have advantages of forward buying but eliminates the disadvantages like significant levels tied up capital. The theory does, however, not present if it is a possible action for the rare earth elements in focus and therefore needs to be further investigated.

The next mitigation strategy is to evaluate the possibility to secure the supply of dysprosium and neodymium and increase the control in the supply chain by vertical integration backwards. Secure supply is an action added to the original framework by Zsidisin and Hartley (2012b), but is considered as a possible way to mitigating price risks of dysprosium and neodymium. Furthermore, Toyota has used the secure supply of rare earth elements, adding support to the action. Therefore secure supply is included in the modified mode. The final mitigation action would be for the company to absorb the risk and reduce the demand by performing actions such as recycling, reusing and redesigning of products to limit the use of rare earth elements.

This own conceptual model, based on prior research, will be used for analysing the empirical findings; in order to evaluate possible risk management strategies for an automotive manufacturer regarding the use of dysprosium and neodymium.

3 Methodology

This section aims to provide a description of the research strategy, design and methods used when performing this investigation. This will make it possible for the reader to evaluate the research and its results.

3.1 Research strategy

In order to understand the market of rare earth elements, information about the metals characteristics, usage, demand, supply and features was collected. After the researchers had gathered this knowledge it was possible to make the decisions of which research strategy to use. A qualitative research approach was chosen to make it possible to gain a deep understanding of the automotive industry. This approach made it possible to evaluate the risk exposure as well as find new ideas of how to handle market related price changes of dysprosium and neodymium. This deep understanding would not be possible by conducting a quantitative study (Bryman and Bell 2011).

Before collecting primary data, a historical overview of the subject was performed, which is of high importance when conducting the qualitative research. The historical review provided a comprehensive understanding of the issues, surroundings and function, which worked as a support when studying the primary data (Collis and Hussey 2009).

Important to be mentioned is that when adapting a qualitative research, there is a high risk of bias. This is because the qualitative research is based on an interpretivist paradigm, where the researchers are not objective but affect the research in order to analyse the complexity of a problem (Collis and Hussey 2009). The aim of this research was to learn something by looking deep into a specific case study and not to achieve a high level of generalization. The results could serve as a source of knowledge for others to use when transferring the results to other settings, environments or areas (Denzin and Lincoln 2002).

This research aims to provide insights and a starting point of a framework of how Volvo could attack the problem of mitigating their risk exposure of dysprosium and neodymium on a managerial level. Other car manufacturers could although use the framework as a benchmark but needs to consider that the research is viewed from Volvo´s perspective.

3.2 Research design

To fulfil the purpose of this investigation, a case study of Volvo was performed. This made it possible to investigate the problem in its natural environment, which provided a deep and comprehensive understanding of the issue. A descriptive case study was used to explain and identify the concept and an exploratory study was used to come up with new ideas and solutions possible to test in a later stage of the research process (Scapens 1990). In this way, information, ideas and strategies founded in different parts of the organization and with the supplier could provide knowledge of how to handle market related price fluctuations of neodymium and dysprosium.

This research was conducted with an abductive approach, which made it possible to go back and forth between theoretical models and empirical findings in the process of fulfilling the research purpose and assembly conclusions (see figure 3.1) (Dubois and Gadde 2002). The abductive approach expanded the understanding of theory and empirical findings, which improved chances of finding improvements in the current theoretical review of how Volvo, and possibly other companies, should view commodity price risks of neodymium and dysprosium.

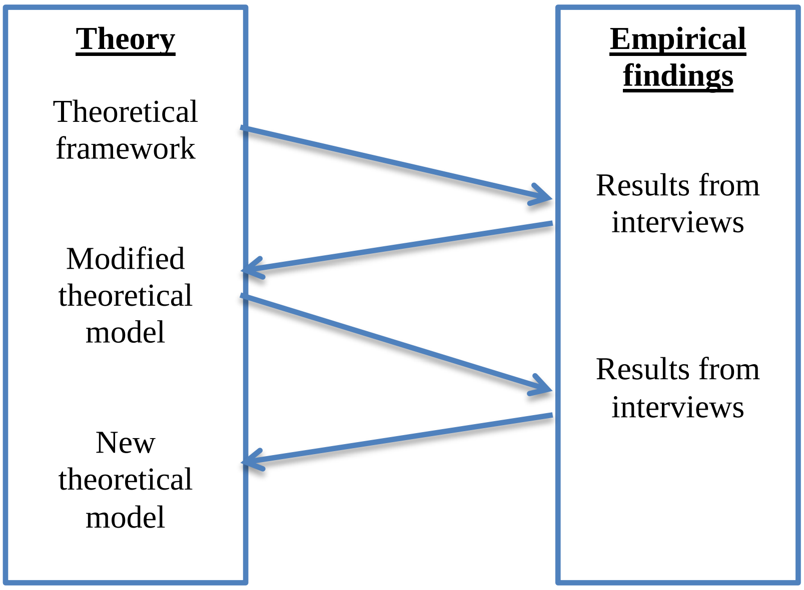

Figure 3.1 Own illustrative model of abductive approach (Dubois and Gadde 2002)

3.3 Research methods

3.3.1 Secondary data collection

The objective of this study was to investigate the characteristics and problems associated with the price risk of dysprosium and neodymium. Both historical information and estimations of the future was conducted to achieve a good overview to understand problems, drives and the characteristics of the subject. The secondary data for the theoretical review was collected from articles and books of earlier research within the field of rare earth elements as well as within commodity price risk and raw material scarcity. These sources were collected from the databases: ScienceDirect, Business Source Premier, Emerald, LIBRIS and GUNDA. All references for the theoretical review have been peer-reviewed and authors and references have been evaluated to ensure a high quality of the theoretical review of this thesis. Furthermore, the researchers have had in mind that the secondary sources have different purposes than this research and therefore must be viewed critically to avoid misleading interpretations. The usage of secondary data made it possible to save time and increase the focus on this research specific purpose. Furthermore, websites of Volvo and relevant industry papers have been used to collect substantial background information for the introduction, problematisation and case description. For these sections also reports from European Commission and U.S. Energy Department have been used.

During the theoretical review the book '*Managing commodity price risk*' by Zsidisin and Hartley (2012b) was found. This was used as a point of departure for the theoretical framework when investigating mitigation of commodity price risks because it is a acknowledged framework, which other articles and studies have referred to as best in practice. Furthermore, this framework by Zsidisin and Hartley (2012b) could be seen as the most holistic and well suited for the investigation conducted in this thesis. This conclusion is supported by the literature review performed by Fischl et al (2014) and by the fact that the purpose of this thesis is to perform a firm-centric investigation. Additional theory was added to the framework by Zsidisin and Hartley (2012b), which is presented in table 3.1 below. These other theories complement the framework both in the focus of rare earth elements and automotive industry. A strategic action to the existing framework was added, for the firm to secure the supply by participating in direct production or in consortia (Slowinski *et al.* 2013). This was done since it is a proven strategy within the automotive industry to mitigate risks related to the prices of rare earth elements, it should be a viable option for the research. Furthermore, other theories were added to include the rare earth element perspective.

There are possible disadvantages of using an existing framework as a starting point for an investigation. It could create a narrow perspective and other possible price risk strategies could be unconsciously excluded. This have been kept in mind when conducting the investigation and during the interviews the researchers consciously tried to capture other inputs from the respondents in addition to the strategies from the theoretical framework.

Subject	References
2.5.1 Price volatility in the rare earth element market	Rosenau-Tornow *et al.* 2009; Golev *et al.* 2014; Nieto *et al.* 2013; Massari and Ruberti 2013; Habib and Wenzel 2014; Hensel 2011; Moss *et al.* 2013; Hoenderdaal *et al.* 2013
2.5.2 Level of dependency of rare earth elements	Kraljic 1983; Nieto *et al.* 2013; Cullbrand and Magnusson 2011; Massari and Ruberti 2013; Hensel 2011
2.6 Mitigation strategies	
• Substituting	Golev *et al.* 2014; Habib and Wenzel 2014; Massari and Ruberti 2013
• Pass/Share risk	Lilliecreutz 1998; Porter 1979; Peleg *et al.* 2002
• Forward buy	Lee 2002; Manikas *et al.* 2007
• Hedge/Cross-hedge	Lee 2002; Manuj and Mentzer 2008; Nagali 2008
• Absorb risk/Reduce demand	Griffin and Hauser 1996; Griffin and Hauser 1992; Bell *et al.* 2012; Banham 2004; Habib and Wenzel 2014; Moss *et al.* 2013; Golev *et al.* 2014; Binnemans *et al.* 2013; Moss *et al.* 2011
• Secure supply	Honglin Zhang 2009; Slowinski *et al.* 2013; Prahalad and Hamel 1990; Moss *et al.* 2012

Table 3.1 Added theories to the framework by Zsidisin and Hartley (2012b)

3.3.2 Primary data collection

For the primary data collection, nine interviews were performed at Volvo. Additionally, three external interviews were supposed to be performed with suppliers of Volvo, in order to get as comprehensive knowledge as possible. Despite long answering time and repeated reminders about answering the questions to the suppliers, only answers from one supplier have been obtained. The supplier we obtained answer from is presented in table 3.2 below.

Company	Department	Industry	Revenues (Dollar)	Number of employees
TRW Automotive group (Supplier C)	Answers collected from many different departments.	Automotive systems	17,4 billion	67 100 (full-time employees) 11 100 (temporary employees)

Table 3.2 Key figures of suppliers interviewed (TRW 2013)

Selection of respondents

In the process of choosing whom to interview, the material system: International Material Data System (IMDS) was used as an initial information source. In this system the components with high level of dysprosium and neodymium could be identified: rear axle (product A), loudspeaker (product B) and servo pump (product C). The rear axle and the servo pump were founded in a V60 hybrid car while the loudspeaker was founded in a *top of the line*[1] V60 car, which was not a hybrid model. These components were chosen due to their high content of the rare earth elements in focus.

This study's objective is not to investigate a specific car model, but to evaluate how production of cars in general, containing dysprosium and neodymium, might be affected by scarce supply of these materials.

The supplier, responsible purchasers and designers (R&D) of the chosen components were identified and interviewed. In this way data could be collected from different levels vertically in the supply chain, which made it possible for the researcher to understand the subject from different perspectives in the supply chain. The purchasers contributed with information of how the purchasing process is performed and how collaboration and negotiations with suppliers works. The supplier was interviewed to conduct information, ideas and input, which it caught up from lower levels in the supply chain, regarding the rare earth elements in focus. This interview also gave an insight of how the supplier views the problem of the supply of dysprosium and neodymium and the collaboration regarding this between the supplier and Volvo.

Additionally, cross-functional interviews were conducted with individuals at Volvo, possessing expert knowledge in the research focus. The departments interviewed were: market intelligence, inbound logistic and optimization and environment & fluid dynamics. Representatives from the market intelligence department were interviewed since this department has a high level of market information and are analysing developments of prices and risks connected to purchase material. Input from the inbound logistic and optimization department was needed to evaluate activities viability, such as forward buying. Furthermore, information could be gathered about differences of transportation

[1] A top of the line car model refers to a car with the best equipment available.

characteristics, depending on where in the world the rare earth elements in focus are purchased. The high importance of the environmental perspective of this thesis created strong incentives to interview representatives from the environment & fluid dynamics department. The respondents interviewed were chosen based on competences, capabilities of the research focus and position in the company to ensure the validity of the information collected. Below a figure are presented of how the interviews been performed (see figure 3.2).

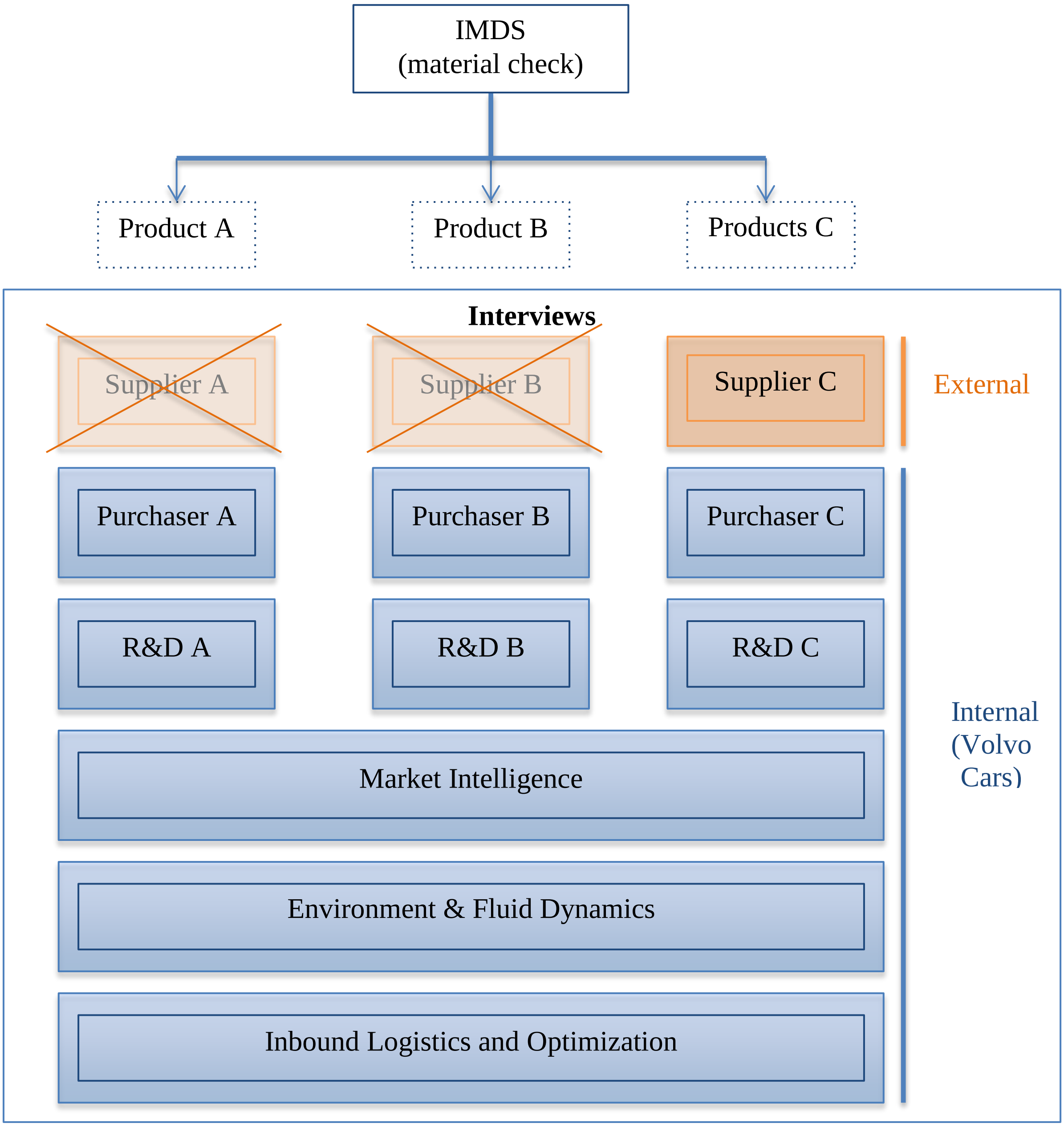

Figure 3.2 Structure of the interviews

Interviews

The interview questions were formulated to make it possible to answer the research questions and fulfil the purpose. The structure of the questions were formed from the theoretical review to create a good and thought through flow in the interviews. The asked questions were adopted depending on whether the interviews were internal or external, to obtain as much information as possible from the different respondents. The internal interviews were conducted to gain a better understanding and to distinguish how risks are handled and interpreted in the company’s activities. At some of the interviews two representatives were present and their answers will be united and referred to as the answers from their department. The interviews were 30-45 minutes, due to limited time restriction from Volvo. However, additional questions were complemented by mail if an answer was not comprehensive enough. In this way an extensive understanding could be perceived even if the interviews were in some cases short. The external interview aimed at finding new input from the supplier that it could absorb from the market. It mainly focused on conducting information of how the supplier looked at the problem and its views on future development. In the process of contacting suppliers the researchers had a close collaboration with the purchasing department and the communication department at Volvo. The introduction letter (Appendix B), interview questions (Appendix C and D) and practical details were reviewed several times to avoid misinterpretations and increase the supplier´s willingness of collaboration. This was also of importance in order to sustain good relationships between Volvo and its suppliers.

Semi-structured interviews were chosen for the qualitative interviews to be able to compare the answers obtained in the interviews and to enhance the flexibility in the interviews. Parts of the questions were prepared on forehand, but there were also space for unplanned questions, which makes it possible to explore the topic and come across rich and deep information (Bryman and Bell 2011). The respondents were in this way given space in developing their answers. This made it possible to catch information and aspects of the subject that could not be foreseen and provided a complete picture of the issue. The different departments at Volvo had various levels of information and knowledge and some had more detailed information than others. If the respondent had no or low level of knowledge of the asked questions, more focus and complementary questions were asked within the topic of where the respondent could provide information. In this way, the research could benefit from the flexibility that semi-structured interview method. The gaps of information in the results are because the respondent did not have knowledge or information of the question.

Open questions were used to avoid yes and no answers and in this way the respondents were forced to provide a more comprehensive answer. The questions for the interviews were based on the theoretical framework and more general questions, created independently from the theory, were asked to obtain complementary information and ideas from the respondents. To avoid bias results the researchers did not reveal any hypothesis to the respondent, which increased the objectiveness of the researchers in the interview setting. In table 3.3 the interviews are presented.

Respondents (Frequency)	Company	Position	Product	Date (2015)	Duration (min)	Channel
Supplier C	TRW	Different departments	Servo pump	18.05	-	E-mail
Purchasing A (1)	Volvo	Cost Estimator Electrical (previously Commodity Buyer, Powertrain)	Rear axel	31.03	31	F2F
Purchasing B (1)	Volvo	Commodity Buyer Infotainment & Connectivity	Loudspeaker	20.04	32	F2F
Purchasing C (1)	Volvo	Senior Commodity Buyer, Purchasing Electrical, Electric Propulsion Systems	Servo Pump	15.04	34	F2F
R&D A (2)	Volvo Volvo	System Manager & Senior Designer Electric Drives Manager Power Electronics & El Drives	Rear axle	08.04	31	F2F
R&D B (1)	Volvo	Component Designer HW, Audio Systems and Attribute Infotainment & Connectivity	Loudspeaker	23.04	32	F2F
R&D C (2)	Volvo Volvo	Development Engineer Chassis & Steering Electronics Manager Suspension & Steering Electronics	Servo Pump	08.04	30	F2F
Market intelligence (2)	Volvo Volvo	Chief economist Raw Material Specialist, Raw materials & Fasteners		31.03	45	F2F
Inbound logistic and optimization (1)	Volvo	Manager of transport optimization and implementation		07.04	32	F2F
Environment & Fluid dynamics (1)	Volvo	Senior Strategic Advisory Environment		23.04	41	F2F

Table 3.3 Overview of the interviews

The researchers started with the internal interviews, which were conducted face-to-face (F2F) and recorded, with the recorder program AudioNote, in order to be able to go back in the interviews. In AudioNote the notes taken during the interview are registered at the point of time the notes are written. This made the interpretation and analysis of the results easier. Both researchers were present during the interview and one was responsible for notes and recording while the other was in charge of asking the prepared questions. The decided roles made it possible both to listen carefully and ask follow up questions, which was done by both researchers. Even if interviews are complex and time consuming (Easterby-Smith *et al*. 2002), this method made it possible to perceive a deep understanding of a complex research problem with different dimensions.

The external interview was not possible to conduct by face-to-face nor by phone, due to limitations from Volvo. This limitation was made because prices of components and commodities are a sensitive subjects and wrong information could affect and harm Volvo´s negotiations with the suppliers. This interview was instead performed by email and had therefore a more structured characteristic compared to the face-to-face interviews. The researchers increased the flexibility in the email interview; by creating possibilities for respondent to complement answers and asking follow up questions when something was unclear. This increased flexibility increases the characteristics of semi-structured interviews. Advantages of collecting information by email are the time and cost savings (Bampton and Cowton 2002) and that the respondent could be contacted independently of geographic location. Furthermore, the respondent gets more time for each question and could therefore provide more comprehensive answers and complete information. Email interviews are a good method of collecting high-qualitative data when the respondents are international, and not have the same language skills (Reid *et al.* 2008).

The disadvantages of collecting data by e-mail are the lack of possibility to express emotions and that the absences of real live voices could generate misunderstandings (Reid *et al.* 2008). Actions have been taken to limit these disadvantages by processing the interview questions together with the purchasing department, who has good relationships and know the suppliers well. Furthermore, the answers were carefully worked through to avoid possible misinterpretations from the suppliers, and when unclear answers were found these were explained by re-entrant mail conversations.

3.4 Data analysis

The theoretical review was summarized in the end of the chapter to identify the most important points and functioned as a support when finding patterns in the primary data. The interviews were recorded and notes were also taken during the interviews to ensure validity of the analysis. The key findings were summarized into different tables to provide an overview of the results before writing the result. The data collected was structured in the same way as the theoretical framework and the interview guide, to make it more clear and easier to follow.

In the interview guide these headings were named *Supply and Demand*, *Dependency* and *Mitigation Strategies* (Appendix C and D). Due to instructions from Volvo, on how to express ourselves when contacting their suppliers, the heading *Supply and Demand* was used instead of *Volatility*, which is the term used in theory. The term *Volatility* was, however, used when presenting the empirical findings and the full description of results from internal interviews (Appendix E) and the external interview (Appendix F) to reduce misunderstanding. By structuring the process like this, the analysis of the findings became more convenient and the data became easy to interpret. To improve the reading quality of the empirical findings and analysis the respondents were referred to as presented in table 3.4 below.

Representative interviewed	**Name referred to in the empirical findings**
Representative from TRW	Supplier C
Purchaser for rear axle	Purchaser A
Purchaser for loudspeaker	Purchaser B
Purchaser for servo pump	Purchaser C
Research and development representatives for rear axle	R&D A
Research and development representative for loudspeaker	R&D B
Research and development representatives for servo pump	R&D C
Market intelligence	Chief economist/Raw Material Specialist
Representative from Inbound Logistic and Optimization	Logistic expert
Representative from Environment and Fluid Dynamics	Environment expert

Table 3.4 Names of the respondents referred to in empirical findings and analysis

When extracting the relevant data from the interviews, the researchers were careful of distinguishing between the findings that were irrelevant to the research focus and which findings that were important but outside the theoretical framework. By doing this, new ideas and aspect of relevant information was collected even if not mentioned in the theory.

Additionally to the interviews, information and documentation have also been received from Volvo. This is presented in the beginning of chapter four to give a good overview of how Volvo is working this the materials in focus today.

