Modeling of supply chain processes of the mineral raw materials industry from the perspective of EM, SCOR and DCOR models

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ABSTRACT IN GERMAN

Mit der Erschließung und der Bereitstellung von Rohstoffen für die produzierende Industrie bildet die rohstofferzeugende Industrie den Ausgangspunkt für eine Vielzahl industrieller Wertschöpfungsprozesse. Eine tiefgreifende Integration der Prozesse der Bergbauindustrie in die sich daran anschließenden Prozesse der Warenerzeugung ist jedoch eher die Ausnahme als die Regel. Ein direkter Vergleich der rohstofferzeugenden und der warenerzeugenden Industrieprozesse ist nur schwer möglich, da sich die Prozesse bei der Rohstofferzeugung bzw. -bereitstellung erheblich von den Prozessen eines produzierenden Unternehmens unterscheiden. Dies erklärt auch, dass es bis heute nur wenige Anwendungen von standardisierten Modellierungswerkzeugen für lieferketten (Supply Chains) im Kontext der Bergbauindustrie gibt. Diese Umstände verhindern aber die heute erforderliche durchgängige Integration von Wertschöpfungsketten.

Die vorliegende Arbeit setzt in den frühen Phasen der Wertschöpfung in der Bergbauindustrie an und konzentriert sich auf die Analyse und Modellierung dieser Prozesse. Übergeordnetes Ziel ist es, einen Beitrag zur Standardisierung und zur verbesserten Integration der Prozesse der Bergbauindustrie in die nachgelagerten industriellen Wertschöpfungsketten zu leisten. Betrachtet man die bestehenden Lösungen zur Modellierung von Wertschöpfungsketten, so fokussieren diese fast ausschließlich auf die produzierende Industrie ohne Berücksichtigung der vorgelagerten Prozesse der Bergbauindustrie. Die steigende Nachfrage nach Rohstoffen und auch die stark schwankenden Preise für Rohstoffe haben gerade in der jüngsten Vergangenheit gezeigt, dass die Verfügbarkeit von Rohstoffen einen wesentlichen Einfluss auf die Wirtschaftlichkeit der nachgelagerten Prozesse haben kann.

Die in dieser Arbeit durchgeführte, detaillierte Analyse der Bergbauindustrie und ihrer Prozesse hilft die Herausforderungen zu identifizieren, mit denen sich diese Branche konfrontiert sieht. Ein erster Vergleich der Prozesse der Bergbauindustrie mit den Prozessen der produzierenden Industrie zeigte die größten Unterschiede innerhalb des Prozessschrittes „Beschaffung“ auf. Der im Rahmen der Arbeit erbrachte Modellierungsaufwand konzentriert sich auf die Erkundungs-, Gestaltungs-, Konstruktions- und Gewinnungsprozesse. Die Entwicklung der Modellierung dieser Prozesse fand mit Hilfe der integrierten DCOR- und SCOR-Modelle statt. Anhand einer Literaturauswertung wurden die Lücken zwischen dem SCOR-Model und den Konstruktions-, und Gewinnungsprozessen sowie zwischen dem DCOR-Model und den Erkundungs- und Gestaltungsprozessen ermittelt. Die Prozesse wurden anschließend einer Analyse unterzogen, mit dem Ziel die SCOR- und DCOR-Modelle auf die

jeweiligen Prozesse anzupassen. Ein integriertes Modell des Beschaffungsprozesses konnte daraufhin erarbeitet werden.

Die Evaluierung des vorgeschlagenen Modells stützt sich auf zwei Fallstudien aus den Prozessphasen „Erkundung“ und „Gewinnung“, welche auf realen Datensätzen von chilenischer Kupferminen basieren. Die Auswahl der Fallstudien erfolgte zum Zweck des Nachweises der Anwendbarkeit des angepassten SCOR- und DCOR-Models. Die Auswertung der Fallstudien bestätigte, dass es möglich ist die Bergbauprozesse mit Hilfe der SCOR- und DCOR- Standardmodelle zu beschreiben. Im Rahmen der Evaluierung wurden die Modelle sowohl konzeptionell als auch sprachlich an den Bergbaubereich angepasst, um so auch gleichzeitig als Anleitung bei der Implementierung zu dienen.

Die vorliegende Arbeit ist der Versuch eine Basis für weitere Forschungsarbeiten im Kontext der Modellierung der frühen Phasen der Wertschöpfungskette in der Bergbauindustrie, welcher von der Verfügbarkeit von Rohstoffvorkommen abhängt, zu liefern. Die Arbeit zeigt auf, wie die SCOR- und DCOR-Modelle auf die Prozesse der Bergbaubranche angepasst werden können. Dies impliziert, dass diese Modelle die Modellierung wesentlicher Aspekte der Bergbauindustrie erlauben, und es nicht notwendig ist weitere generische Prozesse in die existierenden SCOR- und DCOR-Modelle zu integrieren. Es kann davon ausgegangen werden, dass durch die Nutzung der angepassten SCOR- und DCOR-Modelle ein Potenzial für die Integration der frühen Wertschöpfungsprozesse der Bergbauindustrie und der sich daran anschließenden Wertschöpfungsprozesse erschlossen werden kann.

In der vorliegenden Arbeit konnte gezeigt werden, dass sich der “Source”-Prozess des SCOR-Modells vom Beschaffungsprozess im Bergbau wesentlich unterscheidet. Des Weiteren konnte dargelegt werden, dass die Anpassung der integrierten SCOR- und DCOR-Modelle eine Beschreibung dieses Beschaffungsprozesses erlaubt. Dies stellt auch einen wesentlichen Beitrag dieser Forschung dar, da die „Beschaffung“ der Rohstoffe nicht nur aktuell, sondern auch in Zukunft die größte Herausforderung in der Bergbauindustrie sein wird.

Darüber hinaus zeigt die Arbeit, dass die an den Bergbau angepassten SCOR- und DCOR-Modelle die Auswahl und die Nutzung der bestehenden Leistungskennzahlen (KPI -Key Performance Indicators) erlauben. Es kann vor dem Hintergrund aktueller Entwicklungen davon ausgegangen werden, dass durch die Nutzung dieser Modelle in naher Zukunft die Anzahl an Informationen und Standard-KPIs, die aus Bergbaubetrieben abgeleitet wurden, zunehmen wird. Dadurch ergeben sich sowohl Chancen als auch Risiken für Bergbau- und produzierende Unternehmen. In zukünftiger Forschung kann somit die Auswahl von am besten geeigneten KPIs und Best-Practices zur Verbesserungen der Integration, der Transparenz und der Leistungsfähigkeit der Bergbauprozesse beitragen.

ABSTRACT

The mining industry is essential for manufacturing because it provides the basic materials for the related value-adding processes. Deep integration of the mining industry is, however, still an exception rather than a rule. This industry and its processes differ greatly from the processes of an average manufacturing company. This is because we cannot have directly comparable results in the absence of applications of standardized modeling tools for supply chains such as the SCOR model. These circumstances hinder the integration and understanding of, and exchange between, industries relying significantly on each other. The research problem of this thesis is set in the early supply chain processes of the mining industry; it focuses on the modeling of such processes with the goal of standardizing them and improving the integration as well as the performance of this industry in the supply chain. The modeling is based on the adaptation of the integrated supply chain frameworks DCOR and SCOR to the mining industry. Today, the existing solutions of supply chain models focus mostly on the manufacturing industry, instead of the whole supply chain, since they do not incorporate the processes of the mining industry. It was found that these mining processes can have a significant and varying effect on the performance of the downstream processes and hence on the entire supply chain.

In the dissertation, the analysis of the unique characteristics of the mining industry and its processes helps to identify the challenges faced by this industry. Previously, it was determined that the greatest challenges facing the mining industry are in the sourcing process. Moreover, comparing the mining processes with the processes of the manufacturing industry, the sourcing process presented the largest gap. As a consequence, the sourcing process in mining differs from the "source" process of the SCOR model. From the above, the modeling efforts focus on the processes of exploration, engineering design, construction, and extraction. To develop the modeling of these processes, the integrated DCOR and SCOR models were used. Through literature review the gap between the SCOR model and the processes of construction and extraction, and the gap between the DCOR model and the processes of exploration and engineering design, were determined. Subsequently, each process was analyzed in order to adapt SCOR and DCOR models to such processes. After that, an integrated model for the sourcing process in mining could be obtained and analyzed.

The research evaluation was conducted by using two case studies from distinctive mining processes (extraction and exploration) based on "real world" information about copper companies in Chile. The purpose of choosing two cases was to highlight the general applicability of the adapted SCOR and DCOR models. The evaluation confirmed that it is possible to describe the mining processes by

using standard SCOR and DCOR models, which were adapted by using the mining language to guide the implementation of the developed model.

This research work is a first attempt to create a basis for further research in the early part of the supply chain in the mining industry, which relies on the availability of mineral deposits. This paper demonstrates how SCOR and DCOR models may be adapted to describe the processes in the mining domain. This implies that these models allow modeling a crucial aspect of the mining industry, with no need to integrate other generic processes into the existing SCOR and DCOR models. In addition, it can be concluded that there is a potential for integration between the processes of the early part of the supply chain in the mining industry and other processes in the supply chain by using SCOR and DCOR models.

Owing to the unique characteristics of the mining industry, this thesis demonstrates that the process “source” of the SCOR model is different from the sourcing process in mining. This thesis argues that adaptation of the integrated SCOR and DCOR models allows a description of this sourcing process. This is a significant research contribution, since this sourcing is the greatest current and future challenges for the mining industry.

Additionally, this work highlights that the adapted SCOR and DCOR models to mining allow selection and use of key performance indicators (KPIs), and validate best practices along the supply chain. It can be safely said that the amount of information and standard KPIs derived from mining operations will increase in the near future due to these types of models. This offers opportunities as well as challenges for mining companies and manufacturing companies. Consequently, in future research, the selection of the most suitable KPIs and best practices can contribute to improvements in integration, transparency, and performance of the mining processes, and therefore, improvements in the performance of subsequent processes in the supply chain.

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List of abbreviations

APICS	American Production and Inventory Control Society
ATO	Assemble-To-Order
ASTM	American Society for Testing and Materials
BPMN	Business Process Modeling Notation
BTO	Built-To-Order
BTS	Build-To-Stock
CD	Component Design
CNPD	Concurrent New Product Development
DCOR	Design-Chain Operations Reference
DTO	Design To Order
EF	Engineering and Feasibility
EIA	Environmental Impact Assessment
EM	Exploration and Mining
EMMMV	Exploration, Mining, Metals and Minerals Vertical
EOD	Exploitation Options Design
FS	Feasibility Studies
GIS	Geographic information systems
ICS	Integrated Supply Chain
JIT	Just In Time
KPI	Key Performance Indicator
LOM	Life of Mine
MAS	Multi-Agent Systems
MEG	Metals Economics Group
MRO	Maintenance, Repair and Overhaul
MTO	Make-To-Order
MTS	Make to Stock
NCRE	Non-Conventional Renewable Energy
NML	New Mine Level
NPD	New Product Development
OPEX	Operational Expenditure
PD	Project Design
PEA	Prospection/Exploration and Assessment
PM	Project Management
RMI	Raw Materials Initiative
SAP	Systems, Applications and Products in Data Processing

SCC	Supply Chain Council
SCM	Supply Chain Management
SCO	Specification Change Order
SCOR	Supply Chain Operations Reference

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1 Introduction

Minerals and metals have played a role in human economy and development since the dawn of humanity, and they continue to be indispensable for all human activities. Mining and metal production is also one of the most important economic activities in both developed and developing countries (Vial 2004; Technological Geomining Institute of Spain 1997; MacKenzie 1986). Currently, the mineral raw materials industry (mining) has access to different global markets, starting from local markets. This industry sells minerals such as gold, copper, and aluminum globally because they have a high value per unit of weight to be sold in global markets (Dave, Galloway, & Assmus, 2005).

Supply chains nowadays are more prominent of all the business processes (Han & Chung-Yee, 2007), and there has been increased interest in supply chain modeling (Beamon, 1998). By modeling supply chain processes, cross-organizational boundaries can be more easily defined, analyzed, and improved to provide companies with a sustainable competitive advantage. As a result, supply chain processes are becoming more strategic rather than transactional. Given this interest, various supply chain frameworks have been introduced, with the most relevant being SCOR and DCOR. The Supply Chain Operations Reference (SCOR) model and the Design Chain Operation Reference (DCOR) model are part of an integrated standard framework for modeling business processes in the supply chain and the design chain (SCC 2010; Nyere 2006). The processes involved in this framework can be adapted for modeling the specific characteristics of any type of industry.

SCOR and DCOR models were originally designed to fit the requirements to model the processes within a manufacturing environment. Manufacturing and the related processes have been extensively studied. A wide selection of topics describing various successful applications of the SCOR model within the manufacturing industry can be found (Fronia, Wriggers, and Nyhuis 2008; Hwang, Lin, and Jung 2008; Han and Lee 2007; Vanany, Suwignjo, and Yulianto 2005). In addition, some applications of DCOR can be found in different industrial environments (Lyu, Chang, Cheng, & Lin 2010; Juan, Ou-Yang, & Lin 2009; Chen et al. 2006; Wu, Yeh, & Fang 2006).

However, looking at the very beginning of a supply chain, that is the mining industry, it becomes evident that there has been scant research on describing the inherent processes of this industry following SCOR and DCOR models (Tardelli, Barbin, and Cesare de Tomi 2004). Given the definition of supply chain management (SCM) from a business process integration perspective (Lambert 2004), the role of the mining industry within the supply chain is to find, delineate and develop mineral deposits, and then to extract, process and sell (supply) the raw materials derived from these deposits. The supply of mineral raw materials is essential for today's global manufacturing industry; however, despite its significance, there is a lack of integration of the mining processes in the existing supply chain frameworks.

1.1 Motivation[1]

The current supply chain frameworks consider the raw materials industry for minerals as an infinite source—a black box with unlimited resources. Therefore, the supply of mineral raw materials has been more or less excluded from the existing models (Vial, 2004).