In the process of analysing the data, the interviews were first transcribed, which gave the researchers a good overview of the findings. Furthermore, the interviews were rewritten and colloquial language was reworded to make it easier to read (Appendix E and F). The results were then structured and presented in the chapter empirical findings (Chapter 4). The findings were then compared to what the theory presents to investigate similarities, differences and conclude the analysis. The researchers were going back to the transcript results if something was unclear to ensure the results were interpreted correctly.

The analysis is divided into two parts where the first part is a general analysis of the factors of risk management, including centralized information structure of the company, communication of the management and level of market knowledge (chapter 5.1).

In the second part of the analysis (chapter 5.2 and 5.3), our own conceptual framework created from the theoretical review (figure 2.3) was used to analyse the empirical findings, including risk exposure and risk mitigation strategies. The risk exposure of Volvo was appreciated by evaluating the price volatility and level of dependency based on an analysis from the empirical finings and the theory. Theory played a bigger part in appreciating the volatility since it is based on historical development. However, respondents' inputs were also taken into account. The different strategies was analysed in order to validate or reject the findings from the theoretical review. The outcome of the analysis ends up in which mitigation strategies that are applicable in the automotive industry for dysprosium and neodymium. The structure of the analysis and an illustration of how the conceptual model from theory was used could be read in figure 5.1 in the analysis chapter.

3.5 Research quality

When deciding the quality of a research, validity and reliability are usually assessed (Bryman and Bell 2011), but these concepts are more fitting for quantitative studies according to Denzin and Lincoln (2002). Instead, the quality of this research was evaluated based on Guba´s (1981) framework, which is adopted to evaluate the quality of a qualitative research. Research validity, reliability and objectivity will be replaced by credibility, transferability, dependability and conformability (see table 3.5).

Quality in Quantitative studies	Quality in Qualitative studies
Internal Validity	Credibility
External Validity	Transferability
Reliability	Dependability
Objectivity	Conformability

Table 3.5 Quantitative versus Qualitative studies regarding quality evaluation (Own illustration from Guba 1981)

In positivistic research internal validity refers to make sure the research measure what it intend to measure (Shenton 2004). This correspond to *credibility* in qualitative research and refers to the social reality the research found in its results and if it is true in the eyes of the reader (Lincoln and Guba 1985). To ensure high credibility researchers have followed the rules and regulations of *School of Business, Economics and Laws* of how a master thesis is suppose to be conducted. The researchers clarified, for the respondents during the interviews, that honest answers and data shared of free will were of high importance in order to ensure credibility (Shenton 2004). If the respondent did not possessed answers to questions, the researchers instead asked the respondent to complement the interview with correct answers after the interview by mail. Furthermore, the credibility could be considered as high due to the fact that the purpose of the thesis have been kept in mind during all processes in this research. To ensure the quality of that the results had been understood correctly, a meeting with the participants was held in order to discuss the results and the researches interpretations of them. This increased the credibility of the interviews.

Transferability regards if the results in one study could be transferred to another setting (Shenton 2004). This research provides fullness and transferability in its descriptions due to its comprehensive theoretical review performed of both historical and future forecasts. Furthermore, the primary data provides a comprehensive understanding of the reality by interviewing different departments at Volvo and one of its first tier suppliers. The internal and external interviews provided different information and knowledge and by looking into different levels and functions, the density of the research increases and the transferability improves. Additional, comprehensive contextual information has been supplied as background information and in the theoretical review, in order for the reader to be able to transfer the research to another setting (Shenton 2004).

Dependability in qualitative studies corresponds with reliability in quantitative studies and refers to if the results would be the same if repeated and performed in the same way (Shenton 2004). It is of high importance to create a good research design and explain how the research have been performed in order for the reader to evaluate if proper practices have been followed. Detailed descriptions make it possible for other to repeat the study (Shenton 2004). To exclude biased results due to misunderstandings and wrong interpretations, the interview questions were refined during four weeks before asking them to the respondents. The dependability was improved by letting supervisor, both from Volvo and from Gothenburg University, examine the research questions to ensure the quality. To reduce misinterpretations during the interviews both researchers were present and additionally the interviews were recorded. This made it possible to go back and interpret and discuss the answers together if answers were not understood or understood differently. The method used to analyse the data was decided on forehand to ensure the consistency when analysing the data.

There is a risk of answers from supplier not being complete due to limited willingness to share sensitive information. To limit this risk the researchers stressed the importance of getting comprehensive answers and the purchasing manager at Volvo communicated the importance of the investigation.

Confirmability refers to the researcher's objectivity and their impact on the results of the research (Shenton 2004). When performing this investigation the researchers have, not consciously affected or impacted the result with own personal values and theoretical directions. Since a theoretical framework has been used when creating the interview questions, the researchers were meticulous during the interviews to create possibilities and room for the respondent's own solutions and ideas. Thereby the results were not influenced to any specific directions. Furthermore, norms and values of the organization might impact the answers from the respondents and thereby lower the validity of the research.

Decisions, actions and choices made throughout the research have been carefully explained to improve the replicability. Furthermore, both researchers have been involved and active in all processes, decisions and in all steps of the research to improve the internal reliability and it could, after this chapter, be concluded that the researchers have performed the necessary actions needed in order to ensure a good quality of the research.

4 Empirical findings

This section will present the findings from the empirical data collection. The empirical findings will be divided into two parts; findings from interviews at Volvo and the external interview performed with a supplier of Volvo. Full-length interviews are found in Appendix E and F.

In this chapter the results from interviews with three purchasers, three R&D respondents, two from market intelligence department, one from the logistics department, one individual from the environmental department and one supplier of Volvo have been summated.

4.1 Monitoring and forecasting of commodity prices at Volvo

Volvo monitors the market of rare earth elements by gathering information from sources such as Asian Metal and USGS (U.S. Geological Survey). The Chief Economist is collecting this information and has high market knowledge of the development of commodity prices of critical material. A price forecast is created with the information collected from the market and this is shared, together with other information of the market, with other departments at Volvo. In this way Volvo is updated with the newest information and developments of factors affecting price changes.

Weekly Commodity Price Briefer (WCPB)

WCPB is an information letter, which is sent out once a week to different departments at Volvo that handle products containing neodymium and dysprosium. This letter provides information about the markets for different raw materials. It informs how the price changes, spot prices, scrap prices, price index and average movement of the prices the latest six months. A short explanation of reasons of the changes is also explained in this brief.

Forecast of critical rare earth elements

To predict future price changes, the market intelligence department has developed a tool to forecast market prices of rare earth elements since there is no external intelligence to use. The forecasting tool is based on several trends and parameters such as hybridization, production sites, stability of supplying countries, currencies (mainly USD & CNY), producers and consumers, other demand and economic growth in key markets. The historical prices are gathered from the Asian Metal database and additionally information about dysprosium and neodymium prices are collected from USGS. The prices of neodymium and dysprosium exported from China and the prices within China differ. The local prices are lower than the export prices, however, they are following the same volatility pattern. Volvo monitors the prices of the rare earth elements in focus and improves their knowledge and information, which is beneficial in the negotiations with the suppliers.

Dysprosium and neodymium

Table 4.1 and 4.2 gives overviews of the amounts and values of dysprosium and neodymium of the chosen components. It can be seen that the parts are using roughly the same value of both elements.

Rare Earth Elements	Price (dollar/kg)
Dysprosium	490,4
Neodymium	82,9

Table 4.1 Prices of dysprosium and neodymium (export from China, February 2015)

Component	Dysprosium (volume/value)	Neodymium (volume/value)	Total (value)
Rear Axle	49,7 gram / 24,37 dollar	253,2 gram / 20,99 dollar	45,36 USD
Loudspeaker	6,7 gram / 3,29 dollar	62 gram / 5,14 dollar	8,43 USD
Servo pump	6,8 gram / 3,33 dollar	29,9 gram / 2,48 dollar	5,81 USD

Table 4.2 Prices and volumes of dysprosium and neodymium used in the chosen components

4.2 Results from interviews at Volvo

4.2.1 Volatility

The historical price volatility of dysprosium and neodymium has resulted in high costs for Volvo (Purchaser A, Purchaser C, R&D A, Chief Economist and Raw Material Specialist). Today there is no lack of dysprosium and neodymium in the earth crust but the difficulty is mining these materials (Purchaser A). Purchaser A and Purchaser B both think the demand for neodymium and dysprosium will increase in the future. However, Purchaser A thinks the demand will increase due to increased demand for hybrid cars, and Purchaser B believes the increased premium car focus will drive the growth in demand of dysprosium and neodymium. Purchaser C agrees with Purchaser B that the demand will depend on the specifications on performance levels Volvo gives to their suppliers, together with how future prices matures. There have been a lot of worries related to the price changes of dysprosium and neodymium in the past but the current price levels are considered acceptable (R&D C). If the prices are stable, Volvo will probably continue to use dysprosium and neodymium in their products since price is the driving factor in this (Purchaser C).

The R&D departments have some different perception regarding the demand of the rare earth elements in focus. R&D A estimate the demand of dysprosium and neodymium, for Volvo, to decrease in the future while R&D B thinks the demand of these materials will be stable in the future due to stabilized prices. The reason why R&D A argue for decreased demand is because they think Volvo wants to become independent from the material, in order to reduce the risk of increased prices. This is done, for example, by changing the design of the components, so that the temperatures decrease and lower amounts of dysprosium and neodymium is needed. They believe the prices of the materials might decrease in the short run, compared to the price peak 2011, but that there is a risk of new price shocks in the future.

The main difficulties from a commercial perspective are to handle the price fluctuations (Purchaser B). A problem regarding the supply of dysprosium and neodymium is the high dependence on the Chinese supply but the threat of environment regulations is seen as the biggest threat. Volvo could stop using or limit the use of dysprosium and neodymium as a way to communicate proactive sustainability work to customers (Purchaser A and Purchaser C).

All purchasers agree on that the traceability of dysprosium and neodymium in the supply chain is limited to the first tier supplier. The only information Volvo has regarding the origin and handling of dysprosium and neodymium is that they are sourced from China and some additional information given from the first tier supplier (Purchaser C). The purchasing department is not involved in where the suppliers purchase their raw material, but the SQM (supplier quality management) department ensures the quality for the purchasing process by, for example, looking at the supplier's quality of delivery (Purchaser B). The suppliers do have restrictions of presenting all materials used in their components to Volvo according to rules, but there might be possible loopholes (Purchaser C).

According to the Chief Economist and the Raw Material Specialist, there has been a sharp increase in the usage of dysprosium and neodymium. A great deal of the risk associated with the rare earth elements disappeared when WTO ruled to ban the export quotas imposed by China, which China also has accepted. New mines will begin to produce to further lower the risk but it takes time. These two factors mean that a great deal of the risks associated with China's market power, are significantly reduced and it is always the markets that control the prices, according to the respondents. The Chinese government has proven sluggish, in its legislative focus and a crackdown on the environment could come suddenly. However, the prices are not traded on a metal exchange leading to less price volatility and speculation, than if it would have been traded over an exchange.

The Chief Economist provided data of the historical price development of dysprosium and neodymium shown in figure 4.1. The table represent prices received locally in China, which are the prices Volvo is monitoring. As it can be seen, the price for dysprosium is structurally higher than for neodymium per kilogram.

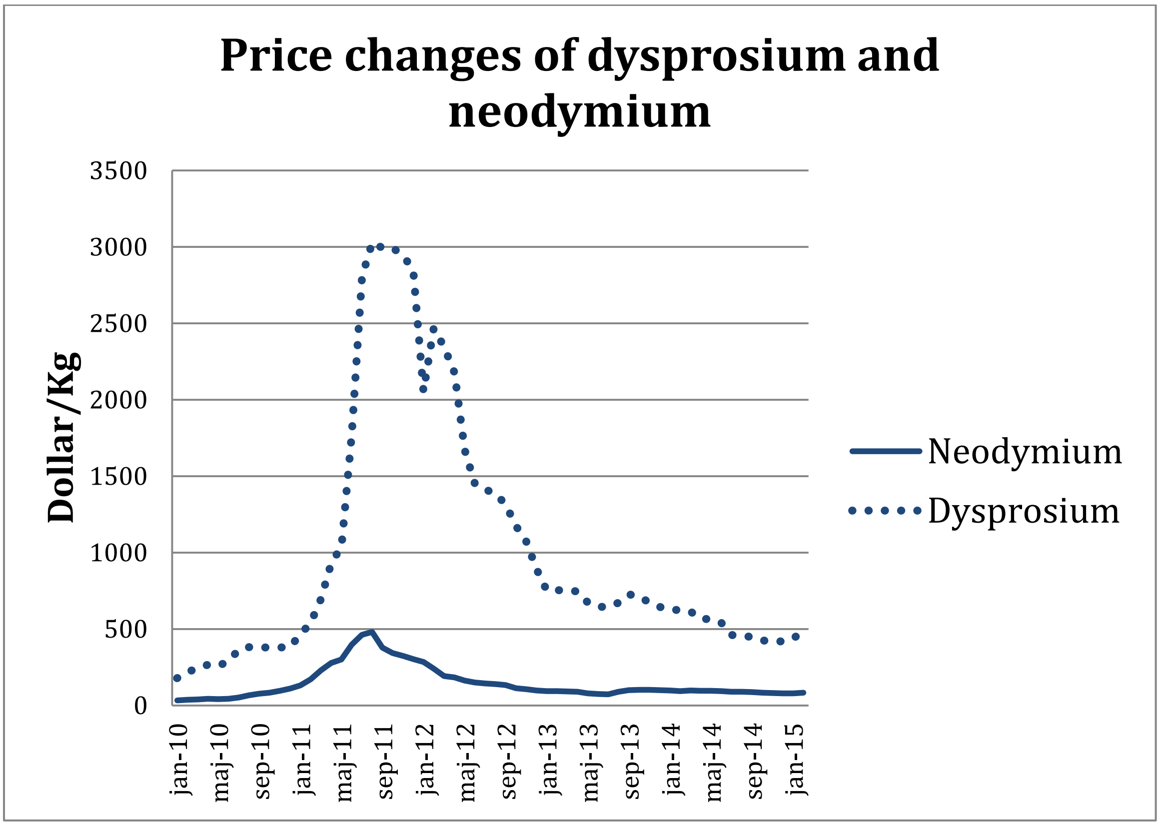

Figure 4.1 Historical price changes of dysprosium and neodymium 2010-2015 (Chief Economist)

The Environmental Expert believes that the use of dysprosium and neodymium could develop into two tracks. One track is that Volvo reduces the amount of dysprosium and neodymium, which results in lowering the level of performance in the components and create cheaper and maybe more simplified solutions. The other track is a high-level performance niche, which would result in the total opposite, from reducing the amount of dysprosium and neodymium to use the same as today or even more. These two tracks would compensate for each other regarding the usage of these rare earth elements and the total use of dysprosium and neodymium could therefore be at similar levels as today. This is if nothing unpredictable occurs that will change the current picture of the market. (Environmental Expert)

The Environmental Expert identifies some risks related to the supply of dysprosium and neodymium. He does not think there are any problems to get these materials physically, but there are commercial risks that could be highlighted as problematic. An example of a commercials risk could be the environmentally damaging production. This is something a company does not want to be connected or associated to, since it could harm the brand. For this reason it could be unsustainable to include materials like rare earth elements in the cars.

For the future, the Environmental Expert thinks Volvo needs to have a better traceability of dysprosium and neodymium in the supply chain. Volvo could inform the suppliers on how they should handle these materials and control that the suppliers take the actions needed. If a scandal is revealed, regarding environmental damaging of producing rare earth elements, Volvo could show that they have taken responsibility in the behaviour of handling these materials (Environmental Expert and Purchaser C). Volvo has a possibility in this situation to be proactive and create some kind of certificate in the production and improve traceability in the supply chain. This is possible due to the size of the company and the small amounts used of these materials compared to other actors create flexibility in the handling. This also would go inline with the company's values of sustainability and environment (Purchaser C).

4.2.2 Dependence

Volvo is highly dependent on dysprosium and neodymium since they are critical for the end product (Purchaser A, Purchaser B, Purchaser C, Chief Economist and Raw Material Specialist). Volvo is also highly dependent on powerful miners and other suppliers further upstream (Chief Economist). However, Volvo might have an advantage being a Chinese company compared to competitors like Toyota who can have a harder time buying these materials from China (Chief Economist). Since the price peak 2011, some of the suppliers of Volvo have reduced the dependency of dysprosium and neodymium by increasing the efficiency of the use. However, the dependency of the rare earth elements in focus is still high (Purchaser C).

Purchaser C presents that the amounts of dysprosium and neodymium used in the components, have decreased after the price increase in 2011. After this, Volvo pressured their suppliers to investigate the amounts used in their components, which resulted in solutions with lower amounts of dysprosium and neodymium in the components.

R&D A explained that their strategy within 3-4 years is to reduce the usage of dysprosium with 15-20%. Furthermore, they want to eliminate dysprosium within 6-8 years. The amounts of neodymium will, at the same time, be reduced as much as possible but it is probably not achievable to eliminate the material completely. This reduction, in usage of dysprosium and neodymium, will be possible by developing constructions with bigger sizes of electric machineries. Another possibility to reduce the usage is to use different mixtures of metals containing lower level of dysprosium and neodymium. R&D A have high awareness of the content in their components including dysprosium and neodymium and want to reduce the dependence of them. R&D C, although, have limited knowledge of the amounts of dysprosium and neodymium in the component, but they explain that dysprosium is needed to increase the temperature resistance of the components.

The rare earth elements in focus are especially critical for the advanced loudspeaker systems (R&D B). There are three different loudspeaker system levels in the car: standard performance, medium performance and high performance. In the standard performance level, ferrite magnets[2] are used; in the medium performance level ferrite magnets are used in the big loudspeakers and neodymium magnets in the small loudspeakers. In the high performance level the loudspeaker system is branded by for example Bauers and Wilkins, and here only

---

[2] Ferrite magnets are an alternative to neodymium and dysprosium magnets. They are low cost magnets that are relatively brittle, have good corrosion resistance and have relative good resistance to demagnetization. Compared to other permanent magnets ferrite magnets exhibit low energy but are used due to their low costs. (Arnold Magnetic Technologies 2015)

neodymium magnets are used. The respondent describes that there is an increased demand for the high performance level equipment.

R&D B continues to explain that depending on price changes, the use of ferrite magnets and neodymium magnets changes. Today Volvo does not, however, want to use neodymium and dysprosium, if not necessary to achieve the required quality or due to size restriction. When constructing the different components the objective of the research and development departments, is to optimize the performance and the costs of the components. A ferrite magnet could, according to R&D B, achieve the same level of performance of loud quality as a neodymium magnet but it needs more space. However, the department is not actively working on reducing the usage of these rare earth elements to reduce the dependence of these materials. This is contradictive to the department of R&D A, where they are actively working on reducing neodymium and eliminating dysprosium from their products.

Volvo does not decide if the suppliers should use neodymium or ferrite magnets in the components. The usage of dysprosium and neodymium is driven by the requirements set by Volvo and if the suppliers are able to use ferrite magnets they will, which Volvo does not interfere with (R&D B).

The Environmental Expert thinks dysprosium and neodymium are not very critical for the standard car. However, for the top of the line products, with high performance levels, the materials are highly critical since they make it possible to achieve the wished performance levels in limited space. The top of the line cars are the products that build the brand and are therefore crucial for the company. Furthermore, dysprosium and neodymium are critical for the plug-in hybrid. In these cars two types of drivelines need to be included in the car, which makes less space available and therefore dysprosium and neodymium are needed to reduce the sizes of the components without lowering the performance.

The dependence of the materials could be lowered in the future if Volvo decides to eliminate dysprosium and neodymium in the cars or focus on electrical car models. Total electrification creates space available for bigger components, since a double set up of drivelines is not needed as for the hybrid car. The components could be bigger and dysprosium and neodymium could be reduced or eliminated. The respondent explains further that Volvo has not come this far yet (Environmental Expert).

When looking at electrified cars, a car producer might get away by producing a plug-in hybrid model in the portfolio today. This might not be enough in the future since then you need to supply a high performance hybrid of electrified car model. In 5-10 years, these models might be relatively common and the demands of performance of these cars might be higher. Then the dependence of dysprosium and neodymium might increase (Environmental Expert).

4.2.3 Mitigation strategies

Substitute

There are today no effective substitutes for dysprosium and neodymium (Purchaser A, Purchaser B, Purchaser C and R&D C) but there were materials before dysprosium and neodymium were found, that probably could be used. However, these are not as efficient as dysprosium and neodymium (Environmental Expert). For the products R&D A are responsible for, terbium is used as a substitute to dysprosium.

As mentioned earlier, ferrite magnets could be used as a substitute for the loudspeaker systems, but then the components are getting bigger (R&D B). Ferrite magnets decrease the performance of the component if not the size increases. For the premium high specific cars, R&D B thinks ferrite magnets would not be enough regarding performance.

There are upcoming substitutes on research level, such as magnetic polymer but these are not available now, but might be a possible substitute for the future (R&D B). If the prices of dysprosium and neodymium would be too high, Volvo might need to change from components containing these materials and switch to use for example ferrite magnets. When the prices exploded in 2011, Volvo begun looking at alternatives with their suppliers, however, after the prices plunged again these efforts were put on hold. There could exist substitutes that Volvo is not aware of but today Volvo is not driving the progress of finding possible substitutes (Chief Economist and Raw Material Specialist). However, if the prices increase again in the way they did 2011, new innovations might be developed and substitutes might be created (Environmental Expert).

One possibility to reduce the use of dysprosium and neodymium is to change the construction and build bigger components. Bigger constructions would be difficult due to limitations in space for the components, but it could be possible (R&D A, R&D B and R&D C).

Pass/Share risk

Passing and/or sharing price risks with customers mean that the costs of a price increase is transferred into the price of the product, for the customers to pay. Passing and/or sharing price risks with suppliers mean that the suppliers are paying the costs of a price increase of the commodity, without increasing the prices of the components sold to Volvo. R&D B explains that Volvo compensates the suppliers for some price increases, and that this could be seen as a share of risk. He further describes that the prices of the components is set to a fixed price, and therefore it is the suppliers that takes on the biggest part of the risk. When the prices increase the suppliers sell the products with lower margins.

The strategy to *pass the risk to the customers* is not possible (R&D B, Chief Economist and Raw Material Specialist). This is due to the fact that the prices are set based on the value it brings to its customer and not on the costs of the car (Purchaser B and C). The only way it would work would be to create customer awareness of the problems in the production of dysprosium and neodymium (Purchaser C). However, the competition on the market is too strong to put the costs of price increases on the customers (Purchaser C). Contradictory the Environmental Expert thinks it is possible to pass the price risk to customers in some cases. This could be done if customers are diversified depending on their willingness to pay for premium products with high performance. Volvo could supply additional high performance components in the car, such as an advanced loudspeaker system, by including dysprosium and neodymium. The customers could then be asked to pay more money for these products. A high performance hybrid car, that is able to perform 0-100 in just a couple of seconds, could possible be priced higher to the customers if Volvo could show the effect achieved with these materials. However, if Volvo wants to produce a budget variant of a plug in hybrid car, it is not possible to add the cost on the car, since there are too small margins and the customers are too price sensitive.

Passing the *risk to the supplier* could be possible, according to Purchaser B, by negotiating a lower price. Purchaser C also reasons that transferring the price risks to the suppliers is only a solution that would work in the short run. Passing risk to the suppliers is, however, not a viable solution according to the Chief Economist since some contracts are index-linked and Volvo tends to take the hit of most price increases. This is an intended strategy by Volvo to prevent suppliers from including risk premiums in its component prices. Contradictory to the Chief economist and R&D A explain that in the negotiation with the suppliers, Volvo could let the supplier cover any market price fluctuations without letting it affect the prices that Volvo pays (R&D A). Transferring the risk to the suppliers, the respondent thinks, will be hard due to the relatively small size of Volvo, from a global perspective (Environmental Expert).

Forward buy

The strategy forward buy, means that Volvo buys large quantities of dysprosium and neodymium and store it in order to ensure the supply. Forward buying is not a possible mitigation strategy (Purchaser B, Purchaser C and R&D A) since Volvo is not purchasing the materials directly (R&D A) and it is also considered to tie up too much capital and would not be profitable (Purchaser A). Dysprosium and neodymium are parts of larger and more complex components, which are the tier one´s responsibility (R&D A, Chief Economist and Raw Material Specialist). Furthermore, it is not feasible, because it would require different logistic and commercial relationships to tier one supplier (R&D A).

Volvo is too small, from a global perspective, and the raw material market is too complex, to engage in forward buy (Purchaser C). If engaging in this kind of solution it first needs to be profitable and a cross-functional team, which could work with the suppliers, would be needed if engaging this activity (Purchaser B). However, the communication needed for this is not yet available at Volvo (Purchaser B). Purchaser C discusses the possibilities of sourcing locally, since Chinese producers perceive lower prices of the raw material but this is only a possibility if, in total, it is a better deal.

The Logistic Expert argues that forward buying might be a possible mitigation strategy solution but that this depends on the value of the materials. For example if the metals are valued very high, special transportation might be needed to protect it from robbery during transport. The Logistic Expert does, although highlights his limited insight of the matter.

The Environmental Expert thinks it would be hard to engage in forward buy, since Volvo should focus on their core business: to develop and produce cars. However, it is not impossible that Volvo could engage in a joint venture with another actor, which is operating the warehouse as separate company. Collaboration with other companies would then be necessary to compensate for the small size of Volvo, from a global perspective. The respondent does not think there is the financial strength to forward buy dysprosium and neodymium yet. Maybe in 5-10 years, when there are twice as many cars in sales and the return on capital on investment is good this might be a solution.

Hedge/Cross-hedge

Hedging means ensuring prices of commodity by buying future contracts of the materials and it is not considered as a possible mitigation strategy in order to reduce price risk of dysprosium and neodymium (Purchaser B, Purchaser C, Environmental Expert, Chief Economist and Raw Material Specialist). As for forward buy, a cross-functional team would be needed for this sort of mitigation strategy (Purchaser B).

Financial hedging is not possible since dysprosium and neodymium is not traded on an exchange. Hedging and market timing of rare earth elements purchase, is ultimately the suppliers responsibility. When comparing offers from supplies, the cost of the component is calculated based on landed cost, which includes all costs from suppliers to Volvo´s facilities. Costs of raw material from China differ depending on if the producer is located in China and gets local prices in China, which are lower than the export prices the international producers needs to pay. Today the export prices and the local prices are following the same development pattern, and the price differences are not big enough to compete on landed costs basis. (Chief Economist and Raw Material Specialist)

Secure supply

Secure supply means investing in mining activities in order to ensure the supply. Secure supply is not a mitigation strategy for Volvo today because the core business of Volvo is producing cars and not to engage in metal supply (R&D A and Logistics Expert). Secure supply might be hard to engage in, due to the size of the company (Logistics Expert). He thinks Volvo might not be big enough for the investment to be worth it; instead Volvo could collaborate with other actors on the market.

After the price increase in 2011, the company considered securing supply by engaging in backward integration into mining business to secure supply, but the option has not been pursued yet (Chief Economist). The reason why it was not performed was probably due to the following year's price fall (Chief Economist).

The Environment Expert thinks that engaging in secure supply could be possible in a commercial objective, showing the world that Volvo uses the elements but ensures its produced in a environment and social sustainability way. At the same time Volvo would benefit from ensuring supply of dysprosium and neodymium at stable price levels. This could also make it possible to use a current construction of a car, including dysprosium and neodymium.

Absorb risk/Reduce demand

Absorbing risk means that Volvo is simply paying the costs of price increases. Reduce demand means that Volvo tries to limit the amount of dysprosium and neodymium in their products, which could be done by engaging in activities such as recycling. Today, Volvo is absorbing the price risk of dysprosium and neodymium by paying the costs of price increases of the materials, to the suppliers. Compensation is negotiated with the suppliers if the prices of dysprosium and neodymium change (Purchasers A, Purchaser B, Purchaser C, Chief Economist and Raw Material Specialist). When Volvo compensates the suppliers for price increases of raw materials, these are only given for a period of six months at the time and it is also a matter of negotiation. Volvo saves money to be able to pay the suppliers for the price increases (Chief Economist and Raw Material Specialist). When the prices are increasing the suppliers are contacting Volvo for compensation for the price increases. Purchaser B experiences, however, that when the prices fall; Volvo is not very alert to get compensation from the suppliers and Volvo could be more active in this matter. The contracts of how the compensations should be handled are different depending on the contract (Purchasers A, Purchaser B, Purchaser C, Chief Economist and Raw Material Specialist).

R&D A and R&D C aim to reduce the demand of dysprosium and neodymium in their components to decrease the dependence of these materials, while R&D B does not actively aim to reduce the demand. The suppliers are responsible for product development and solutions to reduce the usage of dysprosium and neodymium in the components (R&D C and R&D B). R&D A do, however, argue that the suppliers are responsible to find new solutions regarding new mixtures while Volvo is still responsible to find new construction solutions.

Recycling

Recycling is one way to reduce demand of dysprosium and neodymium and this is an activity not performed today of the materials in focus (Purchaser A, Purchaser B, Purchaser C and R&D C). Volvo is currently performing recycling activities of other materials together with the company Stena Metal (Logistics Expert), who pays Volvo for the car when it is ready to be scrapped. Volvo could increase the visibility of the rare earth elements in focus, to get a higher price from Stena Metal, by providing Stena Metal with information regarding which components contain high valued materials and where in the car these components are located. This would make it easy for Stena Metal to find and extract high value materials or components (Environmental Expert).

Recycling is a big possibility (Logistics Expert), if it is technically successful to separate the mixtures to high purity. Additionally there need to be an effective business model (R&D A) and Volvo would need to collaborate with the suppliers when constructing the components to make it easier to recycle (Purchaser A). Furthermore, the possibilities of recycling depends on what the process looks like when recycling the entire car, because these materials do not have to be changed during the cars life cycle (R&D B). At the moment, however, recycling is not an important factor for the price development, according to the Chief Economist and Raw Material Specialist.

Remanufacturing
Today Volvo performs activities called remanufacturing, in small scale, on components with high values (Purchaser B, Purchaser C and Environmental Expert). Everything that is expensive has a possibility to be included in a remanufacturing solution, in a way to reduce demand (Environmental Expert). When remanufacturing today, the supplier (who acts on specification from Volvo cars), performs the renovation. The components are stored after renovating them, and used by Volvo when needed. It might be possible to do a similar activity with components containing high levels of dysprosium and neodymium (Purchaser C).

Remanufacturing is easier to perform than recycling since the components does not need to be broken down to raw material, but only to the level where, for example, the magnet could be extracted and used again. There is a lot of money to earn within remanufacturing and if it is easy to implement and profitable, there is also probably a market for anyone to engage in. This would then work as a link in the supply chain. Remanufacturing is something one should not underestimate, because this is this type of circular economy that makes it possible to handle problems connected to dysprosium and neodymium. For Volvo to perform these activities themselves is probably not possible since they cannot get the volume needed to achieve a level of revenues in this kind of operation. (Environmental Expert)

R&D B thinks it is relatively easy to separate components including dysprosium and neodymium in order to remanufacture. The neodymium magnet is a mixture and not pure neodymium but this magnet does not get worn out, but could be used in another loudspeaker and work as good as a new magnet. The only problem is that it is harder to handle magnets when they have become magnetized. This is the reason why the magnets are magnetized after putting it in the component. Except for this, there are no technical restrictions in reusing the magnets. (R&D B)

Whether to engage in recycling or remanufacturing depends on the characteristics of the components. If the component is exposed to the customer, such as the seat of the car, remanufacturing is not a solution. Also if the component is possible to use again without any big renovations, then this could be remanufactured. However, if remanufacturing of the component demands a lot of work, then it could be worth recycling the component instead, when the car is scrapped. (Environmental Expert)

4.3 External results from a supplier of Volvo

4.3.1 Volatility
Insecurities of dysprosium and neodymium are the risks of Chinese government interventions such as implementing duties, supply quotas etc. and increased demand from other industries such as energy sector (Supplier C). Other global sources of dysprosium and neodymium have been studied but due to stabilization of the prices the motivation has weakened of mining the rare earth elements in focus elsewhere (Supplier C).

Electric Steering is replacing Hydraulic Steering in most applications and this trend will continue until 2018/19. At this time Supplier C believe the electric steering market will be close to saturation. Furthermore the demand of vehicles are predicted to grow globally and further driving demand and rare earth element quantities will follow these growth drivers (Supplier C).

4.3.2 Dependency

Neodymium is very critical for the end product in defining the magnetic strength of the product. Dysprosium is also very critical since it is resistant to high temperatures and its characteristics of preventing demagnetization (Supplier C).

The traceability of the rare earth elements in focus is today reaching down to the magnet manufacturing level, but further than that the traceability is not very good (Supplier C).

Supplier C has experimented with membership of Metal Pages and Asia Metals to discuss the problems of supply of dysprosium and neodymium, but this have not beneficial for the company.

4.3.3 Mitigation strategies

Today Supplier C purchases their dysprosium and neodymium magnets together with a large proportion of motors from China and Japan. However, future product generations will all be sourced from China. The prices of dysprosium and neodymium magnets are referenced to the China Domestic index, where the products are produced in China. The FOB index refers to products produced outside China. Buying dysprosium and neodymium from the local market is presently the best risk mitigation approach; however, it is always under constant review for possible improvements. Supplier C explains that between 2010 and 2012 many mitigation strategies of dysprosium and neodymium were executed in order to handle the price insecurities. These were:

- The manufacturing process was optimized to reduce scrap and recycle waste materials.
- The dysprosium and neodymium magnets designs were optimized in order to use less of the material and assist in manufacturing process.
- The quantities of dysprosium used in the magnets were reduced to align with customer specifications.
- Motor temperature and current demands was considered during system specification.
- The company moved from purchasing materials against FOB index and started to use the China Domestic index instead.
- The usages of dysprosium and neodymium in components have been optimized and there are no further cost efficient optimization opportunities foreseen (Supplier C).

Substitute

There is no effective substitute of dysprosium and neodymium available on the market (Supplier C). There is, however, the possibility to switch from rare earth magnets to ferrite magnets, but then the products need to increase in size and weight considerably to deliver the same power. This is unacceptable to the OEMs (Supplier C).

Pass/Share risk

Since China have very high control of dysprosium and neodymium and Supplier C has had minimal success in sharing risk with the supply base (Supplier C).

Forward Buy
There is no obvious opportunity to engage in forward buy, mainly due to China's strong grip of the market (Supplier C).

Secure supply
Secure supply is something that Supplier C is not engaged in and explains that this is highly controlled by Chinese government.

4.4 Summary of key findings

The respondents agree that the dependency of dysprosium and neodymium is high (see table 4.3). However, regarding the volatility of the rare earth elements in focus the respondents do not agree, but most of them consider the volatility is medium to high except from R&D, which consider it as low (see table 4.3).

Considering the historical price changes of dysprosium and neodymium in figure 4.1, it shows there are some differences between them, where dysprosium have had higher volatility than neodymium. The respondents have answered the questions of volatility of dysprosium and neodymium, together and not separately.

Risk Exposure / Departments	Low	Medium	High
Supplier			Volatility/Dependence
Purchasers			Volatility/Dependence
R&D	Volatility		Dependence
Market Intelligence		Volatility	Dependence
Logistic	–	–	–
Environment		Volatility	Dependence

Table 4.3 Overview of the respondent's perception of the level of risk exposure regarding the use of dysprosium and neodymium

The main finding of different strategies of how to mitigate commodity price risks was that the superior majority of the respondents agreed on the mitigation strategy absorbing risk, which include recycling and remanufacturing as well as paying the costs of price changes. Secure supply was the mitigation strategy three of the respondents agreed upon to be a good strategy. Passing/sharing risk to suppliers was agreed on being a good strategy by four of the respondents. However, one respondent only supported passing/sharing risk to customers. No respondent supported forward buy or hedging as possible mitigation strategies by the respondents. Hedging was not considered as possible mainly due to the fact that the concerned materials are not traded on a commodity exchange. The supplier did not approve for the mitigation strategies: substituting, passing/sharing risk, forward buy or secure supply, but instead optimized the usage of the rare earth elements in focus and bought the materials in the local market in China. This is referred to as of absorbing the risk. Table 4.4 present an overview of the respondent's valuations of the different mitigation strategies.

Mitigation Strategies / **Departments**	Effective substitute	Passing risk to suppliers	Passing risk to customers	Forward buy	Hedging/Cross- hedge	Secure supply	Absorb risk/Reduce demand
Supplier	✗	✗	−	✗	−	✗	✓
Purchasers (x3)	✗□✗ □✗□	− ✓□✓ □	− ✗□✗ □	✗□✗ □✗	✗□✗□ ✗	− − −	✓□✓□ ✓
R&D (x3)	✓ ✓□ ✗	✓✓−	− ✗−	✗ − −	✗ − −	✗ − −	✓□✓□ ✓
Market Intelligence (x2)	✗ ✗	− ✗	✗ ✗	✗ ✗	✗ ✗	− ✓	□✓✓
Logistic	−	−	−	✗	−	✓	−
Environment	✗	✗	✓	✗	✗	✓	✓
Total approval to strategies (excluding −)	2/10 (20%)	4/7 (57%)	1/6 (17%)	1/9 (11%)	0/7 (0%)	3/5 (60%)	10/10 (100%)

Table 4.4 The respondent´s valuation of different mitigation strategies

□ Support for implementing strategy in practice
□ Do not support implementing strategy in practice
− Do not know

5 Analysis

The analysis chapter will provide a discussion and comparison of the empirical findings and the theoretical review. The objective is to modify the own conceptual model, of how to mitigate commodity price risk (figure 2.3), and adjust it to fit an automotive manufacturer perspective.

In the theoretical review some factors were identified to be of high importance in risk management. As shown in figure 5.1 these factors will be analysed in chapter 5.1. The analysis of risk exposure and risk mitigation strategies will after that be presented in chapter 5.2 and 5.3.

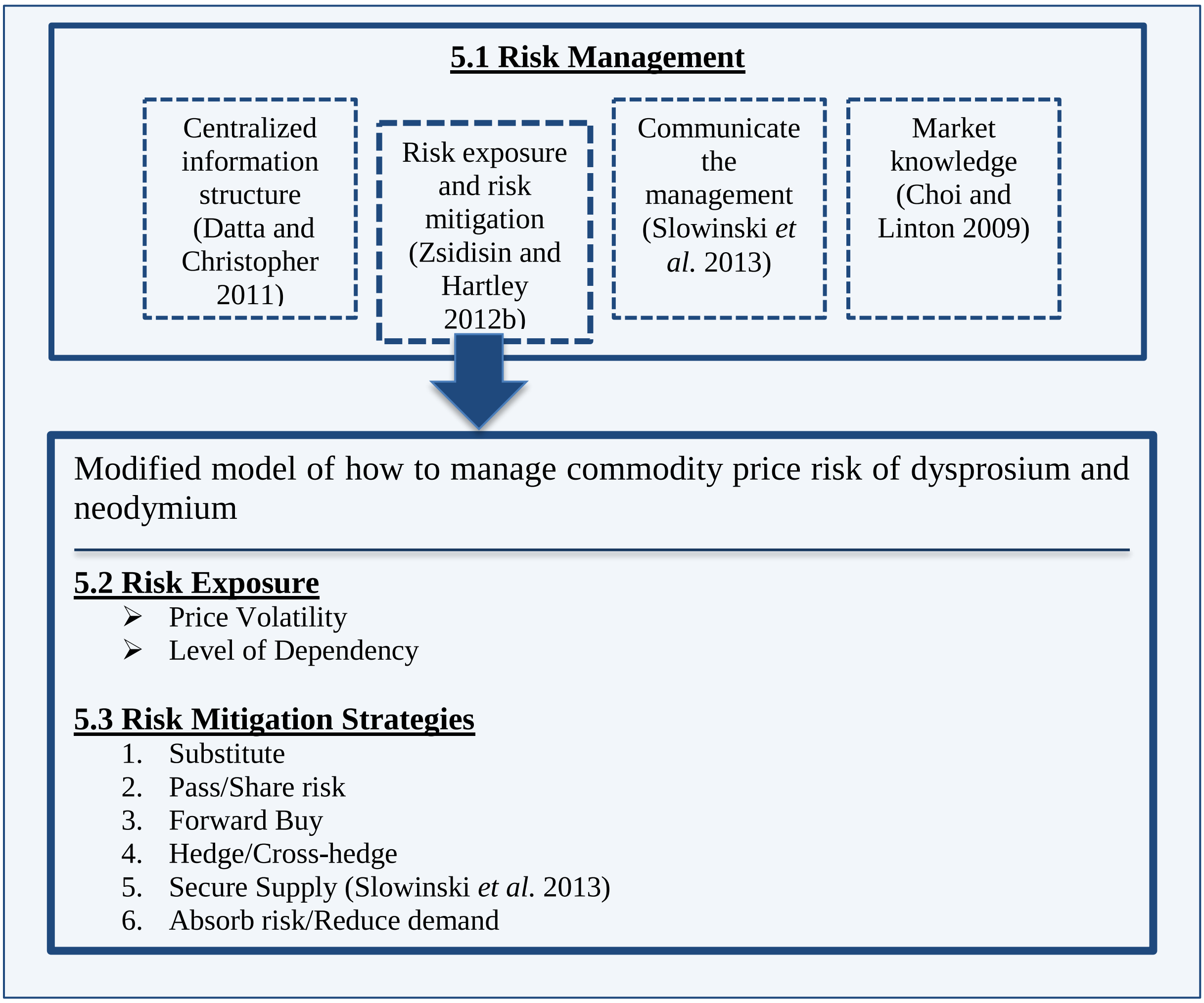

Figure 5.1 Structure of how the own conceptual model is presented in the analysis, of how an automotive manufacturer could mitigate commodity price risk

The outcome of the analysis ends up in which mitigation strategies that are applicable in the automotive industry for dysprosium and neodymium, which could be found in the end of this chapter.

5.1 Risk Management

Information sharing, communication and market knowledge

Centralized market information is a key factor in risk management (Ganguly and Guin 2013; Choi and Linton 2009; Datta and Christopher 2011). Volvo possesses this key factor in the market intelligence department, where the Chief Economist and the Raw Material Specialist have a high level of market knowledge and a good overview of the market situation. Volvo does also use the information about factors in the market that could affect the prices and include some of them in their tool to forecast future prices of dysprosium and neodymium. This forecast makes it possible for Volvo to be prepared of possible price increases. All this knowledge in the market intelligence department is distributed and shared through the company by the weekly commodity price briefer. This type of information sharing and distribution is supported by the theory as a way to mitigate the risk exposure in a company (Datta and Christopher 2001). However, this information letter does not include a strategy of how Volvo wants these risks to be handled. Even if the information is shared, the communication of how to tackle the problem is lacking in the organization. The employees at Volvo also need to possess risk management knowledge (Ganguly and Guin 2013; Choi and Linton 2009; Datta and Christopher 2011) in order for the company to be united in the actions of how to reduce the risk exposure. Furthermore, the conducted interviews signal that the information sharing between Volvo and its suppliers is not as smooth previous research suggests (Wagner and Boutellier, 2002).

Due to fierce competition, the commodity market is hard to be exposed to, in particular for a small actor (Ni *et al.* 2012). Even if Volvo is a relatively small actor in the industry in comparison to global competitors, the company could be considered big in absolute terms and on compared to their Swedish competitors. They managed to absorb the price risks when the prices of neodymium and dysprosium increased 2011, but this did cost the company a lot of money and resources. Firms need to maximize the utilization of scarce resources (Hazy *et al* 2008) and by creating a mitigation strategy of how to reduce the impact of commodity price risk, Volvo could get more resources to their core business.

Traceability

Volvo has a very limited traceability in the supply chain of dysprosium and neodymium according to all purchasers. This holds partly true according to the Supplier C who explained they have a good overview of the supply chain down to the manufacturer of the magnets, which contain dysprosium and neodymium. After that, however, the company has very limited information of these materials. Additionally, the Environmental Expert argues for improved information sharing in the supply chain of the rare earth elements in focus, in order for Volvo to take more responsibility. This is supported from theory, where Choi and Linton (2009) describe that by having a closer dialogue with the sub-suppliers further upstream, the company gets a better view of what the current market trends are.

5.2 Risk Exposure

5.2.1 Volatility

The market prices of neodymium and dysprosium have been volatile in the past, mainly due to China’s great influence on the market (Moss *et al*. 2013; Habib and Wenzel 2014;

Hoenderdaal *et al.* 2013). This is confirmed in several interviews conducted at Volvo. Perhaps most notably, the Chief Economist and Raw Material Specialist pointed at the price spike in 2011, as an example where China exerted its market power. When this occurred Volvo evaluated how the situation could be handled, but as the prices stabilized Volvo did not implemented any mitigation strategies (Chief Economist). Furthermore, a majority of the respondents indicated that the historic price volatility is harmful to the business (Purchaser A, Purchaser C, R&D A, Chief Economist and Raw Material Specialist). This is well in line with the prior research within the field (Habib and Wenzel 2014; Hoenderdaal *et al.* 2013). It could therefore, with great certainty, be concluded that price volatility on the neodymium and dysprosium markets is of great concern for Volvo.