Tardelli, Barbin, and Cesare de Tomi (2004) indicate that a unique mineral raw materials industry characteristic, intrinsic to its own nature, is the fact that the main raw material, namely the ore, has originated from an internal source, namely the mineral resource deposit. Because of this, the mineral raw materials industry is a finite source with limited mineral natural resources. This finitude constrains the number of options available for optimization throughout the life of a mine. Consequently, it is necessary to engage in continuous and successful exploration efforts to find new mineral resource deposits, maintain existing production levels, and survive over time (Natural Resources Canada, 2006).

The processes involved in the mining industry are exploration, engineering design, construction, extraction, processing, and distribution (EMMMV, 2010). All the processes can be grouped into three categories (see Figure 1-1): the sourcing process, the making process, and the delivering process.

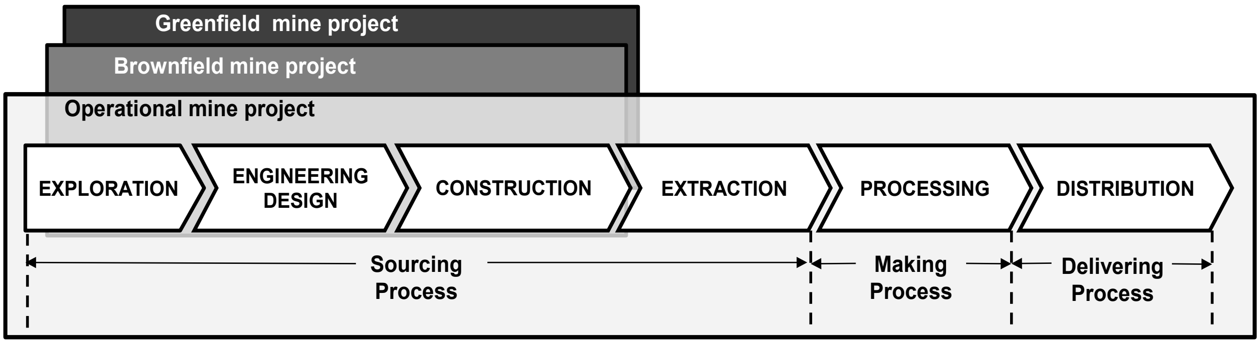

Figure 1-1: Processes of the mineral raw materials industry (Adapted from EMMMV, 2010)

Supply chain integration into the mining industry can help to optimize the total supply chain performance rather than optimizing its component parts, thereby resulting in a better overall outcome (Accenture, 2007). As the mining industry can, in fact, be considered the first supplier for the whole supply chain, such integration seems beneficial for both sides. An improvement in the mining industry processes can generate an improvement in other downstream processes in the supply chain. Given this, a standard framework to the supply chain, which allows modeling the early supply chain processes, can contribute to the integration along the chain and to the success of improvement efforts within this industry.

To improve, simplify, and standardize business processes along the supply chain, companies can adopt the integrated supply chain framework by using DCOR and SCOR models (Nyere, 2006). The adoption of this integrated model

[1] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

helps to improve competitiveness in the supply chain and achieve an increased level of cooperation among supply chain partners (SCC, 2007).

In order to incorporate mining processes into existing supply chain frameworks and improve competitiveness along the entire supply chain, we must identify the mining processes that differ the most from the manufacturing industry. Moreover, these mining processes must have the most influence on the competitiveness in the mining industry. In addition, for integration of these processes in the supply chain, an adaptation of SCOR and DCOR models to these processes is needed. The adaptation of these models to the early part of the supply chain will bring more transparency to the mining processes along the supply chain.

1.2 Problem statement

The mining industry and its processes differ greatly from the average manufacturing company's processes. We cannot get directly comparable results in the absence of the applications of standardized modeling tools for supply chains such as the above-mentioned SCOR and DCOR models. These circumstances hinder the integration, understanding, and exchange between industries that rely significantly on each other. The mining industry is essential for manufacturing by providing the basic materials for their value-adding processes. However, despite its significance, there is a research gap in this field which cannot be accounted for. One possible reason for this lack of research is that the characteristics of several key production processes of mineral raw materials differ significantly from relatively similar processes in manufacturing companies around the globe. Additionally, the mineral raw materials industry, which is home to some of the largest corporations worldwide (e.g., BHP Billiton, Rio Tinto, Codelco, Glencore, etc.), is characterized by the need for large investments, a rigorous focus on supply and demand, and a truly global market (Behre Dolbear Group Inc. 2013). Nevertheless, these companies do not excel in incorporating transparency in their operations yet.

Therefore, the processes of the mining industry have not been sufficiently studied from a supply chain, and, more concretely, from a perspective of SCOR and DCOR models, compared with other industrial manufacturing processes. A better understanding of the complexity and characteristics of the processes can contribute to improve the entire supply chain performance. In this context, the key issue is to increase the understanding and the transparency for the stakeholders further down the value chain. The specific processes are mostly located early, during the launch of the mines.

A thorough review of SCOR and DCOR frameworks reveals a central focus on manufacturing and product supply chain management. To adapt these models to a specific industry, Barnard (2006) states that it is necessary to understand the characteristics describing the processes of this industry. As an example, in the adaptation of the SCOR model to the service industry, the characteristics of this industry are used as input in deriving the processes and terminology of the generalized services of the supply chain. The terminology and processes are used to create a supply chain framework by using input from the SCOR model (Barnard, 2006). SCOR and DCOR models provide a foundation for describing the processes and defining the terminology in an already accepted format.

Besides the lack of similarity between processes of the manufacturing industry and the processes of the mining industry, there are other concepts missing from the current supply chain frameworks—for example, manufacturing industry-specific semantics and processes, and adaptations of current frameworks require translation of manufacturing concepts to mining concepts.

In order to create a supply chain model adapted to the mining industry, the first step is to understand the characteristics of the mining industry operations that contribute to the supply chain. To do this, this research starts by clarifying the research question. What are the unique characteristics of the early part of the supply chain in the mining industry, which should be reflected in the adapted SCOR and DCOR models for mining? It is generally recognized that the mining industry is a distinct industry with unique issues relating to the supply chain (Technological Geomining Institute of Spain 1997). Even with the recognition that mining industry operations are unique, SCC (2010) suggests that a manufacturing model—in this case, SCOR and DCOR models—is a good fit for the early part of the supply chain in mining. A shortcoming relating to this suggestion, however, is that it assumes that a central purchasing agent is involved in the purchase of mineral raw materials. This is not an accurate portrayal of the mining industry whose operations management literature describes the extraction of raw materials to be supplied to the processing plants of the mining industry.

In order to highlight the difference between the processes of the mining industry and the manufacturing industry, Figure 1-2 is a good demonstration of this difference. In the mining industry, raw material is extracted from mineral deposits in the natural environment, as depicted in Figure 1-2a. Tardelli, Barbin, and Cesare de Tomi (2004) emphasize that an important restraining factor for production planning and scheduling is the sequencing of the mine exploitation. In order to be properly extracted, one specific ore block must be at the face of the open pit or underground mine so that mining equipment can gain direct access. In comparison, a manufacturing industry does not have this kind of restraint because this industry obtains its raw materials, to a large extent, from its warehouses and/or directly from its suppliers (see Figure 1-2b) after purchasing them from the global market. While in mining the raw material is still in its natural habitat and has to be extracted from the mine, in manufacturing the raw materials are stored in modern warehouses, planned out, and operated to run efficiently and effectively (Gu, Goetschalckx, and McGinnis 2007; Rouwenhorst et al. 2000). Modern warehousing is based on design, not natural circumstances. The design and location are based on the optimal fit for the planned operations and products. It is, however, the absolute opposite in case of mining. In mining, the sourcing operations have to be adjusted to the naturally given design and location.

The mineral deposit [in situ] is essential for the entire early part of the supply chain in the mining industry. This is why the most important aspect is the role of the mineral deposit as a supplier of raw materials for this industry. The characteristics associated with the mineral deposit and the mining processes involved in the extraction of natural resources are the key for understanding the delivery of mineral raw materials for manufacturing. Therefore, a better understanding of the unique characteristics of the mining industry and its processes can contribute to improved modeling and integration of the early part of the supply chain in the existing supply chain frameworks, such as SCOR and DCOR models.

The research problem addressed in this thesis is set in the early supply chain processes of mining industry and focuses on the modeling of these processes with the goal of incorporating them into the highly integrated supply chains or networks.

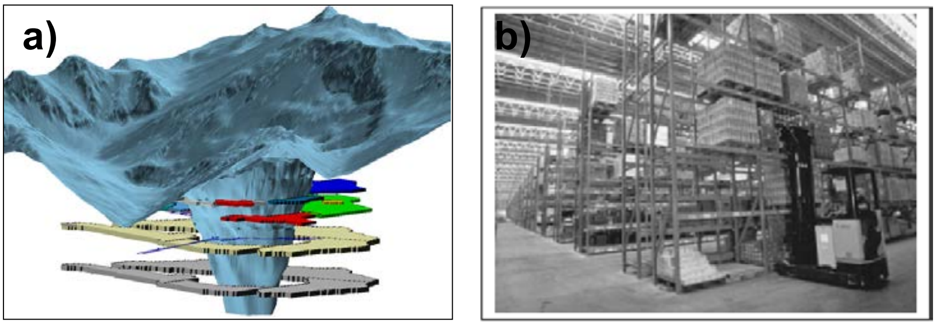

Figure 1-2: (a) ‘sourcing’ in mining (Codelco 2011); (b) ‘sourcing’ in manufacturing (Tardelli, Barbin, and Cesare de Tomi 2004)

1.3 Research objective and procedure

Currently, the mineral raw materials industry has access to different global markets in connection with the supply of minerals raw materials. However, the European Commission (2010) indicates that the supply of mineral raw materials has become a critical challenge to many resource-dependent countries all over the world. In the future, a reliable supply of mineral raw materials will be the main success factor for most of the manufacturing industries (Seifert & Wüst, 2009). Thus, there is a need to integrate the mining processes into current supply chain models in order to improve the understanding and transparency of these processes in the supply of mineral raw materials to manufacturing. The objective of this research is to develop a process model as an adaptation of SCOR and DCOR models to describe the processes of the early part of the supply chain in the mineral raw materials industry. The adaptation efforts will be in the mining processes that differ from manufacturing processes.

Figure 1-3 depicts the methodology addressed in this thesis. In the mapping of mining processes by using SCOR and DCOR models, the SCOR model annotation covers the mining processes of construction, extraction, processing, and distribution. The SCOR model does not focus on the exploration and engineering design processes. Specifically, SCC (2010, p. 11) indicates that the SCOR model does not address sales and marketing, product development, research and development, and some elements of post-delivery customer support. The exploration and engineering design processes are more similar to product development processes or research and development processes, and they are best covered by the DCOR model (SCC, 2006). Therefore, the DCOR model annotation covers the mining processes of exploration and engineering design.

The proposed adaptation of SCOR and DCOR models is based on the following methodology:

Firstly, a content analysis is applied to the mining industry to identify the unique characteristics of the mining industry and its processes. This analysis allows determining which mining processes face the biggest challenges. Then, mining processes are compared with manufacturing industry processes in order to determine which mining processes would present the biggest differences. This comparison includes a content analysis of the existing business process model for mining, namely the EM model, and the existing standard business process models for manufacturing, namely the SCOR and DCOR models.

Secondly, the literature review focuses on identifying the gap between the existing SCOR and DCOR models, and the mining processes with the biggest differences in comparison with manufacturing processes. Subsequently, an analysis of each process is performed in order to adapt SCOR and DCOR models to the aforementioned processes.

Thirdly, once the gap has been identified, the next step is to perform an analysis of adaptations of SCOR and DCOR models, which will provide a description of the above-mentioned processes. To model these mining processes, the integrated DCOR and SCOR models are developed by using Level 2 and Level 3 of these models. The input from the EM model are very relevant for the SCOR and DCOR adaptation to mining processes. When SCOR and DCOR models cannot be adapted to mining processes, the next step must be to study whether other supply chain models can be extended or altered. After that, an integrated model of the early part of the supply chain for mining industry can be obtained and analyzed.

Finally, the integrated SCOR and DCOR models will be evaluated through a case study set in the copper mining industry of Chile. The research evaluation considers “real world” information about a process that is described by using an adaptation of the SCOR model and another process that is described by using an adaptation of the DCOR model.

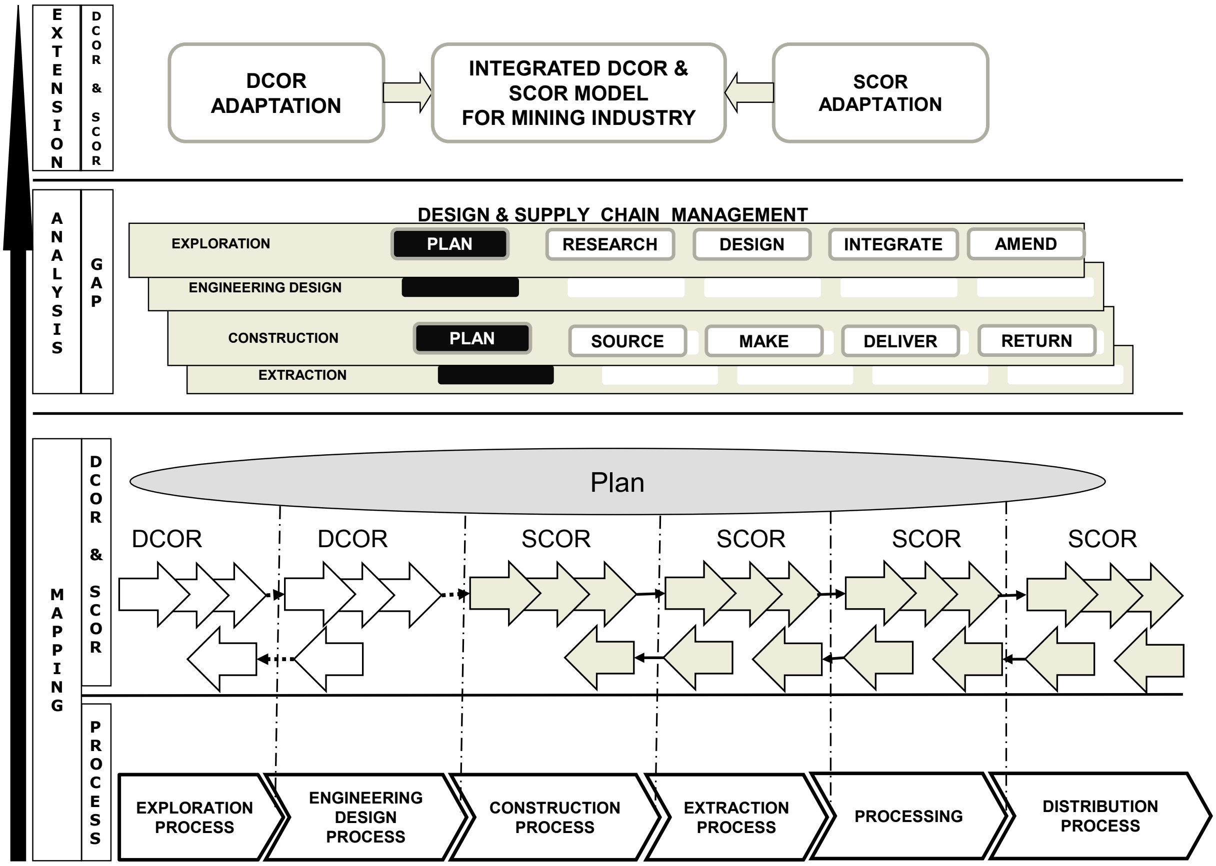

Figure 1-3: The procedure for adapting the SCOR and DCOR models to the processes of mining industry

1.4 Structure of the dissertation

This dissertation is organized into seven chapters. Chapter 1 presents the topic, including the motivation for this research, and identifies a research gap in the literature. The objectives of this research and the steps to achieve these goals are described. Figure 1-4 presents the structure and roadmap of this research.