The Chief Economist and Raw Material Specialist state that much of the price risks of dysprosium and neodymium in the market disappeared when WTO ruled against the Chinese export quotas. This notion is partly supported by R&D C, who argue that there have been worries regarding the high price levels in the past but that the current, lower ones are acceptable. Furthermore, future price stability is a prerequisite for continued usage of dysprosium and neodymium (Purchaser C). Previous research states that when projecting future volatility one has to look back at the events that caused volatility in the past (Zsidisin and Hartley 2012b), which is a slightly more precautious takes on the expected volatility. Theory is contrary to the actions of R&D C, who cite economy as one of the reasons why they are working to eliminate the use of dysprosium. Historic volatility could only be overlooked if it had been caused by accidental events (Zsidisin and Hartley 2012b). The volatility on the neodymium and dysprosium markets have, however, been caused by the structure of the market. It could thus be concluded that the volatility of these markets are inherent. The fact that view of the market volatility differs significantly between the empirical findings and the theoretical review could be a sign that the researched firm could benefit from updating its view of the market.

The argument made, by the Chief Economist and Raw Material Specialist, that new mines will diversify the supply and ease the Chinese dominance can only partly be validated by the academic literature. It is not likely since new mines will impact the supply significantly in the short- and medium-term (Moss *et al*. 2013), nor will the new supply be enough to cover the projected future demand (Habib and Wenzel 2014; Hoenderdaal *et al.* 2013). Furthermore, China has several inherent competitive advantages in rare earth production like low labour cost levels (Hensel 2011) and the control over 70% of the global proven reserves of dysprosium (Habib and Wenzel 2014). Thus, the main chunk of the production is likely to take place in China in a foreseeable future and it is likely that the country will continue to possess their power over market. This receives further support from Massari and Ruberti (2013) who state that countries with market power are unlikely not to make use of it. The Chief Economist and the Raw Material Specialist also argue that they are highly dependent on powerful miners and suppliers upstream, which complicates the situation even more. Also, Supplier C cites China's control over the supply as a limit to their possibilities to act on the market. Further increased volatility could occur if environmental regulations were implemented in China or if the concerned materials were to be included on a metals exchange for trading. These two potential sources of volatility are mentioned in the interviews with Purchaser A and the Chief Economist and Raw Material Specialist respectively. Support for these concerns is, however, only partly to be found in academia (Massari and Ruberti 2012; Kingsman 1987). The Chief Economist further points out that if the concerned materials were to be traded on an exchange, it is likely that it would add volatility due to increased speculation similar to the situation of copper. Fischl *et al*. (2014) supports this notion by citing the fact that speculation as one of the types of market distortions that triggers volatility on markets.

The market intelligence department uses an in-house developed statistics tool to fundamentally forecast the market price several years into the future. This method of forecasting is well known within the academics, which highlights the importance of long-term fundamental forecasting. It would, however, require to be complemented by a subjective fundamental analysis to fully understand the underlying market characteristics (Zsidisin and Hartley 2012b). Short-term technical analysis is, however, not a part of the current practice, which is in contrast to the framework developed by Zsidisin and Hartley (2012b). This practice could help Volvo track short-term market patterns.

Information about raw material price changes is gathered and structured by the market intelligence department and spread out in the organization. Since the prices of neodymium and dysprosium are to be considered highly volatile, Volvo does the right thing to monitor the market closely according to Zsidisin and Hartley (2012b). Furthermore, by monitoring the markets for input material, Volvo improves the ability to maintain a competitive position in the market (Ellram 2013). Supplier C contributes with information of their mitigation strategies and the actions taken regarding the price risks of dysprosium and neodymium. However, all Volvo´s suppliers, including neodymium and dysprosium in their products, might not have the resources and ambition of doing this. It could therefore be argued that Volvo should either make sure the suppliers are engage in mitigation strategies, which reduce the risk exposure, or to implement mitigation strategies of their own. A suggestion would be that Volvo could set a standard of how they expect their suppliers to act regarding these risks, and if the suppliers follow the guidelines, Volvo pays for future sudden price increases.

A strong growth in demand of dysprosium is expected to further support the price increases of neodymium and (Moss *et al.* 2013) together with increased demand, lagging actions to increase supply is projected to push up the prices even further. The opinion at Volvo is mixed regarding the projections for demand and supply of dysprosium and neodymium. The purchasers agreed on that future demand of neodymium and dysprosium would depend on the customers demand for premium features and/or the level of hybridization of the car. This is partly receiving support from the literature stating that hybrid cars are one of the future key users of the concerned materials (Cullbrand and Magnusson 2011; Habib and Wenzel 2014). The R&D respondent’s opinions of future developments were, however, a bit different. R&D A forecasted, Volvo’s consumption of neodymium and dysprosium to decrease vastly in the future. This is mainly due to a planned push to become independent from the concerned materials. Even though this could be a promising undertaking it is worth to notice the discrepancy between this vision and the purchasers forecast of increasing demand. This issue is further pointed out by the literature review clearly stating that internal communication is to be considered key in risk management (Datta and Christopher 2011). The other R&D respondents believe the demand of dysprosium and neodymium will be relatively stable in the future. The estimations of falling or stable future demand provided by departments at Volvo stands in sharp contrast to the answers provided by Supplier C, who sees an increase in demand in the coming years. This growth will be driven by rising numbers of cars produced and the switch from hydraulic steering to electric steering, two drivers not cited in the literature review of this thesis.

5.2.2 Dependency

The dependence on the rare earth elements in focus is still high, even if the dependency is lower than before (Purchaser C). The literature adds support to the majority of the respondents in the notion that Volvo is highly dependent on neodymium and dysprosium (Cullbrand and Magnusson 2011; Massari and Ruberti 2013). The concerned materials are considered key in the struggle to increase performance and/or to reduce the size of the concerned parts according to the purchasing, R&D and the market intelligence department. Moreover, the Environmental Expert explains that dysprosium and neodymium are particularly important in advanced top of the line cars and plug in hybrids. The trade-off between size/performance and the usage of neodymium and dysprosium is something that is covered in the majority of the interviews, and many respondents state the lack of space within the car as a key issue. Supplier C further supports the existence of this dilemma by citing the effects on magnetic strength and heat resistance that neodymium and dysprosium respectively offers. R&D A are trying to reduce the dependency of dysprosium and neodymium, which could create a more stable value of the company (Baldi *et al*. 2014) since when prices of dysprosium and neodymium decreases the value of the company increases.

Despite the strong support from respondents, the dilemma is not very commonly mentioned in the previous studies of the topic. The trade-off could, however, be viewed as the core issue of rare earth dependency. This is confirmed by R&D A, who points at the fact that significant changes in design only can be done when a new manufacturing platform is implemented. This happens quite seldom, which hampers the flexibility that is cited in the academia as a key to implement risk mitigation strategies (Zsidisin and Hartley 2012b). The Environmental Expert highlights the importance of dysprosium and neodymium in the top of the line products, which build the brand image. If these are removed Volvo might have a hard time competing with high performance cars. A possible relief would, however, according to the Environmental Expert, be the full electrification of the car that would free up space since two drivelines are not needed.

The lack of viable substitutes, mentioned both in literature (Golev *et al.* 2014) and by interviewees, makes the dependency even tougher to mitigate. R&D C explained that the ambition is to eradicate the usage of rare earth elements due to high prices but that reduction of dysprosium leads to a lower performance and there are no substitutes available. A reduction of the performance in the components is not aligned with the strategy of Volvo, which focus on premium segment cars with high performance and therefore should be considered with caution. R&D A state that terbium could be used as a substitute for dysprosium, which would reduce the dependency of dysprosium. Also, R&D B describes that ferrite magnets could replace neodymium magnets depending on how the prices change and with a lower performance as a result.

The findings regarding the dependence on neodymium and dysprosium for Volvo, could be further supported by conducting a spend analysis. A spend analysis objective is, according to Zsidisin and Hartley (2012b), to map up the dependence on certain commodities in a clear and structured way. The spend analysis should include the material directly procured by the organization and the material embedded in components bought from suppliers, in order to get the full picture. As stated in the interview with the market intelligence department, Volvo does not procure any neodymium or dysprosium themselves. Therefore the spend analysis conducted in this paper only will focus on the material embedded in purchased components.

Spend analysis

The costs for neodymium and dysprosium in the investigated components (rear axle, loudspeaker and servo pump) in this thesis equals to 60 USD according to the prices given by the Chief Economist (Table 4.2). In a V60 hybrid, however, the total value of the dysprosium and neodymium sums up to 107 USD[3]. When splitting the cost between the two investigated materials, it could be discovered that the expense of dysprosium is almost 50% larger than of neodymium. This could be the reason why R&D C are highly focused on dysprosium rather than neodymium. These amounts can further seem insignificant relative to the total cost of a car and this is also well in line with respondents stating that the current price level is acceptable. If, however, the prices were to increase in the same way as in 2010-2011, meaning a 20-fold price increase according to Nieto *et al* (2013), the situation would be different. A 20-fold increase would imply a total cost of roughly 2 140 USD per car, a sum that could be assumed to be a tough blow for the squeezed margins of a car manufacturer.

5.2.3 Graph of Volatility and Dependency

Volvo is currently stuck in a situation where the important commodities, dysprosium and neodymium, experience high volatility and risk of future price increases. Since it is likely that China will keep its strong grip on the market, it is logical to believe that future market conditions will remain unstable. This is particularly true for dysprosium, of which the supply diversification is harder to achieve by setting up new mines due to China's vast control over the proven reserves. In spite of pressure from R&D departments to reduce the consumption, the commodities are still to be considered as critical (figure 5.3). It seems highly likely that this will be true, even in the short- to medium-term due to long implementation time of design changes and the lack of viable substitutes. Even in the case of dependency, the situation for dysprosium seems to be more severe than for neodymium due to the almost 50% larger spend.

[3] Calculation based on data from IMDS (2014)

This analysis helps to draw up a risk matrix as proposed by Zsidisin and Hartley (2012b) to visualize the risk exposure (figure 5.3).

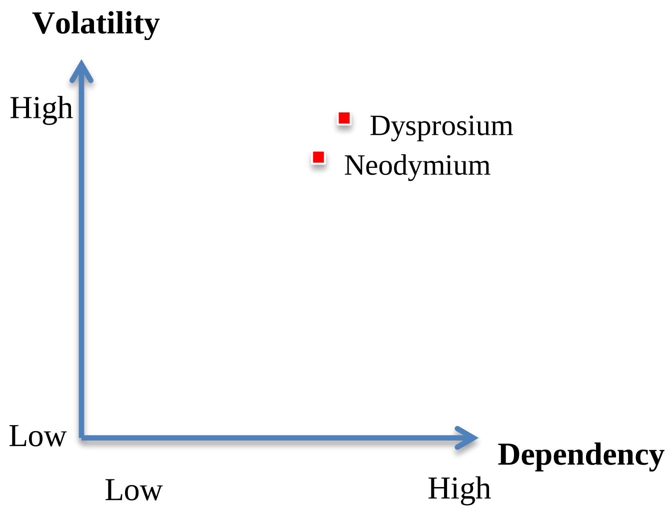

Figure 5.2 An approximate judgement of Volvo´s exposure to price risks related to dysprosium and neodymium

5.3 Risk mitigation strategies

Since the use of neodymium and dysprosium exposes Volvo to risks, the firm needs to act in order to ease the costs associated with being at risk (Banham 2004). From the interviews it is clear that the R&D departments have most insight and have considered how to handle difficulties of dysprosium and neodymium compared to the purchasing departments. However, the R&D departments have different attitudes of what needs to be done. R&D A have a rather aggressive strategy of reducing demand of neodymium and eliminating dysprosium in their products, within a relative short time period (6-8 years). R&D C also try to reduce the use of these materials but not as aggressively as R&D A. R&D B, however, does not actively reduce the use of dysprosium and neodymium but leaves the decision of which materials to use to the suppliers. The different attitudes could be a consequence of different levels of risk tolerance of the different departments. Zsidisin and Hartley (2012b) highlights the importance of understanding the company's (in this case departments) risk tolerance in order to deal with risks in the most efficient way. If not aware of the level of risk the company or/and department is willing to pay, it is very hard to address how to handle the risk.

5.3.1 Substitute

The literature review presents that substitutes for dysprosium and neodymium are very limited (Habib and Wenzel 2014). An effective substitute to dysprosium and neodymium would have a great impact in the decrease of dependency of these materials. However, prior research suggests that the only option would be the application of nanotechnology in a distant future (Massari and Ruberti 2013). All interviewed purchasers, except for Purchaser B and R&D B, points at the lack of substitutes. They argue that low performance speakers could use ferrite magnets instead of neodymium magnets. Ferrite magnets would, however, not be applicable to the branded high performance speakers that are deemed as strategically important to build the brand of Volvo (Environmental Expert). Supplier C, who states that the substitution leads to increased size and weight of components, also cites ferrite magnets as an opportunity. The use of ferrite magnets would, however, be hard to combine with the lack of space in the car (Purchaser A, Purchaser C, all R&D respondents, the Environmental Expert and Supplier C). Switching between ferrite magnets and neodymium magnets in the components does, however, seems rather easy according to R&D B. The respondent further explains that the use of ferrite magnets and neodymium magnets depends of the prices of neodymium. When the neodymium prices are high, ferrite magnets are used instead. Zsidisin and Hartley (2012b) support a shift of materials when it is economically viable but also highlight that it is a major project and requires involvement of several internal business units. But since ferrite magnets are only possible to use in the standard loudspeakers, and not mentioned as an option for the other components investigated, substitution to ferrite magnets can be concluded as a non-viable mitigation strategy. Volvo and Supplier C share the same view regarding the limitations of substitutes and the problems of increasing component sizes to reach the performance specifications. However, the results from the interviews indicate that the priority of the suppliers is that the performance levels of the components are achieved. R&D A further state that terbium could be used as a substitute for dysprosium. The problem with this substitute is, however, the fact that terbium also is a rare earth and therefore are exposed to a similar situation and risks as dysprosium (Massari and Ruberti 2013). R&D B seems to see some possibilities in using ferrite magnets instead of neodymium magnets as a substitute but adds that ferrite magnets are not as effective as neodymium magnets. Furthermore, Volvo does not engage in the development of substitutes of neodymium and dysprosium (Chief Economist and Raw Material Specialist). The Environmental Expert does, however, add that sharp price increases should add pressure to innovate new solutions to substitute dysprosium and neodymium.

5.3.2 Pass/Share risk

The automotive industry is experiencing a high degree of competitive pressure, which causes lower bargaining power when selling to consumers. This leads to difficulties when trying to pass on price increases to customers. The notions of these difficulties are supported by previous academia (Talay *et al.* 2013; Porter 1979), Volvo's Chief Economist, Purchaser B and Purchaser C. The prices, of Volvo´s products, are decided by the marketing department and are set depending on the customers perceived value and not by the costs of the car (Purchaser B and C). This would therefore imply little room for passing on price increases of neodymium and dysprosium to the customers. Despite this, the Environmental Expert argues that an opportunity might exist, to pass on price increases of premium equipment. Even though this is partly supported by Odekerken-Schröder (2003), it seems only applicable to niche products and is, as previously stated, disputed by both a majority of the respondents and part of the academia.

Auto manufacturers are known to have a fair amount of leverage over its suppliers who tend to be smaller and more dependent on the buying firm (Lilliecreutz 1998). This provides an opportunity for Volvo to offload some of the risk on its suppliers (Porter 1979). Both Purchaser B and Purchaser C support the feasibility of this strategy, though Purchaser C argues that it would only be suitable in the short-term. The viability of the strategy is, however, disputed by respondents from the market intelligence department. They emphasize on the notion that Volvo does not want the suppliers to charge higher prices in order to protect themselves from higher commodity prices in the future (Chief Economist and Raw Material Specialist). Furthermore, Zsidisin and Hartley (2012b) refute this solution by pointing at the risk of damaging supplier relationships by taking advantage of the poor financial situation of many suppliers. Theory strengthens the case not to push the risk to the suppliers further by stating that the OEMs tend to be the stronger part in the supply chain and thus would be the most suited to deal with risks (Hofman 2011).

Purchaser C describes that pushing the price risks to the supplier might work in the short run, but is not a good solution if Volvo wants to maintain a good and sustainable relationship with the supplier. This approach is supported by the theoretical review where Wagner and Boutellier (2002) describe that in long-term relationships, relational contracts, the gains and the burdens are shared between buyer and supplier. This means that the buyer in most cases will have to bear the risk of price increases of raw material. In current practice, Volvo compensates its suppliers each 6th month for prices higher than a chosen index, if the suppliers highlight a price increase (Chief Economist and Raw Material Specialist). The cost reimbursement is sometimes explicitly regulated in the supplier contract (Chief Economist and Purchaser B) but it seems to be subjectively set by Volvo in most cases. It could also be worth pointing out that Volvo does not seem to have a coordinated strategy to deal with reimbursements for material price increases but rather do it on a case-by-case basis. In the case of cost reimbursement, Volvo also demands part of the gain when the prices are falling. However, the Chief Economist and the Raw Material Specialist state that Volvo sometimes might not prioritize this. To neglect these issues stand in sharp contrast to the theory, which favours a more active approach (Zsidisin and Hartley 2012b).

Altogether, one can conclude that the different purchasing departments do not approach contracting dysprosium and neodymium systematically, with their suppliers. The theoretical review provides several contracting schemes that could offer more clarity to the process (Zhang *et al.* 2013). Furthermore, the structure with a third-party reference and predefined shares of the burden, as proposed by Zsidisin and Hartley (2012b), could help Volvo become more systematic in its approach. Logically, to come away from subjective decisions and the need to always monitor each situation would improve the efficiency of the firm.

5.3.3 Forward buy

The respondents at Volvo almost unanimously disapprove of forward buying of neodymium and dysprosium. All respondents from the purchasing department agree that engaging in forward buy would not be a possible mitigation strategy. Purchaser A argues that forward buy ties up to much capital and Purchaser C describes that Volvo is, from a global perspective, too small to engage in such an activity. This is well in line with the academic literature on the topic citing the two main drawbacks of the strategy to be, tied up capital and that it requires to buy large quantities, which might be hard for a small firm (Zsidisin and Hartley 2012b). Furthermore, the market intelligence department clearly states that they do not wish to engage in forward buying since it is the responsibility of the supplier (Chief Economist and Raw

Material Specialist). In that statement, however, there is a logical error since it can be argued that Volvo is the one taking the hit for poorly procured commodities due to cost reimbursable contracts. It could therefore be wise for Volvo to pay closer attention to the procurement made by its suppliers. It is also in sharp contrast with Choi and Linton (2009), who state the importance of a firm not to be overly reliant on its suppliers. Supplier C is, however, not inclined to perform forward buy and cites Chinas tight control of the market as a reason. The Environmental Expert additionally argues that Volvo should not engage in forward buy because they should instead focus on their core business. Banham (2004) agrees to this and describes that activities such as absorbing, transferring or hedging risks, force companies to deploy resources that otherwise could be spend on more productive projects. Even if Volvo has a good forecasting tool to calculate future prices of dysprosium and neodymium and could evaluate the future demand it could expose the company to other types of risks, according to Zsidisin and Hartley (2012b). These risks include both risk of unexpected market change and increased of operational complexity due to increased storage. The Logistic Expert presents that forward buy could be possible but stresses the logistic issues that accompany these strategies, like the risk of theft, when transporting the valuable material. However, the Logistic Expert also highlights his limited insight of forward buy of dysprosium and neodymium in practice. Therefore, the other respondents, especially Supplier C, disapproval of forward buy ranks higher, since they have better knowledge and experience of the matter. Supplier C points at China's close grip on the market as a complicating factor which makes it impossible to perform this strategic action. Even though not stated in previous literature, this notion seems highly relevant to the case and it further increases the concerns regarding the strategy.

5.3.4 Hedge/Cross-hedge

To perform financial hedging, a commodity needs to be traded on an exchange, such as the Chicago Mercantile (Zsidisin and Hartley 2012b). Correspondingly, this prerequisite is stated by the Chief Economist and Raw Material Specialist as a major obstacle for Volvo to hedge against the price risk of neodymium and dysprosium. Since the commodities are bought straight from the suppliers, this is not an option for Volvo today. All the purchasers interviewed, further share this understanding and financial hedging can thus be concluded to be a non-viable mitigation strategy for the rare earth elements in focus. The Environmental Expert agreed that this is not a potential strategy today, but it could be a good solution if it gets the financial strength in the future.

Furthermore, there is no mentioning in the empirical findings, of any other commodities following the same price pattern as neodymium and dysprosium that would make cross hedging viable. Since this is neither mentioned in academia of rare earth elements nor in the interviews conducted, this strategic option could be written off with a fair amount of certainty.

5.3.5 Secure supply

Toyota took the mitigation of rare earth price risk a step further when they acquired a part of a Canadian mining company (Slowinski 2013). Further supporting the viability of the strategy, the Chief Economist and the Raw Material Specialist state that there have been discussions, during the last price spike in 2010-2011, regarding investing in mining activities. The fact that the chairman of Volvo, Li Shufu, was the one leading the investigation could be seen as a sign of the significance of the project. Thus, it could be assumed that a secure supply project requires a large long-term commitment from the company in form of focus, time and resources. Secure supply would have a great impact in reducing the risk exposure for Volvo. Nevertheless, the required focus and resources could be seen as the main drawback since it diverts the attention (Prahalad and Hamel 1990), from what really is creating value for Volvo, namely building cars. The Environment Expert, however, argues that secure supply could be competitive both to ensure the material supply of dysprosium and neodymium but also for commercial objectives. Volvo could by this strategy use the amount dysprosium and neodymium needed for their products without exposed to risk and increase traceability and control in their supply chain. Since one of Volvo´s core value is environment, they could ensure social and environmental sustainability in the production and communicate this to their customers.

Due to the small size of Volvo, in a global perspective, secure supply would only work if the firm could partner up with other actors (Logistic Expert and Environmental Expert). This solution helps sharing the risk and financing burden of the often long-term and highly insecure projects of new mining development (Slowinski *et al,* 2013). Furthermore, R&D A argue that secure supply is not a good idea since it is not the company´s core business. Volvo is producing cars and not to engage in metal supply. It is a shift of focus away from the core competencies of the companies, which in most cases of industrial firms can be assumed not to be mining activities. It is of great importance for firms to focus on core competences and not doing so could potentially be harmful to the business (Prahalad and Hamel 1990). Due to these drawbacks, it can be argued that secure supply is a far from perfect but feasible strategy.

5.3.6 Absorb risk/Reduce demand

Pressure from the price increases 2011, pushed the industry to find new materials mixtures containing lower levels of dysprosium and neodymium (Purchaser C). This action lowered the dependence of these materials by reducing the demand (R&D B). Supplier C confirms this and describes that they sought to reduce use of dysprosium and neodymium by recycling scrap, optimizing usage and reducing the performance of the components to meet rather than exceed specifications. Absorbing the risk and reducing demand are seen as the options of last resort in the decision-tool created by Zsidisin and Hartley (2012b). Reduce demand, however, is a strategy that is focused on by R&D C and R&D A. The departments did not describe this as a last resort but as a quite resolute measure and it could therefore be argued that the risk tolerance is fairly low among the concerned R&D departments.

The ambition of the R&D A is to reduce the usage of neodymium significantly and to eliminate the use of dysprosium. This will be possible due to increases in size and changes in material mixtures of the products. Since many respondents (Purchaser A, Purchaser C, all R&D respondents, the Environmental Expert and Supplier C) are noting the scarcity of space in the car it could, however, be questioned how viable this strategy is for other components. The ambition of neodymium and dysprosium reduction is partly shared with the R&D C, but was not fulfilled yet due to too high performance requirements. It is also noted in the interviews the fact that much of the responsibility of product development and finding solutions in order to reduce dependence on neodymium and dysprosium, lays on the suppliers (R&D C; R&D B). Questions regarding component design are Volvo´s responsibility but investigations of different material mixtures are the supplier's responsibility (R&D A). This could make Volvo overly reliant on its suppliers as discussed by Choi and Linton (2009). Furthermore, R&D C argue that there are no resources for inter-firm projects with the suppliers, which contradicts Zsidisin and Hartley (2012b) who support the importance of this type of collaboration.

A possible reason why R&D A, R&D B and R&D C have different ambitions of reducing the usage of dysprosium and neodymium could be because of the different technical characteristics of the components. Therefore, one identical solution of how much dysprosium and neodymium Volvo should use in their components, is not realistic. Instead a centralized vision of how the different departments should handle the issue could be more feasible, in order to reduce the risk exposure and save resources.

Recycling

Recycling of dysprosium and neodymium is not performed at Volvo today but it is an area, which is given much attention in the academic research (Moss *et al.* 2013). Recycling is seen as a key to close the gap between supply and demand of rare earth elements (Habib and Wenzel 2014). Component complexity is the main obstacle in order to realise the full potential of recycling, both according to academia (Binnemans *et al.* 2013; Moss *et al.* 2011) and the respondents at Volvo. The respondents are generally negative to recycling due to, what could be regarded as, short-term obstacles such as product complexity or low levels of material purity. It could therefore be argued that recycling merely has a long-term viability to offer a demand relief. The development of recycling could also, as stated by the Logistics Expert, benefit from a partnership with a specialised actor like Stena Metal or with other suppliers (Purchaser A). This is supported by Golev *et al*. 2014, who sees the involvement of different industries as a key to unlock the potential of recycling. Furthermore, recycling might be possible but Volvo needs to investigate the processes (R&D B) and in case of recycling, a high level of purity of the rare earth elements in focus, needs to be ensured (R&D A). However, the R&D C argue that there are few incentives for their department to engage in these types of activities. This could be a sign of a lack of commitment from the firm to recycling; a conclusion that is further supported by the notion by the Chief Economist that recycling merely is a PR opportunity. From a different angle, Supplier C pursued recycling of scrap to reduce its demand during the price spike in 2010.

Remanufacturing

Several respondents (Purchaser B, Purchaser C, Environment Expert and R&D B) cite remanufacturing as a more viable option compared to recycling. The Environmental Expert further states that this is a prioritized area currently performed at Volvo and has potential to grow. Remanufacturing is said to be less complicated process, than recycling, since it requires less work on the product and it could offer a way to round many of the issues related to recycling. The obstacles to fulfilling the vast potential of recycling are the technical complexity of the materials in the components, according to theory (Binnemans *et al.* 2013; Moss *et al.* 2011). Thus, remanufacturing and recycling could together offer an own viable strategy to reduce the exposure to risk, where remanufacturing could prove to be efficient complement to recycling.

5.3.7 Rare earth price risk mitigation framework

It appears to be no clear solution on how to mitigate price risks related to neodymium and dysprosium. Some strategies, like hedging and passing risks to customers, could be deemed not applicable due to certain characteristics of the automotive industry and the use of rare earth elements. Others could be useful when the circumstances are right, though none of them is to be considered perfect. The departments' different approaches and knowledge of the matter became clear during this investigation. This is common and potentially harmful to the business (Griffin and Hauser 1992) and it would therefore be advisable for Volvo to formulate an overall strategy and information sharing process regarding the firm's usage of neodymium and dysprosium.

Zsidisin and Hartley (2012b) propose a decision-tool for using different strategies to mitigate price risk. After performing this investigation it is, however, hard to see that one of the solutions, singlehanded, would solve the problem in a convenient way. Also, nothing points at the fact that the strategies would be mutually exclusive. Therefore, the priority format could be rejected and it would instead be advisable to see the different strategies as complementary. An example of this would be the strategies of sharing risk with suppliers and secure supply, which would suit different types of issues. When experiencing short-term turbulence, sharing some risk with suppliers would be a suitable measure to reduce the burden of the focal firm. Then, if the market volatility would prove to be inherent and combined with structural price increases, secure supply could offer a more permanent relief, although it would demand high investments and resources.

Volvo is a relatively small actor compared to their global competitors (Purchaser C). They could therefore benefit from the flexibility of being a smaller actor, when implementing a strategy to reduce commodity price risk exposure. Their size could make it easier to act and implement an action compared to a bigger organization, which is slower and might therefore take very long time to implement changes. On the other hand, a small organization might need to collaborate with other actors if the mitigation strategy needs high amount of recourses, which a bigger organization might possess. The theory confirms this by stating that flexibility is of high importance when implementing a strategy (Zsidisin and Hartley 2012b; Slowinski *et al.* 2013).

This analysis have concluded that the mitigation strategies possible for an automotive manufacturer to implement in order to handle the risks of dysprosium and neodymium, are **passing/sharing risk to suppliers, secure supply, reduce demand and recovery (**table 5.1).

FEASIBILITY / STRATEGIES	**Possibility to implement**	**Reasons not possible to implement**
Substitute	Not possible	Technology barriers
Pass/Share risk to customer	Not possible	Characteristics of the market and industry
Pass/Share risk to supplier	Possible	
Forward buy	Not possible	Operational and financial obstacles
Hedging	Not possible	Not yet at an exchange
Secure supply	Possible	
Absorb risk - **Reduce demand** - **Recovery (recycling and remanufacturing)**	 Possible Partly possible	 Technological barriers

Table 5.1 Analysis matrix of effective mitigation strategies (Bold means a feasible solution)

From table 5.1, sharing risk with suppliers, secure supply, reduce demand and recovery are advisable to fit the automotive industry regarding mitigation strategies of reducing risk exposure of dysprosium and neodymium. The advantages and disadvantages of these four strategies are further described in table 6.1 in the next chapter.

Recovery is added as a separate strategy compared to the initial framework discussed in the literature review. Slowinski *et al.* (2013) supports this by emphasising recovery in one of their suggested actions. This has been done since remanufacturing and recycling both recovers material but will be effective in different time frames. Remanufacturing is expected to be the short-term solution, whereas technological is required to perform recycling of the concerned materials.

6 Conclusions

This chapter provides answers to the research questions and present the new framework of how an automotive manufacturer could handle the price risks of dysprosium and neodymium. Recommendations to Volvo, future research and authors reflections are also included in this chapter.

This thesis provides an insight of a car manufacturers risk exposure of the risks connected to commodity prices of rare earth elements. This investigation fills a gap in academia since there are no previous practices or frameworks in theory of how a car manufacturer should act and handle its price risk exposure of rare earth elements. This research provides a new framework of how these risks could be mitigated to avoid being affected by or reduce the affect of sudden price increases.

The purpose of the research was to investigate possible risk management approaches connected to commodity prices of rare earth elements for an automotive manufacturer. Below the answers to our research questions are provided, in order to fulfil the purpose.

What price risk exposure does an automotive manufacturer have of the supply of neodymium and dysprosium?

Volvo is exposed to risk because of its usage of neodymium and dysprosium. This is distinguished by estimating the interplay between the market volatility from prior research and the firm's dependence on a particular input material from the interviews. Overall, neodymium and dysprosium tend to show very similar risk characteristics. Both materials are used to, in one way or another, improve the performance of a car and have features that make them hard to replace. An approximate mapping of the spend on these materials, created in chapter 5.1.2 based on all indirectly purchased neodymium and dysprosium, further supports the notion that Volvo is dependent on the concerned rare earth elements. The mapping concluded that, although only representing a small portion of the cost of a car, a major price increase, could hurt the margins severely.

Even though neodymium and dysprosium are not one of the major materials used by Volvo, the firm is highly dependent on them. Ferrite magnets could be used for standard components in the cars but there are no effective substitutes for the high performance premium components such as the Bauer and Wilkins´s loudspeakers. For some products, terbium could be used as a substitute; however, this does not reduce the risk exposure since terbium is also a rare earth element and follow the same price patterns and risks as for dysprosium. Except for these substitutes, change of construction could reduce the dependence, however, this is something that takes time.

Together with high degree dependence, high market volatility is of major concern for a company. Very few actors are able to impact the commodity markets and most actors are therefore to be seen as price takers. The neodymium and dysprosium markets are inherently volatile due to structural factors, mainly concerning China's market power. This is a little truer for dysprosium since China holds the vast majority of the world proven reserves and supply diversification therefore is harder to achieve. Though respondents have stated that much of the dangers of the rare earth elements commodity market are gone, the structures causing the previous price spikes are still there and the market volatility is still likely to be high in the future.

As a concluding remark it can be stated that Volvo is at risk due to its usage of neodymium and dysprosium. The risk is a bit higher for dysprosium due to a more homogenous supply side and the higher historical price volatility. It would, however, be advisable for Volvo to actively manage the risk related to both materials rather than to monitor the situation.

How can an automotive manufacturer mitigate the risks associated with the commodity price of neodymium and dysprosium?

It is of high importance that companies maximize the utilization of resources in order to perform as good as possible. By implementing a mitigation strategy of how to reduce the risk exposure of dysprosium and neodymium, Volvo could lower the costs of sudden price increases. These resources could instead be allocated to the core business of the company, namely building cars.

From the theoretical review a framework was found and tested in the empirical setting of an automotive manufacturer. In the analysis, four mitigations strategies were found suitable to reduce Volvo´s exposure to the price risks related to neodymium and dysprosium. The following strategic actions are to be recommended for a firm in Volvo’s situation:

- **Sharing risk with suppliers is a possible solution to reduce risk exposure**

Automotive manufacturers tend to have great power over its suppliers and to pass on some of the risk to the weaker party could therefore be a solution. This strategy was approved to use in practice by four out of seven of the respondents, however, the strategy does show distinct drawbacks including that the opportunistic might deteriorate the buyer-supplier relationship. Therefore, it can be concluded that passing the risk with suppliers only is a viable short-term solution.

- **Secure supply involves big resources but is a solution for the long run**

By investing in mining operations of the concerned rare earth elements, a firm can with great certainty mitigate much of the risks it is exposed to. The viability of this strategic action is supported by the fact that Toyota has done a similar project and three out of five of the respondents approved this strategy to be used in practice. This strategic action is, however, a major business undertaking, demanding vast resources. This raises the question of how well the strategic option corresponds with the core competencies of Volvo and if it might harm the business by diverting attention from building cars. Therefore, this should be considered a powerful action mainly suited for severe cases of price increases.

- **Reduce demand is a strategy possible to implement**

Reducing the demand of neodymium and dysprosium is generally the strategy of choice for the interviewed R&D departments at Volvo. The process is negatively impacted by the fact that the concerned materials are used to improve performance and/or reduce the size of the components. Since space is limited, performance is of great strategic importance and design changes are lagged by limited flexibility of the production platform. This solution might be hard to implement for all areas of usage. In the longer term, however, when the platform is changed, new possibilities to change designs in more profound ways could emerge.

- **Recovery - remanufacturing is possible to implement today and recycling is possible to implement in the future**

Recovery is cited in the literature as a key activity to reduce the risks associated with neodymium and dysprosium, both on a firm level and a macro level. In the literature review, recycling is stated to have the greatest potential of all recovery-related activities. In the short-term, however, technical difficulties make it difficult to live up to its potential. Therefore, a greater focus on remanufacturing is advisable in the near future even though it might not have the same potential as recycling.

All respondents in this research supports the mitigation strategy absorb risk and compared to the theoretical framework by Zsidisin and Hartley (2012b), who include both reduce demand and recoveries under the mitigation strategies absorb risk. Our conclusions are, however, that these should be considered separately. Another conclusion made from the analysis is that the strategies should not be considered as a priority list but as complementing and interacting mitigation strategies.

Table 6.1 presents the four mitigation strategies, of how to mitigate commodity price risks for an automotive manufacturer. This framework could be used to evaluate if the strategies are feasible to other automotive manufacturers of possible other companies as well. It is, however, important to be aware that this tool have been created based on one case, Volvo, and therefore would need to be tested on more cases before the tool could be generalized to other companies and industries. The tool could be helpful for managers in the process of decision making of how to act regarding price risks of dysprosium and neodymium.

Characteristics / Strategies	Advantages	Disadvantages	Long-, or sort-term solution
Share risk with suppliers	• Easy to implement • Relatively few resources are needed • Improves transparency	• Relationship could be damaged • Harms information sharing	Short-term
Secure Supply	• High traceability • Ensure the supply • Stable prices	• Vast resources are required • Different focus from traditional core business	Long-term
Reduce Demand	• Decrease dependence • Reduce costs	• Performance might decrease • Size of components increase	Long-term
Recovery	• Decrease dependence • Reduce costs • Environmentally sustainable	• High investment cost • Partly dependent on technology development	Remanufacturing – short-term Recycling – long-term

Table 6.1 Tool to evaluate advantages and disadvantages of strategies of how to mitigate price risk exposure of dysprosium and neodymium, fitted for an automotive manufacturer

6.1 Recommendations for Volvo

Our proposition, to Volvo, is to keep following the path towards a more controlled supply chain initiated by the previous investigations conducted by Cullbrand and Magnusson (2012) and Gustafsson and Samuelsson (2014). To control the risks Volvo is exposed to in its supply chain, the firm needs to understand and address them. This investigation has concluded that Volvo has a high-risk exposure to dysprosium and neodymium. The main reasons are because China is expected to keep a close grip on the market for a foreseeable future and no effective substitutes are available on the market. Whereas it is concluded that the usage of neodymium and dysprosium expose Volvo to risk, it is advisable for Volvo act. This should be done, both by monitoring the situation and to seek to mitigate the risks by active management. An important step for Volvo to actively manage the risks is to improve market knowledge in the affected departments and improve information sharing and communication, both within the company and with important suppliers. To mitigate the risks, four mitigation strategies are advised to consider:

- Sharing risk with suppliers
- Secure supply
- Reduce demand
- Recovery (recycling and remanufacturing)

These actions should be seen as a list of options that could be undertaken simultaneously and that could complement each other. *Sharing risk with suppliers* is partly done today and the idea to transfer more of the risk should be seen as a way to pair short-term fluctuations rather than a long-term solution. The process of monitoring the price changes and how the price changes are handled could be improved. By implementing a warning system, of when the prices increase and decrease, and create a centralized process of how these changes are handled costs could be decreased. In this way Volvo could capture the price decreases in a better way than performed today.

The option *secure supply* has different features than sharing risks with suppliers. Since investing in mines requires vast resources and commitment from the firm, it should be seen as a rather long-term and drastic measure to mitigate the price risk of neodymium and dysprosium. To secure supply would involve a lot of resources and would probably need collaboration with another actor. However, calculations of the profitability of a project like this should be performed including both to secure supply of dysprosium and neodymium but also from a supply chain sustainability perspective. *Reduce demand* has so far been the solution of choice at Volvo and it is to be regarded as a rather risk intolerant solution. It has some obstacles due to design issues and the strategy needs to be evaluated closely to find out if another of the proposed strategies is to prefer. We suggest Volvo to reduce the dependence of dysprosium and neodymium in all their products as much as possible and decide in which products a lower performance level is acceptable. This should be done in collaboration with the supplier. In the top of the line products, lower performance levels are not a good solution, since this is contradictive to the strategy of Volvo. For these products, however, the margins are also bigger and a price increase could be absorbed easier if prices increase. It is important to ensure high qualitative communication with the suppliers to ensure the right performance levels are achieved for the different products.

Recovery is also partly conducted today in the form of remanufacturing, however, not because the components include dysprosium and neodymium. This, together with recycling, when it becomes technically viable, could offer vast potential for Volvo to reduce its demand of neodymium and dysprosium. Our suggestion is, for Volvo, to make investigations and calculations of which products that could be profitable to included in remanufacturing due to containing dysprosium and neodymium.

In order to handling risk exposure, Volvo should evaluate and agree on a strategy of how the risk should be handled depending on available resources. Today Volvo has at least one supplier (Supplier C) with a clear strategy of how to handle the price risks of dysprosium and neodymium and this supplier is actively working with reducing the risk exposure of these elements. Volvo could learn from this supplier and demand other suppliers, who are including these rare earth elements in their components; how they are suppose to act regarding this matter. Volvo could even set up a plan of actions, they expects from their suppliers. This plan could for example include actions of how the suppliers should reduce the use of the elements by reducing slack and making the material use more efficient. This plan could also be developed to including demands of that the suppliers should source dysprosium and neodymium (as well as other rare earth elements) in a social and environmental sustainable way. The communication with suppliers in this regard is of high importance in order for this to work. Volvo and their suppliers need, in this case, to collaborate and decide for the different performance levels in the components and evaluate these in comparison to the amount of dysprosium and neodymium used in the components.

6.2 Future research

Different materials and industries

This thesis has developed a framework for mitigating commodity price risks related to the usage of dysprosium and neodymium in the automotive industry. It would be interesting to asses this framework in future studies by either apply it to other industries and/or rare earth elements in order to test the frameworks generalizability. For example, terbium is cited by sources to be a high-risk element and would therefore be of particular interest to investigate in a similar setting in future research. Other rare earth elements and case objects could be expected to yield different input and it would therefore be a great way to strengthen and to test the framework developed in this study.

The commercial risks of dysprosium and neodymium

During this research, the commercial risk of including dysprosium and neodymium in the products were highlighted as very important. The risk of being connected to environmentally and socially damaging production of dysprosium and neodymium could be devastating for companies. Since environment and sustainability is a very important for Volvo it would be interesting to further assess the public relation-related risks associated with the usage of rare earth element. Environmental restrictions and regulations of the production of rare earth elements have also been mentioned as a risk that could result in increased price. Further investigation of this should be beneficial in order to evaluate the possibility of that it could happen and how it would be affect Volvo. This is, however, left for future research.

Suggestions, from respondents, have been made to get involved in secure supply in order to ensure social responsibility through the supply chain. Secure supply has, in this research, only been considered in the perspective to ensure material flow and protect the company from price risks. However, secure supply could also protect the brand from commercial risk but since this is related to the revenues streams rather than price risk of commodity, it is an area for further research to investigate.

Development of a business model

The suggested actions of this research could be looked into further, on a one by one basis, since there could be potentially many more angles than the ones brought up in this research. For instance, recycling of rare earths is a research area of its own and could therefore offer several interesting research questions on its own. Future investigation and development of a business model of how dysprosium and neodymium could be recycled and remanufactured, in a sustainable and profitable way, is also very interesting since the metals are not destroyed when used. This could create possibilities for actors to create a system or supply, which is combined direct supply and indirect supply from recycled metals.

6.3 Reflections of the authors

During this investigation many ideas and thoughts have come up, which will be summed up here.

Even if the situation of the market of dysprosium and neodymium have stabilized since 2011, when China increased the export quotas, there is a high risk of new sudden disruptions that could affect the supply considerably. There is the risk of new regulation and restrictions, from China, of the supply of dysprosium and neodymium. Even if these might oppose to regulations of WTO, the legal processes takes time and the prices could stay high for a while until China might be forced to remove or change the restrictions. In order to stand up against the power China possesses, Volvo might have to act united with their competitors or other actors, that are dependent critical materials such as dysprosium and neodymium.

Another thought that occurred during this investigation has been the consequences of the environmental damaging production and refinery process of dysprosium and neodymium. People´s constant increased awareness of social and environmental responsibility makes this industry in danger of being detected. If Volvo would be connected to production sites, which are social and environmental damaging, this would affect the company negatively. We agree that there would be a lot of other companies that would be even more negatively affected by a detection like this. However, if taking responsibility and increase awareness to be able to act in best way possible, Volvo could turn a possible disaster to something positive. They could by being proactive in the matter become best in class in the industry, compared to other companies, in the work of improving social and environmental conditions in the production of dysprosium and neodymium.

Due to the technical difficulties and barriers in the different components including dysprosium and neodymium, we also think it is of high importance to create a cross-functional team. This team would include product developers, technicians, strategic advisors, economists and environmental advisors to create a vision of how Volvo would like to handle the problem. Here a further discussion could be hold, based from the results of this thesis and small solutions could make big differences for the company. Examples of small actions could be to actively work in the same direction, increase awareness, improve collaboration and communication with suppliers and increase the demand of social and environmental sustainability further down in the supply chain.

References

Arnold Magnetic Technologies. (2015). *Ferrite Permanent Magnets*, [Online] Available: http://www.arnoldmagnetics.com/Ferrite.aspx [Accessed: 19.04.2015]

Achzet, B. & Helbig, C. (2013). How to evaluate raw material supply risks-an overview. *Resources Policy*. 38(4): 435-447.

Baldi, L; Peri, M. & Vandone, D. (2014). Clean energy industries and rare earth materials: Economic and financial issues. *Energy Policy*. 66: 53-61.

Bampton, R & Cowton, C. (2002) The e-interview. *Forum: Qualitative Social Research.* 3 (2):9

Banham, R. (2004). Enterprising Views of Risk Management, *Journal Of Accountancy*. 197 (6): 65-71

Bell, J., Autry, C., Mollenkopf, D. & Thornton, L. (2012). A Natural Resource Scarcity Typology: Theoretical Foundations and Strategic Implications for Supply Chain Management. *Journal of Business Logistics*. 33(2): 158-166.

Bernstein, P. (1996). *Against the gods.* John Wiley & Sons, New York.

Binnemans, K., Jones, P., Blanpain, B., Van Gerven, T., Yang, Y., Walton, A. & Buchert, M. (2013). Recycling of rare earths: a critical review. *Journal of Cleaner Production*. 51 (7): 1-22.

Bourzac, K. (2011). *New Magnets Could Solve Our Rare-Earth Problems.* MIT Technology Review. [Online] 20th January. Available: http://www.technologyreview.com/news/422459/new-magnets-could-solve-our-rare-earth-problems/. [Accessed: 19/04/2015]

Bryman, A. & Bell, E. (2011). *Business research methods*. 3rd Edition, Oxford University Press, USA.

Campbell, G. (2014). Rare earth metals: a strategic concern. *Mineral Economics*. 27(1): 21-31.

Caniëls, M.C.J., Hegrsitz, M.H. & Semeijn, J. (2013). Participation of suppliers in greening supply chains: An empirical analysis of German automotive suppliers. *Journal of Purchasing & Supply Management*. 19(1):134-143.