Chapter 2 starts with a detailed description of the characteristics of the mining industry, its mineral deposits, mineral resources inventory, the mine life phases, and three types of mining projects. After that, the processes in mining are described in more detail, and the challenges facing the mining industry are presented and analyzed.

In Chapter 2, the sourcing process of raw materials in mining is introduced as one of the most critical challenges for the mining industry. Chapter 3 starts with the definition of supply chain and supply chain management. The chapter discusses that a network of suppliers for the main raw material does not exist for a mining company, in the same way as other companies. The most relevant characteristics of Make-To-Stock supply chain are then analyzed and compared in the context of manufacturing and mining companies. The following section is dedicated to describe the sourcing process of raw materials in a manufacturing industry, and then, the sourcing process of raw materials in the early part of the supply chain is shown. After that, a comparison of sourcing of raw materials in mining and manufacturing is done.

Chapter 4 focuses on the research problem in the sourcing process of the mining industry. This chapter starts with the introduction of the characteristics of the process reference models, the EM model for mining, and the SCOR and DCOR models for the supply and design chains. Afterward, the proposed approach for applying and adapting SCOR and DCOR models in the mining domain is introduced. In the next section, some existing applications of the SCOR model to the process of construction are analyzed. Moreover, exemplary applications of the SCOR model in different industrial contexts are analyzed in order to identify commonalities with the extraction process. In the following section, the existing applications of the DCOR model to the processes of exploration and engineering design are revised in the literature. This section compares exemplary applications of the DCOR model in other industrial contexts in order to identify commonalities with the mining processes of exploration and engineering design in the mining domain. In the last section, a research gap is identified between the processes of SCOR and DCOR models and the mining processes of the EM model.

An integrated SCOR and DCOR framework for solving the problem is introduced in Chapter 5. In the first section, the adaptation of the SCOR model to the construction and extraction processes are developed. The adaptation of SCOR Levels 2 and 3 is done for each process. Then, in the following section, the adaptation of the DCOR model to the processes of exploration and engineering design is presented. The adapted SCOR and DCOR models are finally presented by combining the adapted SCOR model and the adapted DCOR model for sourcing processes in the mining industry.

Chapter 6 examines the adaptation of the integrated SCOR and DCOR models introduced in the previous chapter and evaluates its applicability through a case study in the copper industry in Chile. In the first section, the adapted SCOR model is evaluated in the extraction process. In the next section, the adapted DCOR model is evaluated in the exploration process. The last section presents the discussion of results of the evaluation.

Chapter 7 concludes the dissertation with a summary of the findings, contributions, and directions for future research.

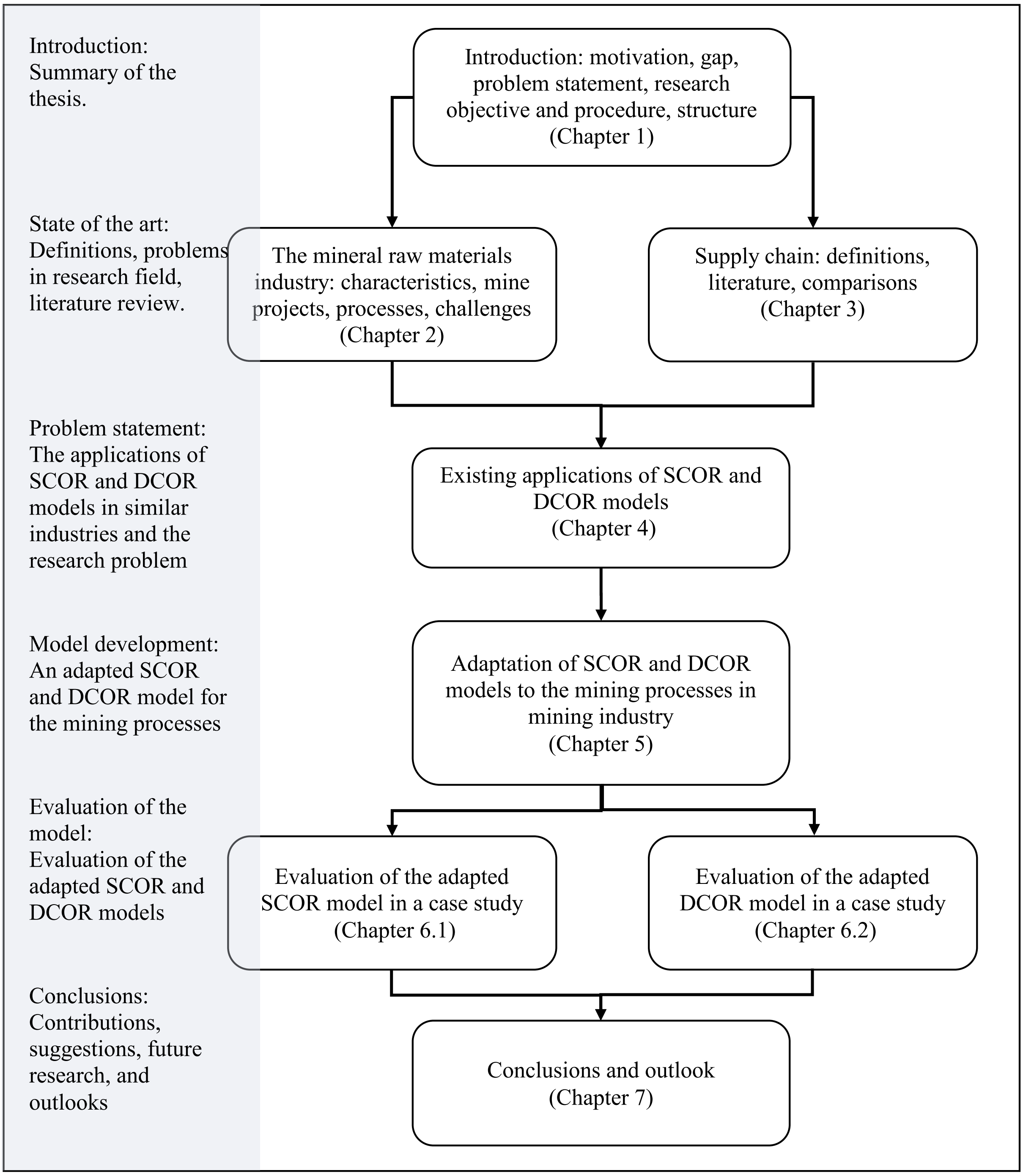

Figure 1-4: Structure of dissertation

2 The mineral raw materials industry: characteristics, projects, processes, and challenges

A unique characteristic of the mineral raw materials industry, intrinsic to its nature, is the fact that the main raw material – the ore – is originated from an internal source, the mineral deposit (Tardelli, Barbin, and Cesare de Tomi 2004). Therefore, the main characteristic of this industry, in comparison to other industries, is determined by the finitude of the mineral natural resource. This limitation determines the life cycle of the mine and creates the need for a continuous stream of projects to survive. In addition, in mining, the sourcing operations have to adjust to the naturally given design and location. The analysis of the processes of this industry contributes to a better understanding of the behavior of its processes and the challenges that this industry is facing. This is elaborated in more detail on this chapter.

2.1 Characteristics of mineral deposits, resource inventory, and mine life[2]

Mining activities involve high-risk investments (Vial, 2004). Mineral deposits have to be located and delineated, entailing large exploration costs, before considering normal industrial development and production decisions. Consequently, mineral exploration is an integral part of the mineral raw materials industry; in fact, successful exploration is essential for mining companies to survive over time. There is also the considerable time lag between exploration and the start of commercial operation. In addition, there is always uncertainty in the mineral commodity markets, which could lead to temporary or permanent closure of operations.

2.1.1 The mineral deposits

Mineral deposits are the source of many important commodities, such as copper and gold, used by our society, but it is important to realize that mineral deposits are a nonrenewable resource. Once mined, they are exhausted, and another source must be found.

Dave, Galloway, & Assmus (2005) indicate that minerals occur in a range of concentrations, not all of which have economic significance:

- A mineral occurrence is a concentration of a mineral (i.e. copper, gold) that is considered valuable by someone somewhere or that is of scientific or technical interest.
- A mineral deposit is a mineral occurrence of sufficient size and grade (concentration) to enable extraction under the most favorable conditions.

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[2] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

- An ore deposit is a mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be mined at a profit. Testing commonly consists of surface mapping and sampling, as well as drilling through the deposit.

The special features of mineral resources deposits, initially unknown, fixed in physical size and location, and variable in quality, result in characteristics that create both problems and opportunities (Technological Geomining Institute of Spain 1997; MacKenzie 1986). The following are the characteristics of the mineral resources deposit.

- ***Location of deposits and project development time.*** Due to the random spatial distribution of the deposits, minerals must be extracted in places where they are discovered: usually in remote and inaccessible areas which involve requirements for transport, energy, water, and social infrastructure in remote regions, which may represent a substantial part of capital and operating costs. This is a highly important characteristic of mining. It produces a differentiation in comparison to other economic activities. Any other economic activity is developed in the place where people decide to install it; mining must go to the place where the mineral deposit is located. Once the exact location of a deposit is known, it takes many years of intense effort to develop the project and eventually produce the expected amount of products continuously. The pre-production periods can take from several years to a decade, depending on the methods of exploitation and processing, size and location of the deposit, complexity of official procedures, etc.

- ***Depletion of natural resources.*** This factor touches on all others as well, as used resources are nonrenewable. Once extracted, the ore is gone and will take a very long time to replenish. Mining activity, therefore, is faced with the sustainability issue. Serious implications may arise if this issue is not properly addressed. The consequences of the gradual depletion of reserves in a deposit are varied. For example, revenues are obtained when there is enough availability of mineral at different stages of the project with the right quality. Consequently, profits are generated within a limited period of mine life, which depends on the reserves and the rate of extraction. The challenge for mining companies is to achieve the best use of these scarce resources by using the right technology. Mining companies must also achieve optimum extraction of mineral reserves with the greatest economic benefit and maximum operational safety.

- ***Impact on environment and high waste/product ratio.*** Mining is undoubtedly one of the human activities that causes the largest amount of environmental change. This is because a mining process removes large amounts of material, which affects the environment and impacts the local geography. The extraction of mineral resources involves extracting valuable, yet low-quantity resources from the earth's crust. This implies that the amount of non-valuable material exceeds the valuable material, thus giving a high ratio of waste:product. Under the technological process, a layout to process these non-valuable materials is required. Often, the beginning of exploitations may be delayed by permitting and legal procedures, and in some cases, refusal by certain opposition sectors. From an economic standpoint, it is also important to consider the additional costs that a company faces after production: to restore the land affected by the operation. In some situations, when evaluating investments, these costs lead to special problems because the cash flow sign is changed and the project becomes unprofitable.

- ***Uncertainties of estimation.*** There always exist a level of uncertainty and estimation errors in areas such as geologic modeling and geostatistics systems or estimated ore quality parameters (mineralogy, metallurgical and chemical grades, granulometry). These parameters can only be discovered when the production process is underway, after initial exploitation. As the uncertainties are in the production process, it is necessary to work with stockpiles of intermediate and final products. Mining companies normally produce raw materials to stock, not to order (Tardelli, Barbin, and Cesare de Tomi 2004).

- ***Capital demand and production costs.*** The amount of capital investment required for a mining project is usually extremely large. This depends on the following factors: the type of mineral or product, exploitation method, mine capacity, location, and other parameters. Large exploitations need billions of dollars for their development. Due to the high capital investment and the high percentage that represents fixed costs in total operational costs, many companies operate mines in 24 hours shifts, seven days a week, for a given production capacity. Moreover, the extraction costs of minerals generally increase along the life of the mines, as the work must usually go deeper and deeper, making the conditions of exploitation, conservation, and maintenance more difficult and causing longer transport distances.

- ***High-risk projects.*** The development of a mining operation has two important pre-operation period stages. The first is the search for mineral resources. This depends largely on technical, economic, and natural factors. In the second stage, a deposit must be found economically exploitable. The assessment is based on two types of factors: endogenous factors, including ore quality, ore quantity, available capital, technology to be used, distance to market, etc. and exogenous factors, including metal prices, tax policy, legal framework, etc. In addition to the risks associated with capital intensity and long project maturation periods, the mining business includes other types of financial risk. The investor can control some of these risks, and others not. In general, these risks can be divided into geological, operational, economic, and political risks.

- ***Indestructible products.*** Another differentiating feature of the mining industry is the indestructible nature of most metals. The immediate consequence is a growing secondary production, at the expense of the primary production. Recycling has numerous economic advantages, due to a smaller amount of energy, lower costs of production, reduced environmental pollution, availability in the potential customers market, etc. In the case of base metals - aluminum, iron, copper, and lead - and other minerals substances, the trend is to increase the recovery of waste or residues, which may affect market conditions and, consequently, the expectations of the development of new projects.