Choi, T. & Linton, T. (2011). Don't Let Your Supply Chain Control Your Business. *Harvard Business Review*. 89(12): 112-117.

Colicchia, C. & Strozzi, F. (2012). Supply chain risk management: a new methodology for a systematic literature review. *Supply Chain Management: An International Journal*. 17(4): 403-418.

Collis, J. & Hussey, R. (2009). *Business research: A practical guide for undergraduate and postgraduate students.* Hampshire: Palgrave macmillan.

Cullbrand, K. & Magnusson, O. (2012). *The Use of Potentially Critical Materials in Passenger Cars.* Master Thesis., Chalmers University of Technology: Department of Environmental Systems Analysis. Gothenburg.

Datta, P. P. & Christopher, M. G. (2011). Information sharing and coordination mechanisms for managing uncertainty in supply chains: a simulation study. *International Journal of Production Research*. 49 (3): 765-803.

Denzin, N.K. & Lincoln, Y.S (2002). *Handbook of qualitative research*. London: Sage.

Dubois, A. & Gadde, L-E. (2002). Systematic combining; an abductive approach to case research. *Journal of Business Research.* 55 (7): 553-560.

Easterby-Smith, M., Thorpe, R. & Lowe, A. (2002). *Management Research: An Introduction.* 2nd Edition. London: Sage.

Ellram, L.M, Tate, W.L & Feitzinger, E.G. (2013). Factor-Market Rivalry and Competition for Supply Chain Resources. *Journal Of Supply Chain Management*. 49 (1): 29-46.

European Commission (2014a) *Report on critical raw material for the EU: critical raw materials profiles.* Published by European Commission, June.

European Commission. (2014b). *Report on critical raw materials for the EU: report of the Ad hoc Working Group on defining critical raw materials*. Published by European Commission, May.

Fischl, M., Scherrer-Rathje,. M. & Friedli. T. (2014) Digging deeper into supply risk: a systematic literature review on price risks. *Supply Chain Management: An International Journal.* 19 (5/6): 480 - 503.

Ganguly, K. K. & Guin, K. K. (2013) A fuzzy AHP approach for inbound supply risk assessment. *Benchmarking: An International Journal*. 20 (1): 129 - 146.

Geely Sweden AB (2013) *Annual report 2013*. Gothenburg.

Global Intelligence Alliance. (2012). A*utomotive Manufacturers Expect to Face Intense Competition in Emerging Markets for 2012-2017*. [Online] Available: http://www.globalintelligence.com/insights/all/automotive-manufacturers-expect-to-face-intense-competition-in-emerging-markets-for-2012-2017 [Accessed: 03/03/2015]

Golev, A., Scott, M., Erskine, P., Ali, S. & Ballantyne, G. (2014). Rare earths supply chains: Current status, constraints and opportunities. *Resources Policy*. 41(9): 52-59.

Griffin, A. & Hauser, J. (1992). Patterns of Communication Among Marketing, Engineering, and Manufacturing - A Comparison Between Two New Product Teams. *Management Science*. 38: 360-373.

Griffin, A. & Hauser, J. (1996). Integrating R&D and Marketing: A Review and Analysis of the Literature. *Journal of Product Innovation Management*. 13(3): 191-215.

Gschneidner, K.A. (2011). The Rare Earth Crisis – The Supply/Demand situation for 2010-2015. *Material Matters*. 6(2) 32-41.

Guba, E. G. (1981) Criteria for assessing the trustworthiness of naturalistic inquiries, *Educational Communication and Technology Journal* 29**:** 75–91.

Gustafsson, C-H. & Samuelsson, H. (2014). *Socially responsible sourcing in automotive supply chain- The Case of conflict minerals at Volvo Cars*. Master Thesis., University of Gothenburg, School of Business, Economics and Law. Gothenburg

Habib, K. & Wenzel, Henrik. (2014). Exploring rare earths supply constraints for the emerging clean energy technologies and the role of recycling. *Journal of Cleaner Production*. 84(12): 348-359.

Halper, M. (2012). Toyota affiliate buys half a Canadian rare earth deposit. [Online] 5th november. Available: http://www.zdnet.com/article/toyota-affiliate-buys-half-a-canadian-rare-earth-deposit/ [Accessed:17.04.2015].

Hazy, J.K., Torras, M. & Ashley, A.S. (2008). Reconceptualizing value creation with limited resources. *Journal of Technology Management & Innovation*. 3(3): 45-54.

Heckmann, I., Comes, T. and Nickel, S. (2015). A critical review on supply chain risk – Definition, measure and modeling. *Omega*. 52: 119-132.

Hendricks, K. & Singhal, V. (2005). An Empirical Analysis of the Effect of Supply Chain Disruptions on Long-Run Stock Price Performance and Equity Risk of the Firm. *Production & Operations Management*. 14 (1): 35-52.

Hensel, D. N. (2011). Economic Challenges in the Clean Energy Supply Chain: The Market for Rare Earth Minerals and Other Critical Inputs. *Business Economics*. 46 (3): 171-184.

Hoenderdaal, S., Espinoza, L.T., Marscheider-Weidemann, F. & Graus, W. (2013). Can a dysprosium shortage threaten green energy technologies? *Energy*. 49(1): 344-355.

Hofmann, E. (2011). Natural hedging as a risk prophylaxis and supplier financing instrument in automotive supply chains. *Supply Chain Management: An International Journal*. 16(2):128-141.

Holton, G. (2004). Defining Risk. *Financial Analysts Journal*, 60(6):19-25.

Honglin Zhang, K. (2009). Rise of Chinese Multinational Firms. *Chinese Economy*. 42 (6): 81-96

Humphries, M. (2013). *Rare Earth Elements: The Global Supply Chain*. Published by Congressional Research Services. [Online] 16th December Available: https://www.fas.org/sgp/crs/natsec/R41347.pdf [Accessed:14.04.2015]

IMDS (2015). *International Material Data System*. Available: http://www.mdsystem.com/imdsnt/startpage/index.jsp [Accessed 2015-02-24].

Joce, C. (2013). In critical supply. *Chemistry & Industry*. 77(10): 30.

Jusko, J. (2006). *Rethink raw materials*, [Online] 13th July. Available: .http://www.industryweek.com/environment/rethinking-raw-materials [Accessed:03.03.2015]

Kingsman, B. G. (1986). Purchasing raw materials with uncertain fluctuating price. *European Journal of Operational Research*, 25 (3): 358-372.

Kraljic, P. (1983). Purchasing must become supply management', *Harvard Business Review*. 61(5): 109-117.

Lee, L. H. (2002). Aligning Supply Chain Strategies with Product Uncertainties. *California Management Reveiew*. 44(3): 105-119.

Lilliecreutz, J. (1998). Orchestrating resource base, role, and position: a supplier’s strategy in buyer-dominated relationships. *European Journal of Purchasing & Supply Management*. 4(2-3): 73-85.

Lin, Y. & Zhou, L. (2011). The impacts of product design changes on supply chain risk: a case study. *International Journal of Physical Distribution & Logistics Management*, 41(2), pp.162-186.

Lincoln, Y.S & Guba, E. G. (1985) *Naturalistic inquiry*, Beverly Hills: Sage.

Manikas, A., Chang, Y. & Ferguson, M. (2009). BlueLinx can benefit from innovative inventory management methods for commodity forward buys. *Omega*. 37(3): 545-554.

Manuj, I. & Mentzer, J.T. (2008). Global supply chain risk management. *Journal of Business Logistics*. 29(1): 133-155.

Maull. H.W. (1984) *Energy, minerals & Western security*. The John Hopkins University Press: Baltimore

Massari, S. & Ruberti, M. (2013). Rare earth elements as critical raw materials: Focus on international markets and future strategies. *Resources Policy*. 38(1): 38-43.

Moss, R.L., Tzimas, E., Kara, H., Willis, P. & Kooroshy, J. (2011). Critical Metals in Strategic Energy Technologies- assessing rare metals as supply-chain bottlenecks in low-carbon energy technologies. JRC-scientific and Technical Reports. European Commission. Institute for energy and transport.

Moss, R.L., Tzimas, E., Kara, H., Willis, P. & Kooroshy, J. (2013). The potential risks from metal bottlenecks to the deployment of strategic energy technologies. *Energy Policy*. 55 (4): 556-564.

Nagali, V., Hwang, J., Sanghera, D., Gaskins, M., Pridgen, M., Thurston, T., Mackenroth, P., Branvold, D., Scholler, P. & Shoemaker, G. (2008). Procurement Risk Management (PRM) at Hewlett-Packard Company. *Interfaces*. 38(1):51-60.

NASA. (2015). *Earth Observations - Where every day is Earth day*. [Online] Available: http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php [Accessed: 25.02.2015]

Ni, J., Chu, L.K., Wu, F., Sculli, D. & Shi, D.S. (2012). A multi-stage financial hedging approach for the procurement of manufacturing materials. *European Journal of Operational Research*. 221(2): 424-431.

Nieto, A., Guelly, K. & Kleit, A. (2013). Addressing criticality for rare earth elements in petroleum refining: The key supply factors approach. *Resources Policy*. 38(4): 496-503.

NRDC. (2015a). *An introduction to climate change,* [Online] Available: http://www.nrdc.org/globalwarming/climatebasics.asp [Accessed:17.04.2015]

NRDC. (2015b). *Global warming solutions,* [Online] Available: http://www.nrdc.org/globalwarming/solutions/ [Accessed: 17.04.2015]

Odekerken- Schröder, G., Ouwersloot, H., Lemmink, J. & Semeijn, J. (2003). Consumers' trade- off between relationship, service package and price. *European Journal of Marketing*. 37(1/2): 219-242.

O'Donnel, B. (2015). *The recycling conundrum at the heart of tech*, [Online] Available: http://horizon-magazine.eu/article/recycling-conundrum-heart-tech_en.html?utm_campaign=March%202015_1_2A&utm_medium=email&utm_source=newsletter&utm_content=36883&utm_term=March%202015_1_2A [Accessed: 13.03.2015]

Peleg, B., Lee, H. & Hausman, W. (2002). Short-term e-procurement strategies versus long-term contracts. *Production and operations management*. 11(4): 458-479.

Perrow, C. (1984). *Normal accidents*. New York: Basic Books.

Pfeffer, J. & Salancik, G. (2003). *The external control of organizations*. California: Stanford Business Books.

Porter, M. E. (1979). How competitive forces shape strategy. *Harvard Business Review*. 57 (2): 137-145.

Prahalad, C. K. & Hamel, G. (1990). The Core Competence of the Corporation. *Harvard Business Review*, 5-6: 79-91.

Purdy, G. 2010. ISO 31000:2009 – Setting a New Standard for Risk Management. *Risk Analysis.* 30 (6): 881 – 886.

Reid, A., Petocz, P. & Gordon, S. (2008) Research interviews in cyberspace. *Qualitative Research Journal*, 8 (1): 47 - 62.

Rosenau-Tornow, D., Buchholz, P., Riemann, A. & Wagner, M. (2009). Assessing the long-term supply risks for mineral raw materials—a combined evaluation of past and future trends. *Resources Policy*. 34(4):161-175.

Scapens, R. W. (1990). Researching management accounting practice: The role of case study methods. *Business Accounting Review*. 22, 259-281.

Shahan, Z. (2014). *EV Sales up 228,88% in 2013 in US (2013 Electric & Hybrid Vehicle Sales Report)*, [Online] 7th January. Available: http://cleantechnica.com/2014/01/07/ev-sales-228-88-2013-2013-electric-hybrid-vehicle-sales-report/ [Accessed: 12.03.2015]

Shenton, A. K. (2004) Strategies for ensuring trustworthiness in qualitative research projects. *Education for information.* 22(2):63-75

Slowinski, G., Latimer, D. & Mehlman, S. (2013). Dealing with Shortages of Critical Materials. *Research Technology Management*. 56 (5): 18-24.

Spekman, R. & Davis, E. (2004). Risky business: expanding the discussion on risk and the extended enterprise. *International Journal of Physical Distribution & Logistics Management*. 34(5): 414-433.

Stanford Magnets. (2015). *Developments of Electric Vehicle will Stimulate for Neodymium Magnets*, [Online] Available: http://www.usneodymiummagnets.com/about.html [Accessed: 27.03.2015]

Talay, M., Calantone, R. & Voorhees, C. (2014). Coevolutionary Dynamics of Automotive Competition: Product Innovation, Change, and Marketplace Survival. *Journal of Product Innovation Management*. 31(1): 61-78.

Tilton, J. E. (2003). On borrowed time?: Assessing the threat of mineral depletion; Resources for the Future. Published by Mines faculty senate: Golden.

TRW Automotive Holdings Corp. (2013) *2013 Annual report, Cognitive safety systems*. Michigan.

U.S. Department of Energy. (2010). *Critical Materials Strategy*, [Online] Published by U.S. Department of Energy. Available: http://www.energy.gov/sites/prod/files/piprod/documents/cms_dec_17_full_web.pdf [Accessed: 17.04.2015]

Volvo Cars. (2014). *Volvo Cars in brief*, [Online] Available: http://www.volvocars.com/se/om-volvo/foretaget/om-volvo-cars [Accessed: 11.03.2015]

Volvo Cars. (2015). *Sustainability overview*, [Online] Available: http://www.volvocars.com/intl/about/our-company/sustainability [Accessed: 17.04.2015]

Volvo Car Group. (2015). *This is Volvo*, [Online] Available: https://www.media.volvocars.com/global/en-gb/corporate/this-is-volvo [Accessed: 27.03.2015]

Wagner, S. & Bode, C. (2008). An empirical examination of supply chain performance along several dimensions of risk. *Journal Of Business Logistics*. 29 (1): 307-325.

Wagner, S. and Boutellier, R. (2002). Capabilities for managing a portfolio of supplier relationships. *Business Horizons*, 45(6), pp.79-88.

Wübbeke, J. (2013). Rare earth elements in China: Policies and narratives of reinventing an industry. *Resources Policy*. 38 (3): 384–394.

Zsidisin, G.A. & Hartley, J.L. (2012a), A strategy for managing commodity price risk. *Supply Chain Management Review*. 16 (2): 46-53.

Zsidisin, G. & Hartley, J. (2012b). *Managing commodity price risk*. New York: Business Expert Press.

Appendix

APPENDIX A - Overview of Rare Earth Elements

2010 Report	2013 Report	Rare Earth Elements
Rare Earth Elements	Scandium	Scandium
	Rare Earth Elements – Light (LREE)	Lanthanum Cerium Praseodymium Neodymium Samarium
	Rare Earth Elements – Heavy (HREE)	Europium Gadolinium Terbium Dysprosium Erbium Yttrium Holmium Erbium Thulium Ytterbium Lutetium

Modification of European Commission (2014b) table of "Classification of rare earth elements in EU Critical Raw Materials studies"

APPENDIX B - Introduction Letter

Request for questionnaire participation regarding rare earth elements

Dear Sir/Madam,

Volvo Cars is currently investigating and mapping the use of the rare earth elements, neodymium and dysprosium in products. Doing so, we have engaged two students from the School of Business, Economics and Law at the University of Gothenburg, to conduct a master thesis about the supply, demand and potential commodity price risks of the elements dysprosium and neodymium.

The purpose of the study is to investigate how automotive manufacturers are impacted by supply, demand and potential commodity price risk and how potential risks can be managed. We are interested in your organization's view and knowledge regarding this topic. Furthermore, this is an opportunity for your organization to increase your awareness and to share your viewpoints regarding the supply risks of dysprosium and neodymium.

We highly appreciate your participation and would like to get in contact with a person within your organization who could answer the questions attached to this e-mail, as soon as possible but no later than April 24, 2015. It would be a great advantage if the interviewee has knowledge of your organization’s sourcing process and supply chain of dysprosium and neodymium. No information about the interviewee or the organizational identity will be disclosed without your consent.

Please return the completed questionnaire to Charlotte Kjellberg or Fredrik Fejne (contact information below), or if there are any questions, feel free to contact us for further information.

Contact information:
Charlotte Kjellberg, MSc Student, University of Gothenburg
charlottekjellberg@hotmail.com

Fredrik Fejne, MSc Student, University of Gothenburg
fredrik.fejne@outlook.com

Thank you for your cooperation.

Yours sincerely,

APPENDIX C - Interview guide External

1. Supply and demand

How are the quantities of neodymium and dysprosium projected to develop in the future?

What insecurities can you identify for the future supply of the concerned materials?

2. Dependency

How critical is neodymium to the end product?

How critical is dysprosium to the end product?

How do you view the supply chain traceability when it comes to the supply of dysprosium and neodymium?

Does your company have any access to a forum of other companies where matters regarding dysprosium and neodymium supply shortages can be discussed?

3. Mitigation strategies

Do you have any mitigation strategies of how to handle insecurities of supply of neodymium and dysprosium?

To what degree is there a potential substitute for neodymium and dysprosium?

What is your view on sharing the risk of price increases with suppliers?

What is your view on sharing the risk of price increases with customers?

Do you see any opportunities in hedging to mitigate the risks associated with dysprosium and neodymium?

Could Volvos footprint in China mitigate the risk of rising prices of dysprosium and neodymium?

Do you see any potential in component redesign to reduce the dependence on dysprosium and neodymium?

Please describe any other actions you have taken to mitigate the impact of supply risks related to neodymium and dysprosium

Besides the strategies mentioned above, do you have any other suggestions? (Both long- and short-term)

APPENDIX D - Interview guide Internal

Briefing

- Introduce ourselves
- Explain the purpose of the study
- Let them present themselves, e.g. roles etc.
- Interview will be recorded unless objected to
- Does anyone have any questions before we begin?

1. Volatility

How are the quantities of neodymium and dysprosium projected to develop in the future?

What insecurities can you identify for the future supply of the concerned materials?

2. Dependency

How critical is neodymium to the end product?

How critical is dysprosium to the end product?

How do you view the supply chain traceability when it comes to the supply of dysprosium and neodymium?

3. Mitigation strategies

To what degree is there a potential substitute for neodymium and dysprosium?

If so, how much would the current material prices have to rise to make it economically viable?

Do you see any opportunity in passing on price increases to your customers?

Do you see any opportunity in sharing the risk of price increases with suppliers?

Do you see any opportunity in Volvo purchasing large quantities in order to mitigate the risk?

Would this action be operationally feasible? What implications would it cause?

Do you see any opportunities to hedge against the risks associated with dysprosium and neodymium?

Do you see any opportunity in Volvo, alone or in a consortium, securing the supply of neodymium and dysprosium by investing in mines?

Do you see any potential in component redesign to reduce the dependence on dysprosium and neodymium?

Do you see any potential in material recycling schemes to reduce the dependence on dysprosium and neodymium?

Please describe any other actions you have taken to mitigate the impact of supply risks related to neodymium and dysprosium.

Besides the strategies mentioned above, do you have any other suggestions? (Both in the long- and short-term)

Debriefing

- Explain that we are starting to finish, what we have learned during the interview.
- We have no further questions. Is there anything else you would like to bring up, or ask about, before we finish the interview?

APPENDIX E - Full description of results from Internal interviews (Volvo)

Purchasing department
Purchaser A - Rear axle
Date: 31.03.2015, 13.00 - 13.31 (duration 31 min)

Volatility

The purchasing department experience increased demand of both dysprosium and neodymium due to the hybrid development of cars. The problem of these materials is not that the supply will run out but that the mining of these materials is very dirty and environmental damaging. Another problem of the supply is the dependency of China, but one of the biggest threats regarding the supply of dysprosium and neodymium is the environmental aspects. The damaging impact the production has on the environment increases the risks of environmental restrictions, which could reduce supply and increase the prices. Furthermore, there is a communication risk towards customers, where Volvo might be associated with a very dirty business, which could be damaging for the brand.

The production of electrical engines was heavily affected when the prices went up after China's implementation of the export quotas. When the prices were at its peak, the metals in focus were 1/3 of the total cost of the electrical engine and Volvo had to pay compensation to the suppliers. Compensations to suppliers for price increases affect Volvo considerably.
Volvo has no traceability of dysprosium and neodymium, since the only contact Volvo has is with the tier one supplier, which they are negotiating these elements with.

Dependency

Volvo has investigated possible substitute but they turned out to be a dead end. Dysprosium and neodymium are critical for the end product since there are no effective substitutes. If Volvo should use something else, this would be a constructing issue, which would take a long time to change.

Mitigation strategies

Substitute

As mentioned above there are no effective substitute that could replace dysprosium and neodymium, without reducing the performance or increasing the size of the electrical engines.

Forward buy

Forward buying could be possible but it is not a good option due to the high costs of tied up capital. Furthermore, if Volvo engages in forward buy, they are then limited to use these materials. To buy the material on other markets together with the suppliers is also not a possibility since Volvo does not intervene in controlling what the suppliers do and is not involved with tier 2 and 3.

Hedge/Cross-hedge

The respondent cannot see any possibility to hedge towards the price risks of dysprosium and neodymium.

Absorb risk/reduce demand
Recycling is definitely a possibility. Volvo could then collaborate with suppliers to change the design of the product to make recycling easier and reuse dysprosium and neodymium in the components.

Purchasing department
Purchaser B - Loudspeaker
Date: 20.04.2015. 10.35 - 11.07 (duration 32 min)
Volatility
Volvo uses two types of magnets in their loudspeaker: ferrite magnets and neodymium magnets. The trend is, according to the respondent, going towards increased usage of rare earth elements due to the setup Volvo uses. The respondent clarifies that this is a guess and that the question is more suited for the R&D department to answer. However, when the performance requirements increase, the demand for rare earth elements, like dysprosium and neodymium, increase. Infotainment is where high quality products should be used and an area of strategic focus for Volvo. The respondent believes the premium segment will drive the growth in demand for the rare earth elements in focus. This is, however, more a question for those responsible for infotainment strategy. The main difficulty from a commercial perspective is to handle the price fluctuations.

Volvo does not monitor the traceability or origin of rare earth elements. The only point of contact is when Volvo´s SQM (supply quality management) organization, ensures that the purchasing department chooses a supplier with the capacity to deliver and to work with quality issues. The SQM organization requires the suppliers to have a SQM organization of their own, so that the quality of their purchasing process can be ensured. The respondent guesses that the SQM also considers sustainability issues but he is far from sure of this information.

Dependence
The concerned materials are critical due to limited space in the car. Smaller space demands stronger magnets, which leads to a higher usage of dysprosium and neodymium instead of ferrite magnets. In this regard it could be deemed as critical. For premium loudspeakers, it could be considered as standard to use the rare earth elements in focus. It is not an area to which the purchasing department handling since, Volvo does not care from where these rare earth elements are sourced.

Mitigation strategies
Substitute
There are no substitutes other than ferrite metals that are discussed at the moment. This is, however, a question for the R&D department. Ferrite magnets could not replace rare earth

magnets for the top of the line cars, because Volvo brands their speakers with Bauers and Wilkins who have specific demands regarding performance. It is not likely that Bauers and Wilkins would agree to use its brand in a system with inferior products, which might lower the performance. It might, however, as mentioned, be possible for the basic speakers. Neodymium and dysprosium magnets will be chosen over ferrite magnets for the components to keep a high performance but for the basic speakers, ferrite magnets could still be used to keep the costs down.

Pass/share risk
It is probably not possible to pass on price increases to customers. The marketing department set the prices and the branded systems are sold based on the value that it brings to the customer not based on the costs of producing the car. To pass price increases to suppliers could be done in commercial negotiations by demanding a lower price. That is a possibility and it is always a matter of negotiation. However, when the price decreases Volvo wants a share of the profits. Today Volvo has no system for this but they focus is on protecting Volvo from price increases.

Hegde/Cross-hedge and Forward buy
The respondent is uncertain whether the financial department engage in hedging and forward buy but believes they are not. He further thinks that there is no system in place in order to work with these activities. It would demand a team, who would work cross functionally with suppliers. Additionally the communication required to engage in forward buy and hedging is not currently available.

When buying components, Volvo tends to base its analysis on ex-works China prices. The current suppliers are from China, Vietnam and Hungary and all rare earth elements are procured from China.

Absorb risk/reduce demand
Price fluctuations tend to become a commercial discussion when striking new deals with suppliers and compensation discussions needs to be handled regarding this. The main issue is that handling of the matter tends to fall between chairs. When the prices are up, the suppliers tend to be quick in claiming compensation from Volvo, but Volvo is not as active on the matter when prices decreases. Typically, the compensation adjustments are made every 6 months. The price adjustments tend to be explicitly written in the contracts, for example price changes are compared to the price level of 2012.

Volvo has no active recycling activities at the moment, but during car service, speakers are changed and renovated. Renovation is done on the components of high value and where it is possible. The suppliers of the components are committed to deliver parts for 15-20 years after the component is out of the supplier’s production. Even if the products are not produced in the production line anymore the parts could be assembled by hand even if it is expensive. An example of what could be done in a renovation is to change a cord that is dysfunctional.

The R&D department is working with identification of the amounts of dysprosium and neodymium in the components in order create better solutions together with suppliers, with lower amounts of the metals in focus.

Purchasing department
Purchaser C - Servo pump
Date: 15.04.2015, 11.04 - 11.38 (duration 34 min)
Volatility
The performance levels of the components determine the amount of dysprosium and neodymium used in the components. For example to produce compact electrical engines, permanent magnets are needed. The development of future demand of these materials dysprosium and neodymium will depend on what products Volvo demands. The specification of performance levels that are set by the research and development department is therefore determining the demand. Even if the purchasing department can present possible solutions suggested from suppliers, that contain less or nothing of the rare earth elements in focus, they do not have control over the specifications of the components.

The future demands also depend on how the prices develop. If the prices stay stable Volvo might continue to use of dysprosium and neodymium in their cars. The prices are the driving factor in this according to the respondent. Then if there are any ethical aspects, such as environment and child labour in the production of the materials, that could affect the demand and be an issue. The respondent does not consider this to be something relevant right now.

When the price crises of dysprosium and neodymium occurred 2011, Volvo had to pay very big amounts of compensation to the suppliers because of the sudden price increase of the materials. After this the suppliers realized that they had to do something about the products containing these materials, since they realized their customers would not like to pay those kind of money if prices increased again. The suppliers created therefore solutions with less dysprosium and neodymium, in for example the electrified components in the steering components. They reduced the amount of dysprosium and neodymium both in the current product and new magnets. For the products that were only in the beginning of the product development the suppliers presented solutions where they had eliminated dysprosium and neodymium. This was done from initiatives from the suppliers but also due to pressure from Volvo. The entire industry realized that something needed to be done about the situation. Volvo does not specify, to the suppliers, how much dysprosium and neodymium the magnets should contain. They do, however, set specifications of the performance levels the products, containing these elements, needs to have. Therefore as long the suppliers can fulfil the specification of performance levels, for example high temperature resistance, the suppliers can decide the amounts of dysprosium and neodymium themselves. However, they need to specify the amounts used in Volvo's material system. When the price increased 2011, the suppliers investigated the content in their products to evaluate if they needed those amounts to achieve the performance level or if they could reduce the use of dysprosium and neodymium.

They tested if the products could contain the quality and customer specifications, which they could even with lower amounts.

If there would be a media discovery of the environment damaging impact from the production of dysprosium and neodymium, possible to trace back to Volvo, there would probably be a similar reaction as for the scandal with child labour of Nike shoes. This could be an argument for Volvo to exclude usage of dysprosium and neodymium in the cars. However, Volvo is a very small actor, from a global perspective, in the industry and therefore other bigger company, such as Toyota and General Motors, would probably be more affected. Since Volvo has the values of sustainability and environment, the company should maybe work more proactive or at least open up the supply chain and create some kind of certificate in the production, to ensure responsible behaviour. According to the respondent, Volvo uses small amounts of dysprosium and neodymium compared to other actors in the car industry, which could create a better flexibility in being proactive in the matter and thereby make it easier to handle.

Today Volvo knows all dysprosium and neodymium used in their products comes from China. It is very hard for Volvo to trace the origin of the materials and Volvo has more or less only transparency to their first tier supplier. There are many levels and actors in these supply chains and therefore it is hard to capture the origin of dysprosium and neodymium. The first tier supplier is buying an engine from tier two supplier, who buy the permanent magnets from a tier three supplier and so on. Volvo knows then the name of the company that are producing the engine and that dysprosium and neodymium are bought from China. The biggest focus for the purchasers in this is the prices and this will continue until we have a reason not to buy these elements anymore.

Dysprosium and neodymium have never been replaced with other materials that Volvo knows of. Volvo has low insight if the producers of the magnets use other materials but according to law the suppliers are responsible to report the content of the components, but there might be some loopholes. The information content of the products is reported into the material check Volvo has, called IMDS. This information is very sensitive and is not suppose to be used in commercial purpose.

Dependency

Dysprosium and neodymium are critical for the products but this is not an area the purchasing department is well informed within and therefore the research and development department can answer the question of dependency better. China does not have the biggest reserves but the possess the biggest production capabilities which they have built up during the years.

Mitigation strategies

Substitute

Substitute for dysprosium and neodymium are, as far as the respondent knows, other types of constructions that results in bigger and possible heavier parts in order to keep the same level of performance. Bigger and heavier constructions are hard to implement since the amount of space is very limited. If constructing the cars from the circumstances that more space is needed, it should be possible to reduce the amounts of dysprosium and neodymium but this will probably be very expensive.

Pass/share risk
There are no possibilities in transferring the price increases to the customer since they are too price-sensitive. Increased prices would result in fewer sold cars since the competition is too strong on the market. Transferring prices to the customers could be possible if all actors in the industry should be forced to do it by law or something similar. An official commercial debate of the metals used in the cars, could direct the entire industry to change because customers becomes aware of the problem. Furthermore, transferring price risks to the suppliers is not an option since they are not willing to reduce their margins. Transferring price risks on the suppliers is possible in the short run but it is not sustainable in long relationship collaboration.

Forward buy
Forward buying is something that could work theoretically. Today Volvo is probably too small, from a global perspective; to do something like this, but when Volvo was owned by Ford, these kinds of solutions was done with some raw materials to secure prices and supply. The industry of raw material is too complex for Volvo to engage in for the case of dysprosium and neodymium, but if there is a business model profitable for the company it might be possible. The respondent argues that you need to know the industry to create the best condition.

Hedge/Cross-hedge
Hedging is not used for dysprosium and neodymium today. If the prices of these elements are much cheaper to buy from Chinese producers it might be worth to buy the products locally, if in total it is a better deal. If the engines are produced in China, Volvo is following other prices than if the engine is produced in Europe for example. Volvo has not noticed that they are using more suppliers in China after the price increase 2011, to capture the lower local prices of dysprosium and neodymium.

Absorb risks/reduce demand
In the contract with the suppliers there are different clauses, which are used if the prices increase. Volvo needs to compensate the supplier if prices increase and if the prices decrease Volvo gets a lower price from the supplier on the component. The settle of compensations are decided in discussions and negotiations with the suppliers, in order for Volvo to create a good deal. Volvo keeps track of the prices and if they decrease to be able to demand compensation from the supplier.

Recycling is not used today but Volvo is renovating components containing higher value. Steering components for example are renovated, which means that Volvo has a change program where these products are replaced and the old products are send back to a warehouse to be stored until Volvo decides to use the components. A supplier is renovating the components based on instructions and specifications given from Volvo. Volvo also decides which component included in the renovating program. It might be possible to perform similar activities to recycle dysprosium and neodymium from replaced components.

Research and development department
Research and development A - Rear axle
Date: 08.04.2015, 11.04 - 11.35 (duration 31 min)
Volatility
From Volvo perspective the demand of dysprosium and neodymium will decrease since the supply in the future of these elements might be scarce and expensive due to environmental regulations among other things.

Volvo thinks that the components including dysprosium and neodymium will probably be cheaper in the short run. These materials are rather expensive and the market prices have fluctuated enormously the last couple of years, where the top prices was in October 2011, when the price of dysprosium was around 4 000 dollars/kg. Then all of a sudden the magnets including these elements represented a significant bigger part of the total cost of the component and this became a factor in purchasing actions. But today the prices have stabilized and dysprosium and neodymium are not representing a big part of the total cost anymore. Of course this depends machinery application but it is not more than 5% of the total cost of the machinery. Of course money is saved when reducing the use of dysprosium and neodymium in the components but this is not the driving factor of the strategy to reduce the use of these elements. The driving factor to eliminate the usage of these elements is rather to be insensitive to future fluctuations, since future political decisions could create new sudden price increases that Volvo wants to be independent from.

Dependency
The suppliers of Volvo, as well as tier 2 and tier 3 are together investigating different possible types of mixtures of metals. There are a lot of actors on the market in this field and new mixtures are created and the old rules are not applicable anymore. They had mixtures before that contained a lot of rare earth elements and because of this was very expensive. But this is not the reality today, but this depends on which mixtures that is used the most, in which quantities and in which volumes it is produced that is deciding the prices. Even if there is alloys containing these elements that are not expensive Volvo wants to reduce the dependence of these elements due to risks of future price fluctuations. Additionally there is the environment aspect of the problem.

Mitigation strategies
Substitute
The most commonly used materials are neodymium, dysprosium, terbium and praseodymium, which are all rare earth elements but there is no substitute with the same characteristics. Instead of dysprosium and neodymium Volvo is using terbium but there are no other substitutes that are not rare earth elements. What dysprosium is doing is that it is protecting

the magnets from being demagnetized at high temperatures and is as far as Volvo knows only terbium that have the same characteristics.

There are although other alternative construction solutions that make it possible to avoid using dysprosium and neodymium. The high temperatures in the engines are a fact that is probably something that can't be changed. So far the suppliers have chosen to be on the safe side by having margins regarding which alloys they are choosing and the amount dysprosium they are using in the magnets based on the use area for the engine. And of course the electrical engine construction, size, thermic mass also affect how warm the magnets becomes and how much dysprosium that is needed. Everything is connected and an advantage is to have a bigger thermic mass since you then warm up the engine slower or if you have a dedicated rotor cooling which also have been studied in different situations. Another solution is to reduce the margin that the suppliers have. If you have a good overview have the car is used, so called duty cycle, on the electrical engine and which temperatures cycles it is exposed to the safety margin could be reduced and use cheaper materials, which Volvo is actively working with.

Pass/Share risk

The respondent present that hedging could be seen as an opportunity as part of the negotiation process with tier 1 suppliers. An example is letting the supplier cover any market price fluctuations without affecting the part price that Volvo pays.

Forward buy

Volvo does not purchase the metals directly, they are part of larger and more complex components such as Electric Machines that are purchased from tier one supplier. Not feasible, would require complete different logistical/commercial relationship to tier one suppliers. Not feasible, would require complete different logistical/commercial relationship to tier one suppliers.

Hedging

The respondent present that hedging could be seen as an opportunity as part of the negotiation process with tier 1 suppliers. An example is letting the supplier cover any market price fluctuations without affecting the part price that Volvo pays.

Secure supply

Secure supply is not really a possibility for Volvo since it is not Volvo’s core business. Volvo should focus on producing cars and not engage in the metal industry. There is probably no financial margin to cover such a large investment.

Absorb risk/Reduce demand

The strategy, the department have regarding dysprosium and neodymium is to reduce demand by reduce the use of these elements in the components in the electrical machinery. In the long run the objective is to eliminate the use of these elements completely, which is one of the biggest parts of the long run strategy for the electrical product program. This is done with a multiple step program of how to reduce the level of dysprosium in the magnets in the rotor. Right now Volvo is doing a pre study of a technique or construction, which might reduce the use of dysprosium in the permanent magnets with 15-20% and hopefully is implemented within 3-4 years. To achieve their elimination of dysprosium and neodymium used in the components Volvo investigates alternative mixtures that are used in the machinery today. Further they are investigating if dysprosium is possible to be replaced with other material such as Terbium. Terbium has the same protection against demagnetisation but is needed in smaller quantities. For the long run dysprosium aims to be eliminated within 6-8 years.

The goal of eliminating neodymium might not be possible even if Volvo will try. To succeed with eliminating neodymium Volvo needs to use ferrite magnets or totally eliminate magnets and use other tropology. So far, however, there is no knowledge that this is possible to achieve and implement, due to the size restrictions of the cars and the demands of characteristics that are set up. Volvo might therefore, not be able to eliminate neodymium completely but they will be reduced.

To be able to achieve the goal of no dysprosium and neodymium in the components there needs to be some adjustments outside the department capability area. Therefore on the long run the department are collaborating together with the strategic department of Volvo regarding other parts of the car. This is because the sizes of their components probably need to increase, which affects other parts of the cars. This is not possible for Volvo to specify how much the component needs to increase but this is technically possible to achieve. To give an example; imagine a startor diameter of 200 mm in an electric machine and this contain a certain amount of dysprosium and neodymium. If the size increases with 20% in diameter there is a bigger air gap area and this contribution to moment effect. One can reduce the rement effect rather much. This demands changes in construction and how much the sizes needs to be increased, we have to wait and see. Before doing these calculations Volvo needs to figure out what possibilities they have in increasing the sizes of the car. In the existing platform there are very limited possibilities to make changes since there are strict regulations one have to align with regarding construction. The next generation of the big cars, the car architecture spar, the next generation of this is in the 2020th where Volvo is trying to match up to. And here there will be a possibility of having better volumes to include the volumes in compared to what Volvo had so far. Further the demands on the characteristics on the electrical driveline increases and especially within energy regarding the battery but also within efficiency and the effect have increased in importance and focus. Also there are higher requirements on operation. And this of course works against reduction of dysprosium and neodymium. This is a big challenge since these elements are helping to achieve the requirements on the electrical field, which makes it contradictory to remove them. When Volvo is implementing change and increasing the performance of the machinery they are not increasing the use of rare earth elements. They might not reduce the used amounts of dysprosium and neodymium but they are not increasing it. Instead they are having an increased performance with the same amounts of dysprosium and neodymium. As mentioned Volvo has discussion about the future strategy depending on what is possible to achieve technically and the strategy so far have been to be as independent of these materials as possible but there are other opinion in the company that wants to have another strategy.

The strategy for Volvo is very specific in the matter since they have been focusing on small combustion engines instead of big ones and the high efficiency version is possible to produce due to electrification. Therefore Volvo has an "accentuated effect requirements". Connected to the product strategy compared to the competitors of Volvo that "peaks" with bigger combustion engines for their high performance cars. Volvo is very dependent on the electrical drive line department that they are creating high level of performance in the cars otherwise Volvo cannot perform the top of the line segment. This has also been proved in journalist testing of the new XC90 for example. Many managers are arguing that the electrical performance is today not yet where they want it to be. To be able to do this the electrical driveline department had to fight to get more space in the new platform but got it in the end, which created possibilities to achieve high performance in the engine, but even this is not space enough.

Recycling might be hard since it is difficult to separate the mixtures with a high level of purity needed for the application they were originally used in. Recycling is not something the electrical driveline department are working with. If there is a technical possibility to recycle the material to the same purity this might be a possibility. Even if getting less purity it might be possible to use for other usage in the cars that does not require high level of purity. If recycling is possible to perform cost effectively it might be a solution. It's a matter of costs. This is also a matter of how the market turns out. If the production gets regulated, it might be a solution if it's effective enough.

Research and development department
Research and development B - Loudspeaker
Date: 23.04.2015, 14.03 - 14.35 (duration 32 min)
Volatility
The respondent explains that he is not an expert of the supply of dysprosium and neodymium, but when talking to suppliers he got the impression that there is a stabilization of the prices of dysprosium and neodymium in the future. The usage of these elements in the loudspeaker will probably be the same and relative constant in t in the future.

Dependency
Dysprosium and neodymium is critical for the end products, especially for the more advanced loudspeaker systems. In these systems neodymium magnets are the only appropriate solution in order to achieve the performance levels that are required by Volvo. For the advanced loudspeaker systems the space is very limited and the required performance standards are high to ensure high quality, therefore the neodymium magnets become very critical for these products. The amounts of space available for the loudspeakers are decided during the process of design and construction. In this process there is a balance between inputs from the research

and development department about optimal positions in the car for the sound affect and which spot is possible depending on the size of the loudspeaker.

Regarding dysprosium, this metal is used, so far as the respondent knows, in both traditional ferrite magnets and neodymium magnets but the respondent is not completely sure of this information.

The department is not actively working on reducing the usage of dysprosium and neodymium to reduce the dependence of these elements. Before the price increase of neodymium and dysprosium, Volvo increased the use of neodymium magnets due to weight savings. The usage of ferrite magnets increases and the use of neodymium magnets decrease when the price for neodymium increases. Today Volvo does not want to have neodymium and dysprosium if not necessary to achieve the required quality or due to size restriction. When constructing the different components the objective for the research and development department is to optimize the performance and the costs of the components.

The respondent explains there are three different loudspeaker levels in the car. The different levels are standard performance, medium performance and high performance. In the standard performance level, ferrite magnets are used and in the medium performance level ferrite magnets are used in the big loudspeakers and neodymium in the small ones. In the high performance level the loudspeaker system is branded by for example Bauers and Wilkins, and here only neodymium magnets are used in the loudspeakers. The respondent describes that there is an increased demand for the high performance level equipment.

The respondent shows two different kinds of loudspeaker. And explains that the bigger version, called a medium priced woofer, is placed in the car doors and includes a ferrite magnet. On the backside of the loudspeaker there is a part in the size and shape as a smaller ice hockey puck. Inside of this there is a hole where the ferrite magnet is located. The part containing the magnet and the magnet is pretty heavy. It includes more or less only iron but it might also contain dysprosium. The respondent explains that loudspeakers will always need some kind of magnetized material but that there are different levels of quality of the magnet materials.

The respondent shows the smaller loudspeaker and explains that this is included in Volvo's new high performance Bauers and Wilkins system. Inside this loudspeaker there is a small button. This button has the size of a Swedish one-coin and made of a neodymium mixture. The small magnet has the same magnetic power as the ferrite magnet in the bigger loudspeaker. There is a big size difference between the ferrite magnet and the neodymium magnet and also a weight differ. However, it is not the weight difference that is the important reason for using the neodymium magnet, but the size due to the limited amount of space in the cars.

The respondent has no information and knowledge of characteristics and differences of dysprosium and neodymium. The only thing he knows regarding this, is that neodymium is used to reduce the sizes of the magnets in the components. How dysprosium is used in mixtures he cannot give further details about.

The usage of the rare earth elements in focus and different possible choices of magnets are often discussed with the suppliers. The most common question from the supplier is if Volvo wants to have neodymium or ferrite magnets in the component. However, Volvo does not decide if the suppliers should use neodymium or ferrite magnets in the components. The suppliers can choose which material to use, as long as the required loud quality performance and the size requirements are achieved. The suppliers, if possible, choose to use ferrite magnets in the components. The usage of dysprosium and neodymium is driven by the requirements set by Volvo. The only consequence of using ferrite magnets is that the components become heavier, which could affect the fuel consumption.

Mitigation strategies

Substitute

On research level there is magnetic polymer but these are not available now but might be a possible substitute for the future. If the prices of dysprosium and neodymium would be too high for Volvo to include in their products it would be possible use for example Ferrite magnets in the bigger loudspeakers, which are in placed in the doors of the cars. The smaller loudspeakers, which are placed at places with very limited space available, would be harder to replace with bigger size loudspeakers. Bigger loudspeakers could probably fit in the same platform that is used today. Therefore, in the short run a change to bigger loudspeakers would be possible even if it would be hard to do with the small loudspeakers.

A Ferrite magnet could achieve the same level of performance of loud quality as a neodymium magnet, even if there are specific exceptions. High performance loud quality could be achieved, independent of magnet, but this would generate different sizes of the components.

Pass/share risk

If the price of dysprosium and neodymium increases, the cost will be divided between Volvo and the supplier, this is handled as a shared risk. Details about this could the purchasing department maybe provide more information about. The respondent explains although that when the price increase uncured 2011, the cost of price increases was shard. The prices of the components is set to a fixed price, and based on this it is the suppliers that takes on the biggest part of the risk since they are selling the product to lower margins when the prices increases. Furthermore, the respondent does not think that the price risks could be transferred to the customers.

Absorb risk/reduce demand

The respondent does not know if recycling is a possible mitigation strategy to reduce demand. This depends on how the process looks like when recycling the entire car because these materials does not have to be changed during the cars life cycle. When the car is dilapidated the materials could be taken cared of. The respondent thinks it is relatively easy to separate the material mixture from the component in order to remanufacture. The neodymium magnet is a mixture and not pure neodymium but this magnet does not get worn out and could be used in another loudspeaker and work as good as a new magnet. The only problem is that it is harder to handle magnets when they have become magnetized. Therefore the magnets are magnetized after they have been put the component in the loudspeaker. There is no technical restriction in reusing the magnets again.

Research and development department
Research and development C - Servo pump
Date: 8.04.2015, 15.30 - 16.00 (duration 30 min)
Volatility
A country in the east had a dominant market position a couple of years ago and then it was a large hype regarding the forecasted price increases. But that was never realized and the prices have retreated since then. The price is not that bad at the moment.

Dependency
The respondent's work with EPAS hardware but has unfortunately no access to the IMDS material register. They do not know what it states regarding the content of their components. It would be highly interesting to get access to that. From a technical standpoint, use dysprosium is to prefer. It offer a much better product since it increases the temperature resistance. To reduce dependence, the temperature resistance is reduced, which leads to a need to be more careful not to get too high temperatures, otherwise it is destroyed. The way to do this is to reduce the performance of the system. They have a very good regard of dysprosium. Neodymium is needed in magnets, they do, however, have no clue of how much that is used. Neodymium is more important to audio-components where is used a performance enhancer. It is, however, not as useful to the much easier if the temperatures were lower.