- ***Production planning mainly focused on efficiency.*** In the early part of the supply chain of the mineral raw materials industry, production planning is not driven by changing customer requirement like most manufacturing industries. Fundamentally, the business planning process is driven by the need of both medium- and long-term optimal exploitation of mineral resources (SAP AG 1999). This way, it is possible to get the maximum investment performance from the resources.

- ***Variability in quality.*** The inherent variability in quality and other geological parameters can also result in the variability of mine site revenue and the operating and capital costs that ultimately affect the returns on investment. Given this, one of the most important competitive advantages of a mining company is the high quality of its mineral deposits. However, Figure 2-1 shows that the average and minimum (cut-off) grades of all metals have decreased with time. In the 1990s, the average Cu grade was about 0.8% Cu and the lowest grade of a predominantly Cu deposit, although with Au coproduct, was 0.17% Cu and 0.79 g/t Au at Cadia Hill, New South Wales; Newcrest Mining Staff. This trend will continue to be influenced by demand and price (Laznicka, 2010).

Moreover, one of the criteria is project optimization, which focuses on maximize profits through the management of high and low-grade ores. By these means, the most profitable and usually, although not necessarily, the highest grade sectors are mined first and the unmined ore is of decreasing average value until the operation is no longer profitable. By optimizing resource quantities, the progressive falling-off in value of the material mined is controlled according to a predetermined strategy. Expressed in simple terms, a sum of money earned now has a greater value than at any time in the future. This strategy determines in part the reason why costs are increasing over time, because it is necessary to process a larger amount of mineral raw materials just to maintain the same levels of production. Therefore, there is a progressive decrease in productivity over time, which requires for its normal development intensive efforts in technology, innovation, and management.

- ***The mineral reserves are dynamic.*** Fluctuating world metal prices and technological advances determine the feasibility and profitability of extracting the ore reserve, thus causing the boundary between ore and waste, and between economic and sub-marginal deposits to change over time.

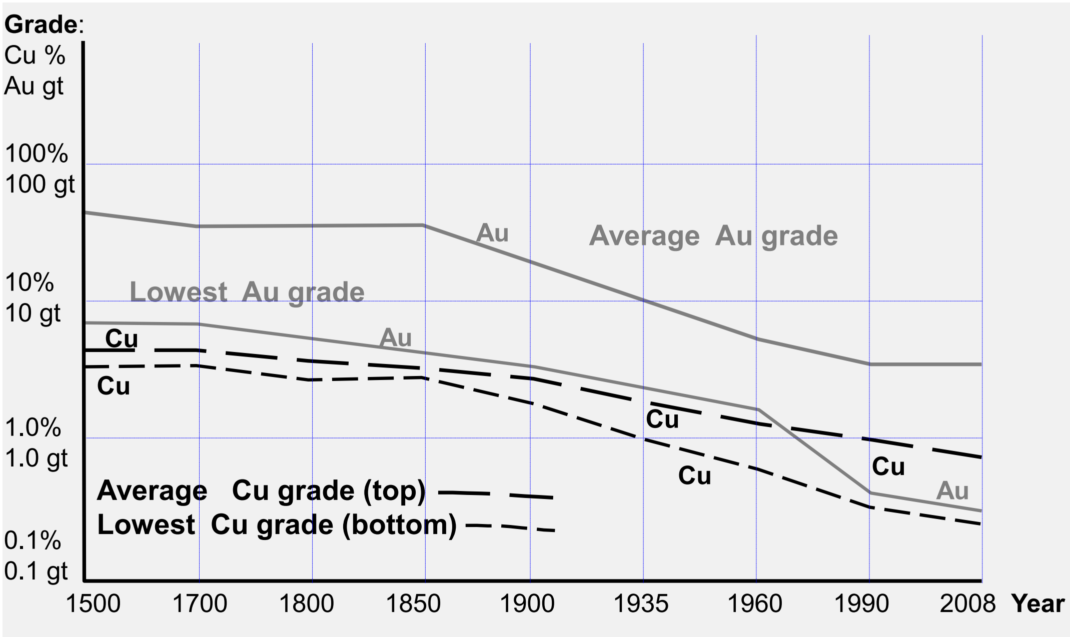

Figure 2-1. The grade decrease of gold and copper ores in the past half-millennium (Laznicka, 2010)

2.1.2 The mineral resource inventory as a stock of mineral blocks

In the mining industry, a geological 'block model' representing the ore body is developed. This model is similar to a mineral resource inventory that represents a stock of mineral blocks (see Figure 2-2). The block model employs geotechnical and geostatistical analyses by using geological information obtained through analyzing ore samples from exploration drilling, geological surveying, and actual mining production. In this way, it is possible to evaluate the ore body continuously throughout the life of a mine. Each block has certain predicted information characteristics such as ore grade, geological zone, and rock type. Planners use this information to create the basis of any subsequent mine-planning activities. Based on this knowledge about the mineral resource, it is possible to answer the following questions: which blocks are viable to be mined? In which sequence can they be mined? Planners need to answer these questions about mine planning and the phases related to this activity.

Figure 2-2 shows the phases of mine planning. The Life of Mine (LOM) plan embraces the current time until the year the final ore block is extracted. The long-term plan outlines the general direction of mining in the ore body, annual capital developments, annual production quantities, and costs. The short-term plan is more detailed, using defined development sequences, as well as production quantities and rates. The production plan is also detailed, including the crusher feed and head feed predictions. It can set the planned period by either shift or daily, although most mines would plan a week or month ahead at this level of detail (SAP AG 1999). This detailed level of planning requires tight integration into the geological systems.

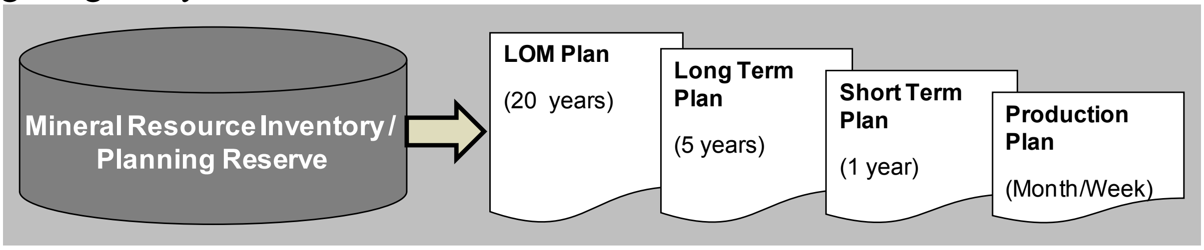

Figure 2-2: Phases of mine planning (SAP AG 1999)

2.1.3 The mine life phases: exploration, development, operation, and closure

Understanding the activities and behavior of processes over their complete mine life can potentially improve the early part of the supply chain, and thereby enhance the supply of mineral raw materials in the marketplace. The mines like people themselves, go through different stages: youth, maturity, and old age. However, unlike people, mines frequently revive or rejuvenate as a result of technological improvements, some discovery, etc. The timeline in the mine life can be occasionally indeterminate, and it is not possible to say that such a cycle is complete if there is still some possibility of new reserves discovery.

Between the beginning of the mine life and its closure, there is a set of characteristic phases that are reflected in Figure 2-3. The main phases of the mining are mineral exploration, mine development, mine operation, and mine closure (Natural Resources Canada 2006; Technological Geomining Institute of Spain 1997). These phases are the following:

Mineral Exploration		Mine Development		Mine Operation	Closure
Geo-science Research	Product (ore) Research	Design	Construction		

Figure 2-3: The mine life phases

- ***Mineral exploration.*** Every new mine starts as an exploration project. However, most exploration projects will not advance to become mines. Before a mining project exists as such and has its own life as an operation, it must go through the testing phase of its viability. At the feasibility stage of property development, exploration results have been sufficiently encouraging to justify starting engineering and economic studies. These studies investigate ways to develop the property as a technically and economically feasible, environmentally sound, mining operation. EMMMV (2010) indicates the following four main processes of exploration: evaluation of grade and tons, a feasibility phase, examining the production options, and the acquisition of the necessary rights. At a strategic level, the outputs are the exploration strategy, exploration projects, and quantification of a potential exploitable mineral resource. The outputs at tactical level are the mineral deposit evaluation report, quantification of a potential extension to known mineral resource, updated geological model, and expanded mineral inventory. At an operational level, exploration involves the day-to-day enhancement of the level of confidence in the geological model. The outputs at operational level are operational budget/updated short-term exploration plan, routine updated geological model, and definition of ore reserves (EMMMV, 2010).

- ***Mine development.*** EMMMV (2010) describes this important phase as focusing on all the activities needed to create a mining environment, for example, the entire infrastructure. At a strategic level, the outputs are the Long-Term Plan (LOM) and finance for the operational mining and beneficiation environment, up to and including trial mining and beneficiation to the desired level of performance. The outputs at tactical level are the medium-term plan, budgets and specific establishment projects, and commitment to a budgeted period. At an operational level, development involves the creation of further access to the ore body with the entire associated supporting engineering infrastructure. This is funded by operational budget (OPEX). The outputs at operational level are the detailed plan, budgets and execution of specific establishment projects, safe and environmentally sound access to the ore body and related infrastructure, facilities, and processing capabilities.

- ***Mine operation.*** This phase involves hiring, training, commissioning, production, and mine expansion. There are two types of mines: underground and open pit. Marketing and sales activities include client establishment and servicing. Production involves the extraction of ore, separation of minerals, and disposal of waste and shipment of ore/minerals. Additional sampling, drilling, planning, and mapping are required if a mine is to extend its useful life. Moreover, Macdonald (2007) indicates that most of the exploitations follow a specific sequence of operations because this determines the pattern of earnings and has a strong influence over valuation criteria such as present worth, internal rate of return, and pay back. One of the criteria is the project optimization, which focuses on maximizing profits through the management of high and low-grade ores. By these means the most profitable and usually, although not necessarily, the highest grade sectors are mined first and the unmined ore is of decreasing average value until the operation is no longer profitable. These factors account in part for increasing costs over time, because it is necessary to process a larger amount of raw materials just to maintain the same levels of production.

- ***Mine closure***. Due to the nature of mineral deposits, in most cases mine closure occurs because a mineral deposit has a finite life. The two most common causes of mine closure are a) depletion of the ore resource, and b) low commodity or metal prices, which make the mine operationally unprofitable. Other factors can also play a role, for example, long strikes and expropriations may cause closure of a mine for indefinite time periods. Therefore, determining (or predicting) the life cycle of a mining project is a complex task with some uncertainty, but forecasts are necessary for successful mine design and development.

In contrast with the deterioration phase of products created by manufacturing industry, for example a Television, the final phase of abandonment (mine closure) is not because consumers are not interested in the mineral commodity. In the business context of the mining industry, new mine projects must be established when one mine project begins the abandonment phases of mine life. A mining company requires a continuous stream of projects to survive, as shown in Figure 2-4. As project A and B begin their decline, new efforts (project C) must be developed for resource reallocation. In an ideal situation, these new projects will be established at such a rate that total revenue will increase and company growth will be clearly visible.

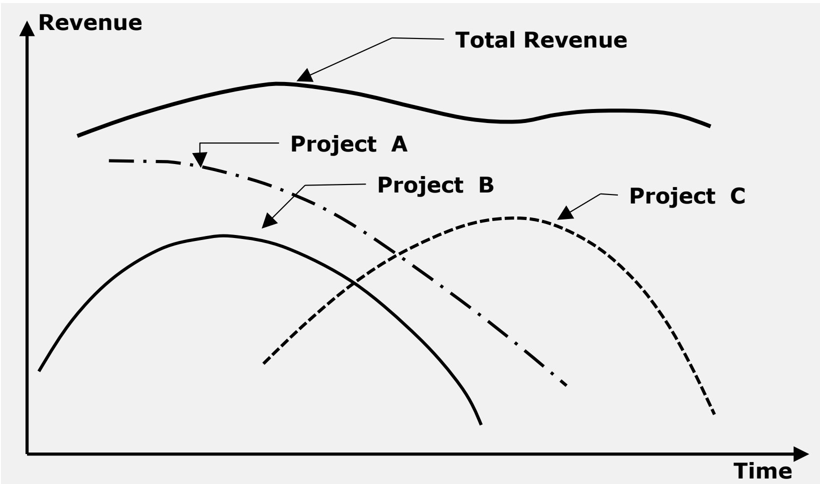

Figure 2-4. Constant launch of new mine projects (Adapted from Kerzner 2009, p.70)

The terminology of “new product development” is not applicable to the context of this mining industry because it is not possible to create a “new mineral commodity” which is different from the existing one. However, the term “new mine project development” has a similar meaning when used to indicate that a new mineral deposit must be developed to produce a product (mineral commodity). In this context, it is very important to understand that a mine project development is determined or influenced by the type of exploration activity.

Every new mineral deposit or mine has its beginnings as an exploration project. The degree of newness in a mine project depends of the level of complexity and risk of an exploration activity. Therefore, a mine project development can be a Greenfield mine project, a Brownfield mine project, or an Operational (on-mine site) mine project. In the next section these type of projects are described in more detail.

2.2 Types of mine projects: Greenfield, Brownfield, and Operational

Since every new mine has its beginnings as an exploration project, the exploration activity determines the type of mining project to be developed by the mining company. There are three types of exploration activity: Greenfields, Brownfields, and Operational (on-mine site).

- ***Greenfields exploration.*** It is also known as grassroots exploration, and refers to the activity undertaken in unexplored or incompletely explored areas. Its key purpose is to discover new mineral deposits in new areas and typically away from the immediate vicinity of existing mines. Greenfields exploration provides the foundation of the resources sector and is how all major mines begin. It is imperative to ensuring the discovery of new resources and maintaining a pipeline of new resource projects. Without ongoing Greenfields exploration activity, there is no opportunity to replace depleting resources (Hronsky, Suchmel and Welborn 2009, p.29). If the exploration is succesfull, the identification for this project for the next stages is a Greenfield mine project.

- ***Brownfields exploration.*** In contrast to Greenfields, Brownfield exploration conducts activities in areas where the mineral endowment of the area is already established. It aims to extend an existing mine's operating life and to take advantage of existing infrastructure. Brownfield exploration does not deliver more than incremental growth as existing mineral deposits are depleted (Hronsky, Suchmel, and Welborn 2009, p.29). If the exploration is successful, the identification for this project for the next stages is a Brownfield mine project. Brownfield exploration is lower risk in comparison with Greenfield exploration, and therefore the investments are lower in the development phase.

  Greenfields are high-risk, but high-reward projects that create long-term option value if new deposits are discovered. Brownfield exploration is lower risk, but is unlikely to deliver more than incremental growth, and the Brownfield exploration opportunities in any one location will ultimately be depleted. The success rate for exploration is extremely low for Greenfield exploration. Fewer than 1 in 10,000 mineral showings discovered actually become a mine (Prospectors and Developers Association of Canada 2006, p.6).

- ***Operational exploration***. This is done to expand a mineral resource that has already been found and developed on the property of an existing mine

(Prospectors and Developers Association of Canada 2006). At an operational level, exploration involves the day-to-day enhancement of the level of confidence in the geological model. The outputs at the operational level are operational budget/updated short-term exploration plans, routine updated geological models, and definition of ore reserves (EMMMV, 2010). If the exploration is done in the existing mine the identification for this project is an Operational mine project.

Mining represents one of the most important economic activities in many countries of Latin America. However, its dependence on global market conditions and the financial sector makes this business risky. The most important products in value and volume are oil, copper, bauxite, iron ore, gold, and silver. Thanks to massive mining, Latin America is a world leader in the production of iron ore (Brazil), copper (Chile), and silver (Peru). As well, it is listed among the major producers of molybdenum, lead, zinc, manganese, and tin in the world (Editec S.A., 2012).

Table 2-1: New mine projects – Greenfield and Brownfield in Latin America (Editec S.A., 2012)

Countries	New mine projects in Latin America			% Participation
	Greenfield	Brownfield	Total	
Chile	21	24	45	43%
Peru	22	3	25	24%
Argentina	17	0	17	16%
Brazil	11	4	15	14%
Ecuador	2	0	2	2%
Paraguay	1	0	1	1%
Total Projects	74	31	105	100%
% Participation	70%	30%	100%	

Organizations such as the Metals Economics Group (MEG) indicate that Latin America has dominated for the past three years in the discovery of potential sites for base metals and precious metals. A mining projects survey from 2011-2012 shows 105 new mine projects in Latin America (see Table 2-1). Of these, 74 are Greenfield and 31 are Brownfield. In total, there are 70% Greenfield mine projects and 30% Brownfield mine projects. Chile has 45 projects, which represent 43% of all new mine projects in Latin America. Of these 45 projects, 21 are Greenfield and 24 are Brownfield. Given the large number of projects, Chile is the world leader in new mining projects.

In comparison to other countries, the growth of mining production in Chile is based primarily on the development of Brownfield mine projects, i.e. in the development of new projects close to an existing mine. However in other countries, growth is based on developing projects in new districts, where there is no nearby mine. This is because Chile began many years ago in mining, and the other countries began many years after Chile. For instance, in Chile it is more difficult to find new mineral deposits in new districts in comparison with Peru.

2.2.1 Case example of a Brownfield project in Codelco-Chile

Codelco-Chile company is the world's largest copper producer and one of the most profitable companies in the industry. Codelco has the largest reserves and resources known on the planet, which represents the 9% of the planet. At current production rates, mining operations have an estimated useful life of 65 years. Codelco has US$31,645 billion in assets, and at the end of 2012 its equity totaled US$12,178 billion. Its main commercial product is Grade A copper cathodes. The other products that Codelco produces are: copper concentrate, molybdenum, anode mud, sulfuric acid, and copper rod (semi-finished product). In 2012, Codelco produced 1,758,000 metric tons of fine copper. This is equivalent to 10% of the 2012 global mine copper output. Additionally, the Company is one of the world's top producers of molybdenum; in 2012, it produced 19,676 metric tons. Copper sales in 2012 were to the following destinations: 59.8% to Asia, 17.9% to Europe, 11% to South America, and 10.2% to North America. Cathodes accounted for 76.9% of sales, copper concentrates 17.7%, and blister sales accounted for 5.5% of sales.

In the business context of Codelco Company, new mine projects must be established when one project begins the abandonment phases of mine life cycle. Figure 2-5 shows the production level in Codelco in 2021, with and without projects. If Codelco develops projects, the level of production is going to increase in 2021. In contrast, this production level is going to decrease dramatically in 2021 if Codelco does not develop new projects. This explains the importance of developing exploration activities for discovering new mineral deposits and then, developing the investments. Codelco needs to develop a Brownfield exploration to extend the mine life in the existing mining operations in the Codelco Divisions (districts). In addition, Codelco can increase the mineral reserves by doing Greenfield exploration in other districts, which are not close to the existing operations.

Table 2-2 shows information until September 2012 about the status of Codelco's five main projects (the structural projects). All these projects are Brownfield mine projects. El Teniente 'New Mine Level' is one of the projects with the highest production capacity per year. This project is analyzed in more detail in this section.

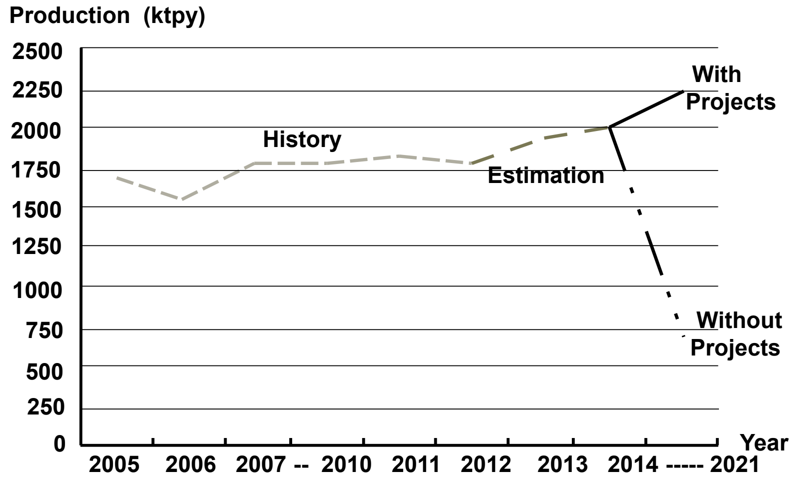

Figure 2-5. Codelco's output evolution (Codelco, 2013)

Table 2-2. Priority of mining projects execution (Codelco, 2012)

	MH	RT Sulphides Phase II	El Teniente New Mine Level	Chuquicamata Underground	Andina Phase II
Description	Open pit, concentrator and roaster	Open pit, concentrator and desalination plant	New level of extraction at El Teniente	Underground mine at Chuquicamata	Increase in capacity from 94.000 to 244.00 tpd
Capacity (tons of copper /year)	170,000 -	345,000	415,000	343,000	306,400
Pre-Production Investment (US$ million)	2,433	4,482	3,200	3,828	6,270
Status	In execution	In feasibility	In execution	In feasibility. Early construction first activities	In feasibility

The new mine project 'El Teniente New Mine Level'

Currently 'El Teniente' district is the world's largest underground copper mine that produces 403,616 metric tons of fine copper per year. It has been mined since 1905 and has more than 3,000 kilometers of tunnels.

As depicted in Figure 2-6, the district 'El Teniente' should close its operations in 2022 if a new investment project is not developed for extending the mine life. Furthermore, Figure 2-6 shows that the copper grade is decreasing in the current deposit, which increases the costs of exploitation of this deposit. The latter indicates that it must develop a new mine project with a better quality of mineral resources, near the existing operations. This new discovery is a result of a Brownfield exploration project. This new project is the 'El Teniente New Mine Level'.

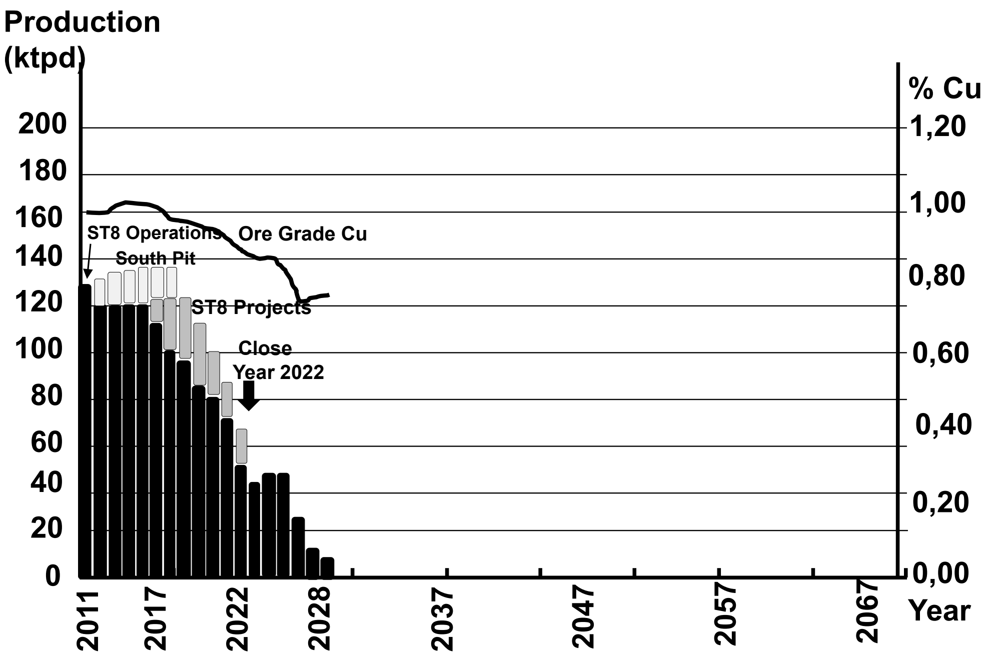

Figure 2-6. El teniente division without new projects (Codelco, 2011)

Figure 2-7 shows the New Mine Level (NML), which requires expanding the 'El Teniente' mine deeper into the hill (1,880m above sea level), and increasing the mine area an additional 2,050,000 m^2, ensuring the continuous operation of El Teniente Division. The NML project adds 2.02 billion tons of reserves, with a 0.86% copper grade and an average 0.022% molybdenum grade. The production is equivalent to more than 17 million tons of fine copper, over a period of 50 years in operation starting at the end of 2017, as shown in Figure 2-8.

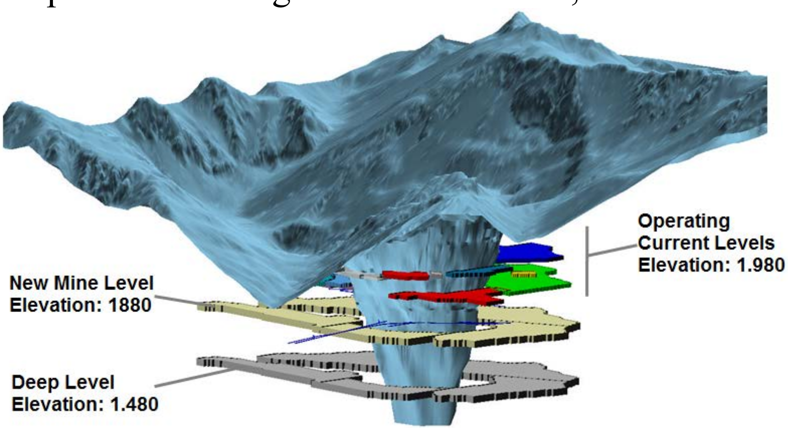

Figure 2-7. Description of the project: New Mine Level (Codelco, 2011)

Figure 2-8 depicts that The New Mine Level will maintain the existing capacity at El Teniente of 137,000 tons per day (t/d) of material, equivalent to around 415,000 tons per annum of fine copper. In addition, it leaves open the option, until 2020 to start the work required to produce 180,000 t/d.

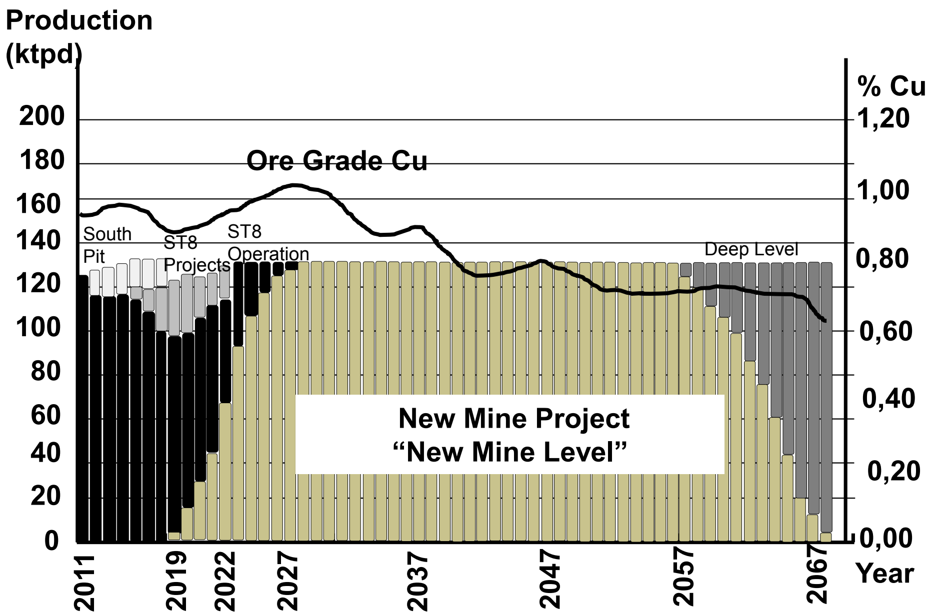

Figure 2-8. El teniente division with new projects (Codelco, 2011)

Time required to develop ‘El Teniente New Mine Level’ project in Codelco

The time required to develop an open pit mine project is less than an underground mine project. As an example of an underground mine project, Figure 2-9 shows the time for each stage of the New Mine Level El Teniente. This is an underground mine project, with a development time of around 19 years, from 1999 to 2018. The exploration process (exploration and feasibility studies) lasted around 12 years, from 1999 to 2011. The development process (investment phase) takes around 7 years, from 2011 to 2018. The transference of this project to the extraction process (operation phase) is estimated to begin in 2017 and this transference process is going to finish in 2018. After that, the extraction process is going to operate this project until the end of the mine life. This means the production is going to start in second semester of 2017.