The trend has developed from full use of dysprosium, via halved usage to, as the vision is now, no usage at all in our components. This vision holds for the components similar to the servo pump. The consequence of the eliminated use is an inferior end product. It will mean a tighter safety margin against temperature impact, rather than an inferior product. It will become more sensitive. This leads to an increased demand of monitoring. Also the temperature needs to be reduced which will hamper the performance at least under some driving modes. This is, however, hard to measure. It will not impact the standard function but rather the thermal-related applications leading to protective measures need to be used more frequently. When the price increases, this has to be done since most customers never experience the difference. Economic reasons are driving the push for reduction of dysprosium. The discussions regarding rare earth reduction began three years ago, maybe longer. The dysprosium reduction is done by changes in the mixture of materials used for different applications to keep the same crystal-structure. Variation in processes further helps the reduction efforts. They have, however, not spent a lot of time on the matter but tend to follow what the suppliers do. The elimination vision could be changed if the requested performance is not achieved. The bottom line is that size is balanced against cost. The earlier construction phase needs to be influenced to add flexibility. If there were space available, it would be a no-brainer to reduce the use of expensive material. Pack volume is, however, scarce, making it more difficult. Automotive products do not have the optimal efficiency to start with due to its cost and size optimization compared to large electric machines.

Suppliers deliver to several companies and are therefore responsible for much of the product development. There are no resources for any major inter-firm projects. All tiers in the supply chain are cooperating and it is therefore hard for Volvo to do anything different. It is, however, interesting as a source of information. Volvo´s strategy is to develop new technology in areas that are strategically important like active security. For the foundational systems, however, buys the complete system from its supplier and there is limited opportunity in requesting specific materials. Most of the times, Volvo has an incentive to follow the herd to get a better price. It would be hard to think of what could motivate Volvo to go its own way in this field. In times of extreme prices, the rest of the industry has the same incentive to act as Volvo. If Volvo were to drive the performance development that no one else is interested in a special situation could arise. This is, however, very unlikely. The question regarding dysprosium will probably not be the most important question in the future.

Mitigation strategies

Substitute

There are no substitutes currently but no one knows what will happen in the future. Price is key for a substitute to be viable.

Absorb risk/reduced demand

Recycling is not currently considered. The department has no direct incentive for working with recycling, only baseline requirement. The department only gets the costs. The department is only responsible for lifetime articles and no consumption articles and thus remanufacturing falls out of the scope. This is currently not up to discussion.

Market Intelligence department

Chief Economist/Raw Material Specialist

Date: 31.03.2015, 10.00 - 10.45 (duration 45 min)

Volatility

Historically, the consumed volumes of dysprosium and neodymium have increased and will probably increase even in the future. The increase is mainly due to hybridization and electrification trends. In 2011, when the prices of rare earth elements exploded because China implemented export quotas, Volvo begun to discuss alternative solutions with their suppliers. The prices then fell to very low levels and the plans were put on hold. Now, China has lost in the WTO (World trade organization) court and accepted the verdict and they are not allowed to have export quotas of rare earth elements. Because of this a big part of the risk of scarce supply has disappeared. Volvo can now also see that new production kicks off around the world, even if it takes a bit of time. It is always up to the market to dictate the prices and more demand increases the prices. In the long run, however, increasing environmental concern in

China could impact the supply negatively and cause higher market prices. China does also do all legislation stepwise and focuses on one area at a time. Maybe rare earth elements are up next, to be regulated regarding environmental impact. Including dysprosium and neodymium could also become a communicative risk in the future, due to its soiled production and refinery processes.

If there is a great price increase the supplier comes to Volvo with the problem. The purchasing department turns to the market intelligence department for support and validation of the problem. There is a great demand for information regarding material prices. It is important for Volvo to do a good forecast to be prepared on possible changes. Volvo worked for three years to develop a forecasting tool, which has proven to be highly robust. It helps the company to follow the price development. The forecast calculates prices of dysprosium and neodymium five years ahead but the tool cannot be used to forecast structural and sudden changes. The parameters the forecast is based upon are: hybridization, total supply and demand, currencies, correlation with other metals, the world economy and the most important: producers and consumers together with many others.

Dependence

Dysprosium and neodymium is highly critical to the end product. Volvo is highly dependent on powerful miners and other suppliers further upstream. The respondent thinks, Volvo has an advantage in its good relation with China compared to for example Toyota, this is because a Chinese company owns Volvo.

Mitigation strategies

Substitutes

The materials are critical in the way that there is no substitutes that could be deliver the components with the performance levels required. However, this is an area the research and development department knows better. Volvo does a review of what is around us and for catalysts for example, different materials tend to be used. Volvo requests new solutions but it is not a driving force but maybe some new solutions will be available if prices increase.

Pass/share risk

It is very unlikely that it would be possible to pass on price increases to consumers. The suppliers will, however, demand compensation for price increases. If prices increase the market intelligence department needs to confirm this compensation if the price increases are valid and gives advice on how to handle the topic. Compensation is only given for a brief period (6 months) at a time. It is always a matter of discussion on how large and long the compensation should be. There are funds set aside for this matter to pay the compensations. You never know the prices and therefore a certain sum is blocked for this issue but this is, however, not communicated with the suppliers. In most cases when it is motivated, the suppliers get reimbursement since it is in Volvos interest that the suppliers remain in business. Volvo does not want the suppliers to increase their prices to be able to handle price fluctuations. Volvo is also interested in when the prices go down and then Volvo sometimes has the opportunity to decrease the prices, which is written in some contracts. The suppliers tend to not report price decrease in the same extent as increases.

Forward buy

Volvo does not buy any neodymium and dysprosium themselves, these activities are only performed by the suppliers. Volvo does, however, buy steel and aluminium and for these materials, hedging can be discussed. For rare earth elements, however, the responsibility is on the suppliers and if they buy at the right price levels well they can make a profit. It is Volvo's job to find good suppliers who can do a good job managing the purchases of these materials. Insufficient suppliers might do errors in ordering the materials, forecasting prices or lack have flexibility to meet changes in demand, which then might affect Volvo negatively.

Hedge/Cross-hedge

Hedging is not used today and the reason is that hedging is only used for the metals that are traded on a metal exchange and that is not the case for neodymium and dysprosium. It is the same situation as it is for lithium. Volvo can also see a much greater stability in prices for the metals not traded on a metal exchange. The metals are brought straight from the producers rather than with a middleman. For metals traded at the metal exchange it is a different situation, the aluminium prices are extremely volatile due to speculation, which his is also true for copper and zinc. When comparing offers from supplies, the cost of the component is calculated based on landed cost, which includes all costs from production of the components to delivery to Volvo´s facilities. The prices of dysprosium and neodymium from China differ, depending on if the producer is located in China and gets the lower local prices or if the producer is located in for example Europe and perceive the higher export prices. Today the export prices and the local prices are following the same development pattern and the price differences are not big enough to choose Chinese producers over other produces since other costs eat up the difference.

Secure supply

Investigations have been done regarding to engage in secure supply. The respondent further present that he thinks, Li Shufu (the chairman of Volvo) was involved in some rare earth mining projects. But he has no more information regarding this. After the price increase in 2011, the company considered securing supply by engaging in backward integration into mining business to secure supply, but the option has not been pursued yet. However, this was nothing that was performed, probably due to the following year's price fall. The respondent further presents that the company, however, share information about the risks with suppliers.

Absorb risk/reduce demand

Recycling is not a parameter in the forecasting model. Recycling could offer a PR opportunity for Volvo.

Inbound Logistic and optimization

Manager of transport optimization and implementation

Date: 07.04.2015, 09.00 - 09.32 (duration 32 min)
In the process of purchasing components Volvo is responsible for the transports from the tier one supplier to Volvo's properties. Raw material is also handled but this is handled with free delivery, meaning Volvo is not responsible for the transport. A most common complications the logistic department come across are that the suppliers are not picking up the products on the correct days, in time and that they don't keep the transportation lead times. Today over sea flows transports are not included in the transport management system (TMS) but instead are handled manually ad hoc, which makes Volvo not able to follow the processes of the transport. It might take three years until it is included in the system. Before the suppliers were forced to have a hub in Europe where Volvo bought its components even if they were produced in China. Today, however, this regulation have been removed to make it possible for the purchasing department to source more locally for example in China. But more suppliers in China would be more administrative work for Volvo and thereby problematic due to the need for more manually administrative work. Also there are longer lead times and less flexibility to make changes.

The logistic department is indirect involved in the purchasing decisions. When the purchasing departments are sourcing, a Land cost calculation is performed. The total cost of buying one component is calculated including taxes, fairs transportation and so on. This makes it possible to compare the total cost of buying one component in China compared to Europe. The logistic department provides transportation cost information to the Supply network department, who are making the land cost calculation.

Mitigation strategies
Forward buy
Might be possible, but the respondent highlights his limited insight of the matter. But depending on the prices of this material this might generate big risks during transportation because of thieves. If the material have high values the goods needs to be transported in special transports. If Volvo could handle the material in a normal transport process it might be worth it for Volvo to forward buy, store the material and then sell to tier one.

Hedge/Cross-hedge
Hedging might be a possible solution if it exists for rare earth elements.

Secure demand
Secure demand might be a problem since Volvo might not be big enough for it to be profitable. Toyota for example is so much bigger than Volvo and therefore this might not be possible. One solution could be to collaborate with other actors in the market. Since Volvo is not big enough to make big investments in joint ventures with a mine on their own. The respondent thinks Volvo could do a benchmark on how other actors, who buy big quantities, are handling the problem.

Absorb risk/reduce demand

Other materials are today recycled with Stena, who buys the waste from Volvo and then recycle the materials. This could be possible with dysprosium and neodymium as well. The respondent does, however, not have more information about which materials are recycled.

Environment and fluid dynamics
Senior Strategic Advisory Environment
Date: 23.04.2015, 14.40 – 15.21 (duration 41 min)
Volatility
The respondent believes that there will be two tracks of developments of the supply and demand of dysprosium and neodymium in the future. The total use of these elements might not be very different compared to what it is right now if it does not accrue something unpredictable that will change the current picture of the market. One track is that Volvo reduces the level of performance in the components and create cheaper and maybe more simplified solutions. Maybe also other materials are used for this scenario and accept that the components are getting a bit bigger, even if the respondent self have a hard time believing the company would do that. Additional to this Volvo there will be a high level performance niche, which would present the totally opposite from reducing the use of dysprosium and neodymium maybe even more than today. These two tracks would then compensate for each other regarding the usage of these elements. What Volvo could do differently is if Volvo changes direction and decide to eliminate systems or if focusing on only electrical cars and thereby open up the available space in the car. This is possible due to that it is possible to remove for example the gearbox. Then is possible to have an electrical engine, which is 10% bigger but still have the same level of performance as if dysprosium and neodymium were included. But we have not come this far yet.

The respondent identifies some risks related to the supply of dysprosium and neodymium. He does not think there are any risks to get these materials physically, but there are commercial risks that could be highlights as an issue, such as the environmentally damaging production and refinery processes of these rare earth elements. This is something a company does not want to be connected to since it could harm the brand. For this reason it could be unsustainable to include materials like rare earth elements in the cars. If the use and production of these rare earth elements becomes very transparent and possible to connect to Volvo this is an issue, which could be very relevant on high levels in the organization. This could also be a reason for why Volvo should go in another direction and start using other materials and solutions. The commercial risk the respondent thinks is hard to connect with the price risk to the component and its content. This risk regards the revenues more than the costs of the components and materials. However, there is a price tag on trying succeeding on the market with a product that is strongly connected to the environmentally damaging production of materials. This could be very difficult for the company. If looking back at debate that occurred about the cars in the old P2 platform, where Volvo due to space reasons in the car put the battery in the back of the car. Then a wire was connected under the car into the front to the engine. Then there was registered electromagnetic field that was far under all the values allowed, but this was anyway discussed as a big issue. Volvo could not technical or logical argue their way out of this debate. Volvo could do almost anything not to end up in situations like this since it is not possible for Volvo to win a debate like this and then it will harm the brand. The situation with the commercial risks of dysprosium and neodymium is similar. Volvo could be labelled as an actor working with “the wrong people”, which they want to avoid.

The decisions regarding how to handle dysprosium and neodymium seems to be regulated in a department level, and different department seems to act and look at the problem differently. If a department thinks it is problematic and difficult to include dysprosium and neodymium in the product, these are reduced as much as possible. Some departments have a clear strategy of how to reduce and in some cases eliminate these materials: other department continue to use the rare earth elements in focus.

Dependency

For the most common car sold by Volvo dysprosium and neodymium is not very critical. However, for the top of the line products with high performance, that position the brand of Volvo with strategically collaborations and so on, the materials are highly critical to achieve the wished performance for the products. For these products these materials could be completely crucial. But totally, out of 500 000 cars, this is important for 500 cars, but these 500 cars are the ones that are building the while brand. Therefore the materials are not important regarding sales, but when looking at the brand and brand building this is highly important.

Dysprosium and neodymium is critical for the plug in hybrid since two types of drive lines needs to be included in the car there will be very limited place available in the car, and therefore these elements is needed to reduce the sizes of the components without lowering the performance. Otherwise the sizes of the cars would be too big, and they have enough problems to fit the battery in these cars. Due to the space limits available in the cars, the respondent thinks the industry will refer to product in “litre” instead of “kilo”, since the space is more important than the weight. Even if the weight is important regarding the fuel consumption, it is more important to create the right size and a good looking designed car, which is working commercially.

Electrification of cars is something that is an increasing focus, and this will increase. Independently if it is a hybrid car or a fully electric car, Volvo needs to possess the skill to drive the cars with electrification, and this will need big electrified engines in every car. This development could both increase the dependency of dysprosium and neodymium, but also decrease the dependence if finding a way to come around the problem when developing the fully electrified cars. Also when looking at electrified cars a the car producers might get away by producing a plug in hybrid model in the portfolio, but this might not be enough in the future since then you need to supply a high performance hybrid of electrified car model. In 5-10 years, these models might be relatively common the demands of performance on these cars are higher.

What Volvo, could do in a Swedish way, is to collaborate with small local suppliers in looking at problems and creating solutions together. This was done during the time Volvo as owned by Ford. Then the suppliers and Volvo shared the pre-stage of the development process and tested products, solutions and prototypes in order to solve different problems that occurred. This model could be possible in trying to make small steps in creating solutions forward in how to exclude or minimize the use of dysprosium and neodymium. One problem, however, is the suppliers these kind of collaboration models could be done with, is not located in Sweden. The strength of Sweden is that we do not have limitations in which we could call for help or tip even between companies. Someone from Volvo could call someone at Scania to talk about creating a lightweight solution of a component for example. However, this is not possible to do in other countries without creating suspicions. Other types of collaboration or solutions such as information sharing or similar could be possible between companies. Volvo has realized that they need to improve the social collaborations, after Ford sold them. Now Volvo is their own company and cannot use the social frameworks of Ford anymore. The social collaborations are then needed to be built up by the company and could be solutions regarding neodymium and dysprosium.

The respondent thinks that the environmental awareness of the increases with the customers that buys more than one car. They want more detailed information from a sustainability perspective, which is not only regarding the product itself but also includes the company. This trend the respondent thinks only will increase.

Volvo is a small actor, globally, and if there is a scandal or price increase of dysprosium and neodymium, this will affect other actors in the market much harder than Volvo. Then the entire industry will start looking at the problem and suppliers will pop up, offering similar solutions to almost the same prices.

In the future the respondent thinks that Volvo needs to have a better control and information what is happening in the supply chain of these elements. If someone questions the use of dysprosium and neodymium in Volvo's cars, they need to supply a good and trustworthy answer. Being very clear on informing the suppliers on how they should handle dysprosium and neodymium and controlling that the suppliers take these actions could do this. This does not have to be a comprehensive operation but Volvo could for example start pointing out a specific component, which is the worst example and this should therefore be controlled. If another component highlight to be as bad, Volvo has a process already of how they should handle these kinds of problems.

Mitigation strategies

Substitute

The respondent explains he has limited knowledge regarding this, but describes that of course here were materials, which were used before dysprosium and neodymium were found. These were, however, probably not as efficient as dysprosium and neodymium. The respondent also highlights that if the issues of these elements are highlighted on the market and in the industry the innovations development in this area will increase. If for example the prices increases in the way they did 2011, and the current available substitutes are not an alternative the motivation of what could be used instead will increase.

Pass/share risk

If Volvo could, with these elements, show a level of performance in terms of being able to supply additional products for the car, such as a high performance loudspeaker system, which the customers need to pay more money for then the risk could be transferred to the customer. Then the customers probably would not care if the high performance loudspeaker system cost 40 000 SEK extra or 44 000 extra. But if Volvo wants to produce a budget variant on a plug in hybrid car, it is not possible to add the cost on the car, because dysprosium and neodymium is expensive materials used in the cars components and the margins are too small. A high performance hybrid car, that is able to perform 0-100 in just a couple of seconds, could possible be priced higher to the customers if Volvo could show the effect achieved with these materials. Transferring the risk to the suppliers the respondent thinks will be hard due to the small size, globally, of Volvo.

Forward buy

The respondent thinks it would be hard to engage in forward buy. Far back in the history of Volvo, the company engaged in other businesses such as buying parts of ABBA seafood. This was a trend at this time, and a way to split the risks, if one business was bad another was good. Since this time Volvo is careful in going into businesses that is not their core business, which is developing and producing cars. It is not impossible and Volvo could engage in a joint venture with another actor, which is operating the warehouse as an own company. But this would probably be performed together with other companies to compensate to the small size of Volvo, from a global perspective.

Hedge/cross-hedge

The respondent does not think there is the financial strength in dysprosium and neodymium yet. Maybe in 5-10 years, when there are twice as many cars in sales and the return on capital on investment is good this might be a solution.

Secure supply

The respondent think that engaging in secure supply could be possible in both commercial objective and a way to ensure availability of dysprosium and neodymium together with showing the world, that Volvo use these elements but ensures its produced in the right way, regarding environment and social sustainability. This could make it possible to use a current construction of a car, using these elements, but still get away with using the materials in focus, even if it demands a project like investing in a production site for example.

This problem is similar like conflicts materials, bought from for example Congo. The company does not want to stop using these materials due to social reasons since the people needs these businesses to survive. Volvo, however, only wants to do legal businesses, which is sometimes hard to separate from the illegal activities in the countries the materials are bought from.

Absorb risk/reduce demand

The respondent explains that he thinks all materials or a component in the car that is expensive has a possibility to be included in recycling and remanufacturing solutions. If looking at the electrified engines they are already included in remanufacturing systems today.
Remanufacturing is easier to perform since then the components are not broken down to raw material level but only to the level where the magnet, for example, could be extracted and use it again. Remanufacturing could be a step in the direction towards recycling, as a solution possible to perform and implement in the short run compared to recycling that stills needs some technical innovations to be possible to achieve. Remanufacturing is possible for Volvo to perform in their system together with resellers and suppliers. There is a lot of money to earn within remanufacturing and if it is easy to implement is there also probably a market for anyone to engage in, and work as a link in the supply chain. This is something one should not underestimate, because this is this type of circle economy that makes it possible to handle problems connected to dysprosium and neodymium.

Volvo could engage in remanufacturing as long as it stays in control of what Volvo could handle. Volvo chooses to mark some specific components and systems, and when the resellers of Volvo receives those components these are send back to Volvo to be renovating. Volvo has then control over the situation and has information even which car the component comes from, the year of the model and so on in their system. Volvo has then information about where the component have been and where it could be used in another car, instead or using a new component. In this way Volvo can save a lot of money. Remanufacturing would not be profitable if for example Meconomen, which makes a lot of services on Volvo cars, would send back the components since they are not in the Volvo system and therefore this would be less effective. Remanufacturing would, however, mainly be used for components with a sufficiently high price and to be easy to replace.

Recycling, demands collaboration with an actor like Stena Metal. Dysprosium and neodymium are elements that are included in the price negotiation with Stena Metal. Stena Metal is paying Volvo for the car when this should be recycled. Volvo could increase the visibility of these elements to get a higher price from Stena Metal. Volvo could provide Stena Metal with information regarding which components contain, which high valued materials and where in the car the components are located to make it easy for Stena Metal to find and extract these.

Whether to engage in recycling or remanufacturing depends on the characteristics of the components. If the component is exposed to the customer, such as the seat of the car, remanufacturing is not a solution. Also if the component is possible to use again without any big renovations, then this could be remanufactured. However if it demands a lot of work, then it could be worth recycling the component instead, when the car is scrapped.

APPENDIX F - Full description of results from External Interview (Supplier)

ZF TRW automotive
Supplier C – Servo Pump
Date: 18.05.2015, Answers given my mail

Volatility

The volatility of prices of dysprosium and neodymium will depend on Chinese government intervention (such as duties, supply quotas etc.) and the increased demand for non-automotive purposes (energy etc.).

Electric Steering is replacing Hydraulic Steering in most applications, this trend will continue until 2018/19 when we believe the electric steering market will be close to saturation. Global vehicle build is predicted to grow year on year further driving demand. Rare earth quantities will track these growth drivers.

Dependency

Neodymium is very critical in defining the magnetic strength of the product and dysprosium is very critical in high temperature and high current applications where it prevents demagnetization. The traceability of the rare earth elements in focus at the magnet manufacturing level is good but before that not so good. The company experimented with membership of "Metal Pages" and "Asia Metals" to engage in discussions with other companies regarding the problems of supply of dysprosium and neodymium but have not found too much benefit from such membership.

Mitigation strategies

Many mitigation strategies were executed in the 2010-2012 timeframe during the peak of material inflation, these included: Optimizing magnet-manufacturing process to reduce scrap and recycle waste material, optimizing magnet design to utilize less material and assist manufacturing process, lowering the quantities of Dysprosium used in magnets to align with customer specifications rather than exceed them, consider motor temperature and current demands during system specification and move from purchasing material against the FOB index to the China Domestic index.

TRW purchases magnets in China together with a large proportion motors and also Japan although future product generations with all be sourced in China. Magnets are referenced to the China Domestic index where produced in China and FOB index where purchased outside China. This is presently the best risk mitigation approach but is always under constant review. TRW purchases magnets and motors from a selected supply base including China and non-China companies and locations. Designs have been made common (make to print) to allow movement within this supply base. This balanced supply base is presently our best mitigation strategy.

Substitutes

Supplier C is not aware of any substitutes. There is a possibility to switch from rare earth to ferrite magnets but the product would need to increase in size and weight considerably to deliver the same power, something unacceptable to the OEMs.

Pass/share risk
Due to the tight control on this commodity by China we have had minimal success in sharing risk with the supply base.

Forward buy
No obvious opportunity apart from the security of supply in a challenged market, controlled by the Chinese government.

Secure supply
No obvious opportunity apart from the security of supply in a challenged market, controlled by the Chinese government.