Investment Decision
June-2011

PROCESSES	EXPLORATION PROCESS			DEVELOPMENT PROCESS	EXTRACTION PROCESS
STAGES	PROFILE	PREFEASIBILITY	FEASIBILITY	INVESTMENT	OPERATION
YEARS	1999-2006	2007-2009	2009-2011	2011-2018	2017-2018
METERS OF EXPLORATION	72.400 m	26.700 m	20.000 m	27.600 m	-

Figure 2-9. Investment project cycle of the Teniente Division (Codelco, 2011)

In addition, Figure 2-9 shows an estimated total value of 146,700 meters of exploration (samples) for this project, in the exploration process and the development process. Also, this is an underground mine project with large reserves of minerals and a high production level. This implies that the development time is longer than an open pit mine development of similar production level.

2.3 The processes of the mining industry

In an existing mine, the raw material is hidden under the surface of the earth in a mineral deposit. Some processes need to be performed prior to the extraction of the raw material and its transfer to the processing plant (see Figure 1-1). The sequence of processes required to obtain the raw material at the processing plant of the mine are indicated as follows.

- First, the exploration process identifies and selects the suitable blocks to be extracted, based on an estimation of its quality and parameters related to geo-metallurgical properties.
- Second, the engineering design process must create the drawings and technical specifications that allow access to the place where the blocks are located.
- Third, based on the information provided by engineering design, the construction process can commence its activities. For example, when starting excavation of an open pit mine, the construction process must remove millions of tons of sterile material covering the blocks. Subsequently, the construction process must continually build ramps and roads, according to the level of advancement of the development and exploitation of the mine. This is done because mobile equipment needs access to the place where the blocks are going to be extracted (drills, shovels, loaders, trucks, etc.).
- Fourth, once the blocks are in sight, the extraction process can commence its activities. The main role of this process is to extract the raw material from the mineral deposit. This means breaking mineral blocks in order to reduce the rock size and so that it can be transported to the processing plant. The extraction process produces useful mineral rock that is sent to the processing plant or temporarily sent to a stockpile. Sterile material to be transported as dumped waste is also produced. In most open pit mines, the amount of sterile material is greater than the amount of mineral rock.
- Fifth, the sequence of the processes listed above is repeated continuously during the mine life.

Given the above, it is clear that the extraction of raw materials from a mineral deposit in the mining industry is more complex than ‘sourcing’ of raw materials in other types of industries. Once the mineral raw material is obtained, the processing plant transforms this raw material into a product with a better added value (for example, copper concentrate 30% ore quality or copper cathodes 99.99% of purity). After that, the distribution process delivers these products to the warehouse in the ports before to deliver them to the customer.

In this section, the main processes of the mining industry are described. These are the sourcing process, the processing plant, and the distribution process.

2.3.1 The sourcing process in mining

The sourcing process includes the exploration, engineering design, construction, and extraction processes. Figure 2-10 shows the sourcing processes, which are part of the reference EM model for mining industry proposed by EMMMV (2010). Based on the EM model, the development process is split into two processes, the engineering design process and the construction process. Each of the processes is presented in this section.

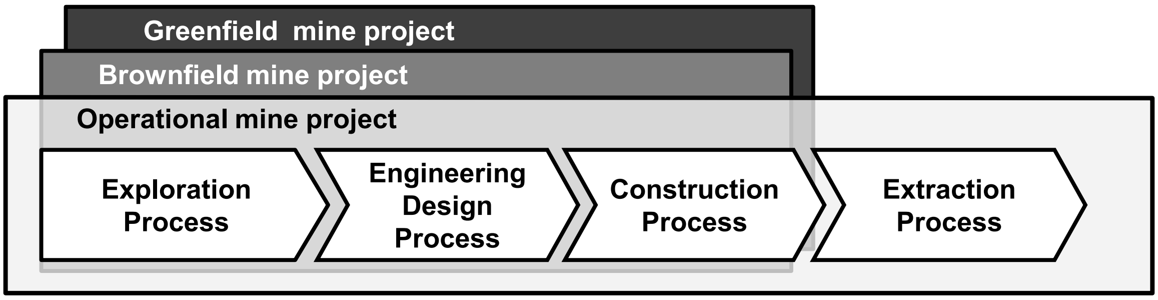

Figure 2-10. The sourcing process in mining industry (Adapted from EMMMV, 2010)

2.3.1.1 The exploration process

EMMMV (2010) indicates that the ‘exploration’ process includes the following sub-processes (see Figure 2-11). Each of these sub-processes can be part of a mine project (Greenfield, Brownfield, or Operational). These types of mine projects are explained in section 2.2.

- ***Prospect/Explore.*** Explore aims to locate the presence of economic deposits and establish their nature, extent, and grade. Exploration techniques include: geological surveys, geophysical prospecting (may be ground, aerial, or both), soil and grab samples, geochemical, boreholes, and trial pits, surface or underground headings, drifts, or tunnels. The term exploration is sometimes applied to this extension of the discovery work. The output for this process is the geological and mineralogical data with spatial attributes.
- ***Assess mineral resource.*** This process focuses on considering the attributes of structure, density, grade, and tonnage. The output for this process is a geological model used as the basis for mine planning.
- ***Examine production options.*** This process involves the production of a technical mine and beneficiation plan at an appropriate level of confidence. The process is focused on improving levels of confidence moving. The output for this process is the technical mine plan (i.e. volume and product profiles over time).

- ***Develop business plan.*** This process is focused on the analysis (including options) and creation of the financial viability plan associated with the establishment of a particular site in order to make a go/no-go decision. The output for this process is the documented business case to enable decision making. On mine site/ Operational includes the production forecast and budget (for operational costs).
- ***Acquire.*** This process involves the securing of all the necessary rights applicable to mine a particular site, including mineral rights, Environmental Impact Assessment (EIA), approved environmental plan, surface rights, access rights, approved social and labor plan, and water (riparian) rights. The output for this process is secured rights and sufficient information to make investment decisions.

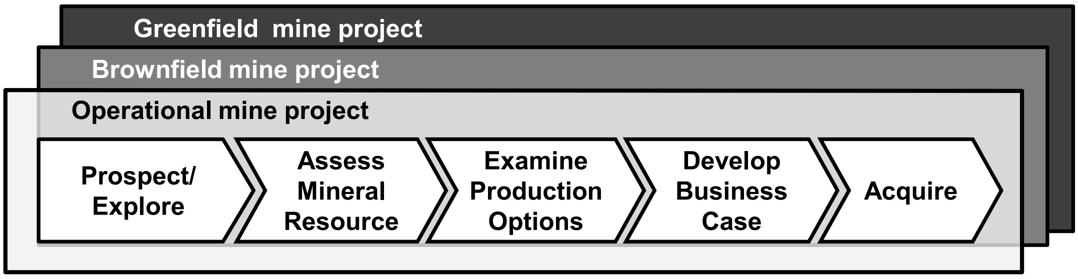

Figure 2-11: Sub-processes of the exploration process (EMMMV, 2010)

2.3.1.2 The engineering design process

There are two key processes as part of the development process, the engineering design process and the construction process. The engineering design process has an important participation in the development phase of a mine project (Greenfield or Brownfield), but it also has a participation at an operational level of a mine project. The engineering design for an operational project is done to expand the exploitation of mineral resources in an existing mine which is in operation.

EMMMV (2010) indicates that the ‘engineering design’ process includes the following sub-processes (see Figure 2-12). Each of these sub-processes can be part of a mine project (Greenfield, Brownfield, or Operational). These types of mine projects are explained in section 2.2.

- ***Collect engineering design criteria.*** Obtain and confirm all relevant technical parameters and standards that will be required to produce the requisite designs. The output for this process is the engineering design criteria.
- ***Produce conceptual engineering designs.*** Produce alternative designs based on relevant criteria. The output for this process is the conceptual engineering designs.
- ***Select final engineering designs.*** Consider and choose the appropriate design. The output for this process is the selected final design.

The results of the engineering design process are the final (approved) engineering design, and the final mining layout designs, including all mining technical inputs (e.g. ventilation and rock engineering). These results allow initiating the construction process.

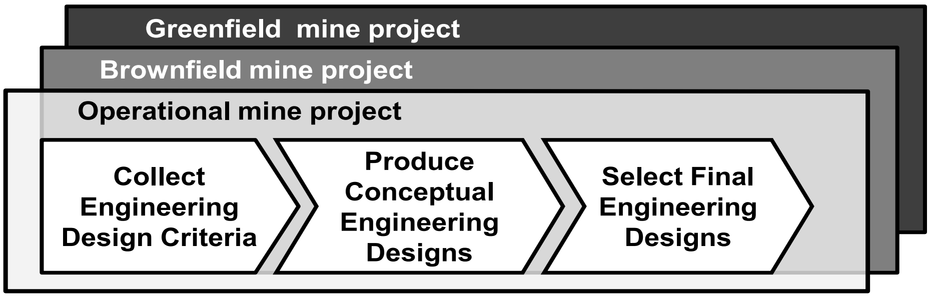

Figure 2-12. Sub-processes of the engineering design process (EMMMV, 2010)

2.3.1.3 The construction process

EMMMV (2010) indicates that the ‘construction’ process includes the following sub-processes (see Figure 2-13). In addition, each of these sub-processes can be part of a mine project (Greenfield, Brownfield, or Operational).

- ***Develop operational capability.*** Acquire and deploy the necessary human resource, materials, and equipment to execute the project. The output for this process is the execution team and resources.
- ***Build mineral resource/ Reserve extraction capability.*** Create access to the orebody and establish the necessary materials-handling infrastructure (e.g. shafts, haulages, cross-cuts, rolling stock, hoists, conveyors, waste dumps, and tailings dams). The output for this process is the accessible ore-body.
- ***Build beneficiation capability.*** Create the necessary processing capability (e.g. concentrating, smelting, and refining plants). The output for this process is the processing plant(s).
- ***Build facilities.*** Create necessary operational infrastructure (e.g. roads, rail, office blocks, housing). The output for this process is the facilities and infrastructure.
- ***Deploy utilities.*** Establish services networks to support production activities (e.g. electrical power, water, compressed air, chilled air). The output for this process is the utilities networks.
- ***Commission.*** In the same way, EMMMV (2010) indicates that commission sub-process is split in two sub-processes: Run pilot operation and Handover to operations.

  -Run pilot operation. Prove, on a trial basis, the mining and processing capabilities against the design specifications, including trouble-shooting, before commissioning. The output for this process is the proven operational capability (i.e. project delivered to specification).

-Handover to operations. Formal transfer of an operational mining environment (i.e. custodianship and accountability) from the project team to operational management. The output for this process is the operational mine.

The results of the construction process can be the constructed facilities and infrastructure operational mine site, the operational beneficiation site, the accepted operational environment (mine) - as per specification, and the signed acceptance certificate. These results allow initiating the extraction process operations in the case of a Greenfield or Brownfield mine projects.

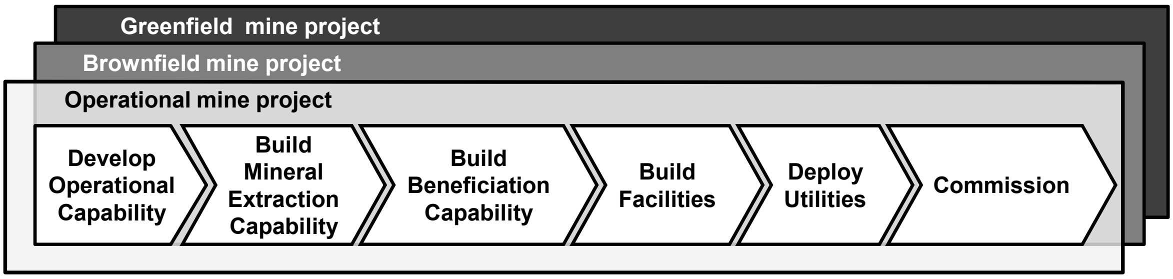

Figure 2-13. Sub-processes of the construction process (EMMMV, 2010)

2.3.1.4 The extraction process

The analysis starts with the definitions and descriptions of this process using the reference EM model proposed by EMMMV (2010). This model defines the extraction (exploit) process as follows: “For a given mine type, rock type, and mining type, this process includes the breaking and removal of 'rock'. Rock is a generic term used to describe all types of mineral resource host material. It also includes the transport of the broken rock and waste material from the working place to the plant and/or stockpile.” Moreover, it is also relevant to indicate that there are different rock types (hard or soft) and appropriate mining methods in the extraction process exist for all types. Table 2-3 depicts the classification of mining methods for surface and underground mine types.

Table 2-3. Surface and underground mining methods (EMMMV, 2010)

Mine Type	**Surface**				**Underground**				
Rock Type	Hard		Soft		Hard		Soft		
Mining Type	Open Pit	Glory Hole	Placer	Open Pit	Tabular	Massive	Coal	Other	Solution
Mining Method	Single bench		Panning & sluicing	Single bench	Self supported	Self supported	Self supported	Self suppor-ted	Frasch
	Multi bench		Hydrauli-cking	Multi bench	Supported	Supported	Supported	Suppor-ted	Hot water
	Quarry		Dredging	Strip Mining		Caving			Leaching

As shown in Figure 2-14, the extraction process includes two main sub-processes: ‘break rock’ and ‘remove rock’. EMMMV (2010) defines the ‘break rock’ process as: “For a given mine type, rock type, and mining type, this process includes having access to the ore body, mining the ore body, and extending any necessary infrastructure.” In the same way, ‘remove rock’ is defined as: “For a given mine type, rock type, and mining type this process includes classifying, moving (transporting), and stockpiling the broken material. Rock can be moved by various means, for example: hopper tramming, hoisting, conveyor belt, hauling and trucking (dump trucks), train/ship/barge, and front-end loaders.” The transported rock can go into the processing (beneficiation) plant, or waste dump, or to a stockpiled ore.

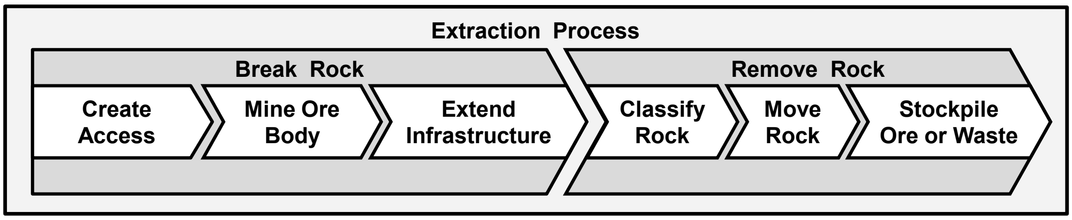

Figure 2-14. Sub-processes of the extraction process (EMMMV, 2010)

The break rock process includes the following sub-processes.

- ***Create Access.*** Develop and establish new entry points to support the mining activity. The output for this process is the exposed mining face.
- ***Mine Ore Body.*** Extract/liberate desired material from the deposit. The output for this process is the mined material, waste, and resultant voids.
- ***Extend Infrastructure.*** Establish facilities and utilities necessary to sustain a given production profile. The output for this process is the extended infrastructure.

The sub-processes for the remove rock process:

- ***Classify Rock.*** Identify and separate desired material from waste. The output for this process is the classified ore and waste.
- ***Move Rock.*** Transfer material from source to destination. (e.g. backfill, stockpile, crushing, hopper, silo). The output for this process is relocated ore and waste.
- ***Stockpile Ore or Waste.*** Temporary storage of desired material or waste. The output for this process is stockpiled ore and dumped waste.

2.3.2 The processing plant

These processes are part of the reference EM model for mining industry proposed by EMMMV (2010). The processing plant focuses on the processing of ores for the purpose of regulating the physical properties of the desired product (e.g. size), removing unwanted constituents, and improving the quality, purity, or assay grade of a desired product. EMMMV (2010) indicates that the 'processing plant' includes the following sub-processes (see Figure 2-15).

- ***Handle Material.*** This process involves the collection of all material required for processing, and if needed, includes the blending of material (mixing materials from different sources). It also involves getting the material ready for input to the plant and subsequent treatment.
- ***Treat Material.*** This process focuses on liberating the mineral/metal from the ore (including crushing and/or grinding), concentration of the desired material (adding of re-agents), separation and removal of waste, and recovery of the desired final material (drying, sizing etc). The process also includes all the associated chemical and metallurgical processes, storage of waste, and discarding of tailings or waste product. Typical processes include: crushing, milling, floatation, magnetic separation, gavimetric separation, leaching, filtration, cementation, calcination, sizing, sorting, blending, washing, drying, roasting, and smelting.
- ***Refine Material (purification process).*** The process(es) by which the material is treated further in order to separate the desired material(s) from the unwanted matrix (gangue) material and so generate a purified product. Typical processes include: electrowinning, solvent extraction, ion exchange, dissolution and selective precipitation, osmosis, leaching, gravimetric separation, magnetic separation, adsorption, calcination, cementation, distillation, filtration, washing, roasting, drying, reduction, oxidation, and smelting.
- ***Handle Product.*** This process includes the classification, blending, packaging, and storage of saleable materials, including by-products.

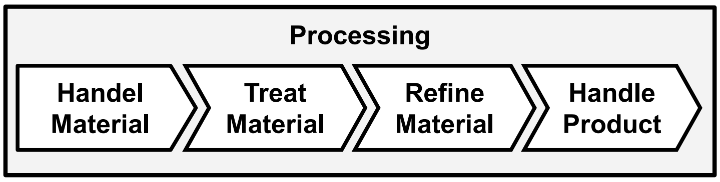

Figure 2-15. Sub-processes of the processing plant (EMMMV, 2010)

2.3.3 The distribution process in mining

The distribution process focuses on dealing with customers in order to dispose of the product and attain revenue. This process also includes product marketing. EMMMV (2010) indicates that the 'distribution process' includes the following sub-processes (see Figure 2-16).

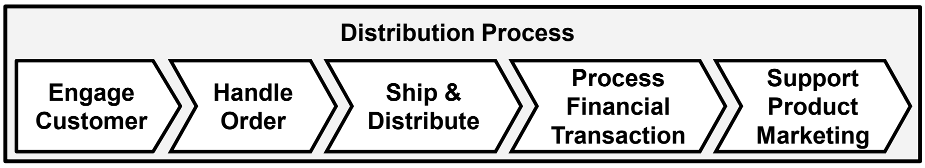

Figure 2-16. Sub-processes of the distribution process (EMMMV, 2010)

- ***Engage Customer.*** This process focuses on the interaction with the customer, including the necessary information to identify and interact with the customer.
- ***Handle Order.*** This process focuses on obtaining the correct information regarding the specific products and associated quality and quantities ordered so that the organisation is in a position to fulfil the order and analyse trends regarding customer preferences.
- ***Ship and Distribute.*** This process executes the shipping and distribution of products ordered to the correct customers.
- ***Process Financial Transaction.*** The financial transaction that occurred as a result of an order being fulfilled needs to be completed in order to recognise the revenue and/or follow up on the debt.
- ***Support Product Marketing.*** Product marketing requires information from customers and orders as well as input of a strategic nature to ensure that the correct products are marketed to the correct customers in line with the organisational strategy.

2.4 Challenges for mining industry

Taking into account the unique characteristics of the mining industry and its processes described in this chapter and the constraints imposed by the countries in which this industry must operate, this industry faces several challenges. These are some common challenges for this industry in the world. In a general context, its competitiveness not only depends on variables related to management focused on increasing efficiency and productivity. Its competitiveness depends on at least four dimensions that occur in the country where a mining project is developed. The dimensions are the quality of the mineral deposit, productivity, institutional regulatory framework, and the social context of the country (IIED and WBCSD, 2002). These dimensions are very important, especially when companies make new investments in Greenfield and Brownfield projects in a given country, due to the level of risk involved in these four dimensions. Once a mining project comes into operation and there are no outstanding issues regarding the regulatory framework and the social context, the first two dimensions become the focus for the mining industry. An overview of these four dimensions is as follows:

- ***The quality of the mineral deposit.*** This refers to the ore grade of the mineral deposit, with a good or bad quality. In addition, it is considered the extraction capacity to obtain these minerals. A good quality deposit represents a very important competitive advantage for a mining company.
- ***Productivity.*** Shaffer (2014) indicates that regarding productivity in mining, with most of the easily accessible high grade ores almost tapped out, companies are faced with the challenge of either mining low grade ore bodies or mining in difficult or remote regions. In the case of low grade ore bodies, it is very important to remove as much of the desired ore from the mined material as possible in order for the mining operation to remain economically

feasible. The higher grade ores that are still minable are often located in regions of the world that are difficult to access because of climate, altitude, or unstable social situations. In addition, there are critical inputs related to the costs that affect the productivity of mining projects such as energy costs, and costs of labor, among other inputs. Regarding the efficiency of investment in mining projects, there are significant differences between countries. There are countries where it is required to make further additional investments due to the lack of infrastructure such as roads, ports, schools, homes, hospitals, etc.

- ***The institutional regulatory framework***. This represents the difficulty in obtaining permits, and to what extent the law is respected. This delay in the permits represents a delay in the operation of the mines. For instance, approval of environmental permits takes more time in Peru than in Chile.
- ***The social context.*** This represents the difficulty of doing business in the localities where mining companies finally have to operate the mine. In some countries, large conflicts with local communities that prevent developing a mining project are created. In most cases, conflicts are related to water use in agriculture and livestock. Water is a scarce resource in some countries, and is necessary for mining processes.

By combining the above dimensions, the mining industry decides where to make new investments in mining projects. In addition, an important input to consider is the cost of labor, as this affects the productivity and competitiveness of mining projects. For example, the highest labor cost is in Canada and Australia compared to countries in South America and Africa. Africa has the lowest labor costs, but some African countries are difficult places to develop mining projects due to the weak institutional regulatory framework.

Some countries have advantages in the quality of their mineral deposits and productivity due to lower operating costs, which compensates the higher investments required in infrastructure. However, the dimensions of the institutional regulatory framework and the social context of those countries determine the final decision.

The mining industry requires fulfilling with many legal requirements, social responsibility, environmental, safety, and quality to become operational (IIED and WBCSD, 2002). It is an industry of high investment and it depends on the international prices of metals. Thus, in an existing operational mine project, the only way to be internationally competitive is through proper management of productivity with the existing mineral deposit and considering the environmental and social impact. Chile is a leader in mining in South America (Editec S.A., 2012) and it is a good example for presenting the specific challenges that mining companies must face in this country oriented to mining project development.

2.4.1 Challenges for the mining companies in Chile

The favorable growth potential of the country's mining industry, given its attractive mineral resource base, also poses significant challenges for companies, the Chilean State, and the local communities in which mining operations are inserted. Some of the challenges that mining industry are facing are the quality of the mineral deposits, productivity and costs, energy management, water management, and the social context.

- ***The quality of the mineral deposits.*** Regarding geological conditions, the mines are ageing and this implies lower ore grades (lower quality of mineral deposits), deeper mines, and longer hauling distances. The ore grade decline has direct and indirect implications for mining operations. Some of the reasons for this are the following: remote mines, capital cost escalation, and operational cost escalation.

  Remote mines. Increasing the need to go to remote areas in order to find larger and better deposits. As a result, remote and automated operations are required, and employee retention in those areas is more difficult.

  Capital cost escalation. Exploring in a remote location with a low ore grade impacts the cost of new projects since it requires more intense and complex operations for mineral extraction and beneficiation.

  Operational cost escalation. A more complex mining operation will affect operational costs throughout the process ranging from energy to maintenance. Any mine operation with low quality is by nature much more ‘process intensive’ since it requires more from the mine and its unit operations to get the same amount of minerals as a high ore grade mining operation. Such operations must work at optimum capacity to be as feasible and profitable as possible through planning, scheduling optimization, process optimization, energy efficiency, and water efficiency.
- ***Productivity.*** Mining in Chile is facing rising production costs. As ore grades decline, electricity costs and wages increase, which is not in accordance with productivity growth. The average cost in Chile rose 46% in five years, while costs in the rest of mining countries increased by only 25% in the same time period. In this scenario, the process efficiency and the use of critical resources, combined with increased productivity and proper management of costs remains a central challenge for the industry. Moreover, water is a key resource to the mining sector, particularly considering that most of the operations are located in areas of water scarcity. Water scarcity limits the amount of ore that can be processed, so some mining companies are beginning to use seawater, thereby incurring higher costs. Improving efficiency in the use of this resource is the main challenge for the sector.
- ***The institutional regulatory framework.*** Chile is considered a country oriented towards the exploitation of minerals. In addition, Chile is considered a country where there is clear institutional regulatory framework that contributes to transparency for the approval of environmental permits.

- ***The social context.*** Undoubtedly, what made the country's agenda in recent years has been the increasing social unrest. The society mobilizes against issues of common interest and localities demand greater corporate accountability against their environmental impacts, and greater commitment and contribution to the development of the host localities.

While Chile has higher energy costs that affect the productivity of the mining industry, Chile remains more competitive compared to other countries in the dimensions of the institutional regulatory framework and social contexts. In these dimensions, Chile has major advantages over other countries in South America and some countries in Africa.

Minerals and metals are relatively difficult and expensive to extract. The process is capital-intensive, not only financially but also in terms of energy consumption, land use, and water extraction, so the environmental and social impact is of growing concern.

2.4.2 Challenges for mining under natural resource scarcity

If we want to understand the future supply of mineral resources, we must consider the cycle of supply and demand (Vial, 2004). This cycle is driven mainly by the price of minerals or metals, although it should be noted that other aspects, such as increased environmental and social awareness, are playing an increasingly important role. As announced by almost all analysts, the world population is growing faster than at any other time in history, and consumption of minerals increases faster than the population growth, so long as new consumers enter the mineral market because of increasing quality of life. Therefore, it is very important to understand that there is an increasing scarcity of nonrenewable and renewable natural resources, such as energy, water, and minerals. For instance, scarcity of water is currently a relevant challenge for mining companies in Chile. The interrelationships between these resources are strong, meaning that both the causes of scarcity and the solutions are complex. Schoolderman & Mathlener (2011) indicates that there is a fine line between 'just in time' and 'just not there', which for a manufacturing company in a global supply chain may mean a serious problem.

There is a survey study about the impact that minerals and metals scarcity is likely to have on seven manufacturing industries (Schoolderman & Mathlener, 2011). This study focused on critical minerals and metals that are important to the operations and supply chains of these companies and to the economies of the countries and regions in which they operate. In this study, senior executives were interviewed in many of the leading organizations that are central to the future growth of these industries to gauge the relevance and effects of this scarcity. It was found that the supply of many minerals and metals is struggling to keep up with rapid increases in consumption, resulting in price hikes and delivery delays.

One important suggestion of this study is that efficiency and collaboration through the supply chain would help address this issue. For a large majority of the companies interviewed, efficiency and collaboration throughout the supply chain are seen as essential to responding to the risk. While the effects of scarcity can cause stress at any link of the supply chain, it is especially evident as you move down the supply chain. For all manufacturers currently using mineral raw materials in their value chain, the latter are essential for production.

Seifert & Wüst (2009) highlight that all value-added processes from cooperation network start with the purchase of raw materials. They pointed out that without reliable access to the necessary raw material, the client's needs cannot be fully met, and network competitiveness from the whole cooperation network is at risk. They identified the purchaser as the converter, who has to acquire raw materials to offer the cooperation network the appropriate resources. However, they mention that mineral raw materials suppliers, in the main, are not well integrated in the supply chain. Considering the aforementioned information, the challenge is to make the mining industry an active partner in the supply chain. The purchase situation of higher risk, is why building an integration with the mining industry would help reduce uncertainty and perceived risk.

Supply chain integration into the mining industry can help to optimize the total supply chain performance rather than optimizing its component parts, resulting in a better overall outcome (Accenture, 2007). Because the mining industry can in fact be considered the first supplier for the whole supply chain, such integration seems beneficial for both sides. An improvement in the mining industry processes can generate an improvement in other processes downstream in the supply chain.

2.4.3 Challenges under the dimensions of quality and productivity

In analyzing the current challenges facing the mining industry, the dimensions related to quality of the deposits and productivity prevail as those with a higher incidence in the competitiveness of a mining company operating in a given country. This is because the dimensions of regulatory framework and the social context of a country affect more or less equally any foreign mining company that has operations in the same country. Furthermore, if we add to that the challenges facing the industry in the future due to the scarcity of natural resources, we can infer that the sourcing process faces the biggest current and future challenges of this industry. This process faces the biggest challenge because it has a greater interaction with nature in comparison with the processing plant and the distribution process of a mining company. The sourcing process embraces exploration to find new mineral deposits, engineering design process to study ways how to access to the mineral resources, the construction process to create the access to these mineral resources, and the extraction process to extract that resource.

Table 2-4 shows clearly how the unique characteristics of the mining industry greatly affect the sourcing process in this industry compared to other processes. This is demonstrated by the allocation of each characteristics of those processes in the mining industry, where it has greater influence. To estimate the influence on each processes, the support of some experts was used. The criteria considers the allocation of a weight ponderation of equal importance to each process where this characteristic is applicable. In the summation of each column, the sourcing process has accumulated a total of 25 allocations, as this process includes the processes of exploration, engineering design, construction and extraction. These allocations represent 73% of total allocations. Given the above, the processing plant reaches 18% and the distribution process only 9% of assignments. Therefore, under the criterion used to assign each characteristic to each process, the sourcing process meets the major challenges of this industry.

Table 2-4. Mining processes assigned to the unique characteristics identified

Mining industry characteristics	Sourcing process				Proce-ssing	Distri-bution
	Exploration	Eng. design	Cons-truction	Extrac-tion		
Location of deposits	X					
Project development time	X	X	X			
Depletion of natural resources	X					
Impact on environment and high waste/product ratio				X	X	
Uncertainties of estimation	X	X	X	X	X	X
Capital demand (higher)			X			
Production costs				X	X	
High-risk projects	X	X	X			
Indestructible products	X					
Production planning mainly focused on efficiency				X	X	
Variability in quality	X	X	X	X	X	X
The mineral reserves are dynamic	X	X	X	X	X	X
Total	8	5	6	6	6	3
Total (%)	23.5	14.7	17.6	17.6	17.6	8.8

In addition, with the purpose of highlighting the importance of the sourcing process in a real case, the opinion of an ex-CEO of Codelco-Chile company is presented (Lasnibat, 2006). The Codelco-Chile company is the world's largest copper producer in the world. The ex-CEO believes that exploration, engineering design, and construction processes provide the highest added value in the value chain of a copper mine company in Chile. He says that the difference in a mining company is the resources available in the mineral deposit. If ore reserves are depleted, there is no business. Therefore, it is most important to have good mineral reserves and good geological models that aim to maximize the present value. He indicates that processing and distribution processes in mining have similarities with other processes of manufacturing companies.

Given the above, the sourcing process should be the focus of attention of the mining industry to face current and future challenges. Any improvement in this process has a major influence on improving processes downstream in the supply chain. Therefore, in the next chapter, an analysis in greater detail of this process from the point of view of the supply chain is done, and then is compared with the manufacturing industry. Considering the results of this analysis, the standardization of the sourcing process by using standard frameworks of manufacturing industry as SCOR and DCOR models is studied in chapter 4.

2.5 Summary

One of the most important characteristic of mining industry is the fact that the main raw material – the ore – originates from the mineral deposit. This is one of the reasons why the quality of the deposit is one of the most relevant characteristics that affect the productivity and competitiveness of this industry. The mineral natural resource limitation determines the mine life phases and creates the need for new mine projects development. A mine project can be Greenfield or Brownfield; they are initiated in the exploration phase of a mine. Instead, an Operational mine project starts during the operation phase of an existing mine.

Given the unique characteristics of the mining industry and the constraints imposed by the countries in which this industry must operate, this industry faces several challenges. Its competitiveness depends on variables such as mineral deposit quality, productivity, institutional regulatory framework, and the social context of the country. The amount of risk involved in any of these variables is important to the success or failure of mining project, whether Greenfield, Brownfield, and Operational projects. Minerals and metals are relatively difficult and expensive to extract. The process is capital-intensive, not only financially but also in terms of energy consumption, land use, and water extraction, so the environmental and social impact is of growing concern.

In thinking about future supplies of mineral resources, we must consider cycles of supply and demand. These cycle are driven mainly by the price of minerals or metals. Therefore, it is very important to understand that there is an increasing scarcity of nonrenewable and renewable natural resources, such as energy, water, and minerals. This scarcity may affect the entire supply chain. The efficiency and collaboration through the supply chain would help address this issue and respond to the risk. Thus, the mining industry must be an active partner in the supply chain with greater motivation to improve the performance of its processes. The improvement in the performance of mining processes can generate an improvement in the performance of other downstream processes in the supply chain. However, the sourcing process faces the biggest current and future challenges in the mining industry. Any improvement in this process has a major influence on the supply chain.

3 Comparing mining industry and manufacturing industry from a supply chain perspective

Various definitions of a supply chain have been offered in the past several years as the concept has gained popularity. According to the American Production and Inventory Control Society - APICS, the supply chain is:

- the processes from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies; and
- the functions within and outside a company that enable the value chain to make products and provide services to the customer (Cox, Blackstone, & Spencer, 1995).

Other authors expand the definition, embracing reverse logistics, "green logistics," covering "from the source of raw materials to the final product and its potential recycling and re-use" (Tan, 2001). Supply Chain Council (1997) dictates that supply chains: "encompass every effort involved in producing and delivering a final product, from the supplier's supplier to the customer's customer".

In addition to defining the supply chain, several authors have further defined the concept of supply chain management. There is no consensus when it comes to defining SCM. Some authors view SCM as: a shared endeavor (Supply Chain Council, 1997), a strategy (Tan, 2001), a management approach (Metz, 1998), a network of organizations (Christopher M. , 1994), integrative function (Council of Logistics Management, 2003), business process integration (Lambert D. , 2004).

Although there is no consensus on SCM definition, the latter definition is chosen because it is focused on the business processes integration and is more suitable to the requirements of this research. This is the definition of SCM developed and used by the members of The Global Supply Chain Forum: "Supply chain management is the integration of key business processes from end-user through original suppliers that provides products, services, and information that add value for customers and other stakeholders" (Lambert D. , 2004).

According to the above definition, the role of the mining industry in the supply chain is to find, delineate and develop mineral deposits and then to extract, process, and sell the raw materials derived from these deposits. Consequently, the mineral deposits are a central point of the mineral supply process in the mining industry. The physical existence of mineral deposits in nature and the demand of mineral raw materials in the domestic or global economy are the basic incentives for mineral supply in the supply chain. In other words, what drives this industry is the existence of a market demand of mineral raw materials.

The sourcing process of mining industry has been introduced as one of the most critical challenges for mining industry. For a better understanding about the behavior of this process, a comparison between the sourcing process in mining industry and in manufacturing industry under the supply chain perspective is required. This comparison contributes to finding the main similarities and differences between the processes of mining and manufacturing. In addition, a gap between the standard model used in mining and the standards model used in manufacturing can be identified.

3.1 The supply chain network structure

The supply chain will look different depending on a company's position in it (Lambert D. , 2008). The horizontal structure and the horizontal position of the focal company in the network are essential for the description, analysis, and management of a supply chain (see Figure 3-1). The horizontal structure refers to the number of tiers in the supply chain. This can be long or short, it depends of the existing number of tiers. For a focal company positioned in the middle of the supply chain (see Figure 3-1), for example a consumer goods manufacturer or an automotive company, the supply chain looks like an uprooted tree where the roots are the supplier network and the branches are the customer network. In the case of the network structure for the automotive industry, this is very long. The auto parts are manufactured in various sites in the world by several suppliers, which send their products to assembly centers of the main cars' subsystems. Then, these products are moved over long distances for the final assembly of the vehicle. Corresponding to the relative horizontal position of a company within a supply chain, a company can be considered a first supplier or an end consumer, or somewhere between these extremes of the supply chain.

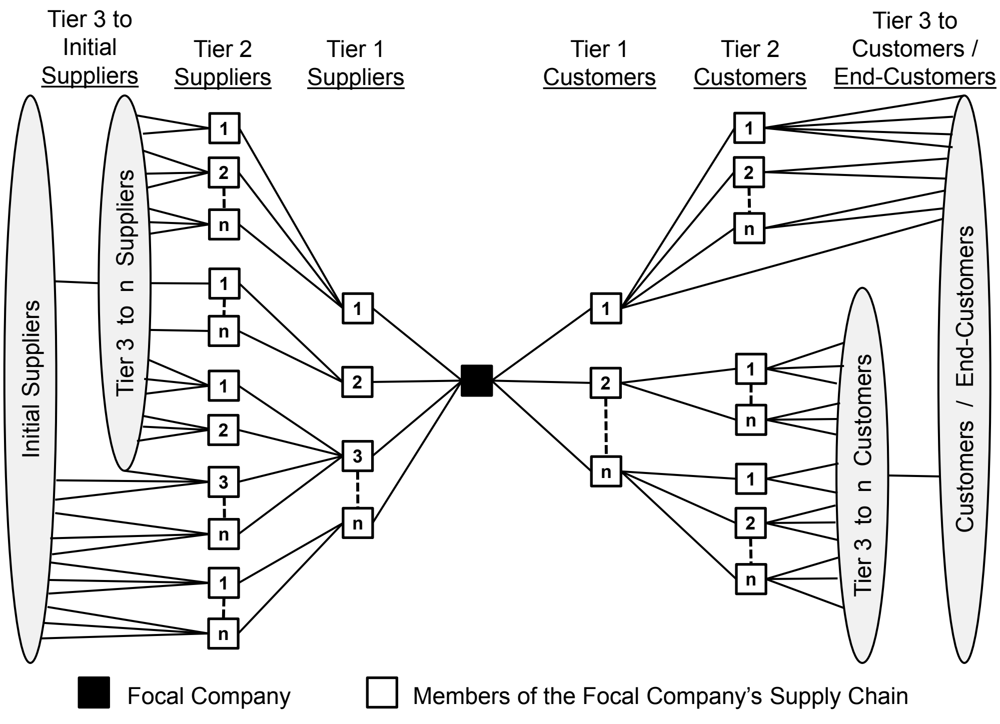

Figure 3-1: Supply chain network structure (Lambert D. , 2008)

The position of the focal company determines a certain number of tiers and a number of suppliers for each tier. Each of these suppliers supply critical raw materials to the next company (customer). However, a focal company that is positioned at the early part of the supply chain, i.e. Initial Suppliers in Figure 3-1, does not have suppliers to obtain critical raw materials. Consider a typical mining company that obtains its critical raw material from a mineral deposit. The supplier of raw materials for this company is the mineral deposit, which supplies non-renewable natural resources to this focal company. Therefore, the sourcing process for a focal company located in the early part of the supply chain is different when compared with another focal company positioned in another tier in the supply chain.

In a typical focal company with a network of suppliers, supply chain management is about relationship management. Each link in the supply chain needs to be managed to achieve a good performance and competitiveness in the supply chain. However, to better understand the difference between a focal company located in the early part of the supply chain and a focal company positioned in another tier, a comparative analysis of the characteristics of the products and processes in a make-to-stock (MTS) supply chain for each is needed. In the next section, this issue is discussed in more detail.

3.2 Characteristics of products and processes in a MTS supply chain

Euthemia Stavrulaki (2010) indicates that products can be produced with one of four distinct supply chain structures: make-to-stock (MTS) or build-to-stock (BTS), assemble-to-order (ATO), make-to-order (MTO) or built-to-order (BTO), and design to order (DTO). He proposes a framework based on identifying four representative supply chains that are appropriate for different products depending on the product's characteristics. Moreover, he indicates that the proposed framework is compatible with the SCOR model. Each supply chain structure is appropriate for different products based on their demand characteristics. Each supply chain structure orients its production and logistic processes differently based on its strategic priorities. This framework allows evaluating and comparing a product's competitive positioning with that of similar products and supply chains. He uses the manufacturer as the focal point in the supply chain.

In the context of a mining industry in the early part of the supply chain, MTS supply chains are common (Tardelli, Barbin, & Cesare de Tomi, 2004). In any case, in MTS supply chains the end consumer has no individual inputs into the configuration of the product. This consideration applies in the same way for a product that is produced by a mining company. However, a mineral commodity is far away from end users. Normally a mineral commodity is purchased by a manufacturing company or an intermediate in the global market. In standard products, typically the product is purchased from a retailer or e-tailer but none of the products associated with this supply chain are made specifically for individuals. Some examples are books, lamps, beds, appliances, etc.

In this section, the analysis is focused on a comparison of the characteristics of MTS supply chains, in the context of a mining company positioned in the early part of the supply chain and a manufacturing company positioned in another tier in the supply chain. These characteristics are regarding products, production processes, logistics processes, and supply chain strategy.

3.2.1 Product characteristics

MTS supply chains are very common because they are appropriate for high volume, low profit margin, and commodity products. These low-cost products tend to have a relatively stable demand, which can therefore be forecasted with a low degree of error when accurate historical demand information is available (Euthemia Stavrulaki, 2010).

For a mining company in the early part of the supply chain, the cost to produce a mineral commodity is a significant variable. Mining companies move high volumes of mineral commodity, but the profit margin is variable because it depends on the international price of metals. Normally, these are not low-cost products. The mineral deposits' quality is also variable. The demand, however, is more or less stable, and this demand can be forecasted with some degree of error given price fluctuations in the stock market. Even when historical demand information is available, accurate forecast of the demand is not possible.

3.2.2 Production process characteristics

In manufacturing industry, the production processes for these mature, highly standardized products focus primarily on achieving low-cost operations, which is typically accomplished with high volume transformation processes, such as continuous processes or high-volume assembly lines. Production is often highly automated, and there is little or no human labor directly involved (Euthemia Stavrulaki, 2010).

In the mining industry, the production processes for the mineral commodity product, which are highly standardized products, focus primarily on achieving low-cost operations, which is typically accomplished with high volume transformation processes. In the mining industry, however, while production is often automated and asset intensive, the labor cost is significant. As an example, labor represents around 20% of total costs in Codelco-Chile company (Lasnibat, 2006).

3.2.3 Logistics process characteristics

Euthemia Stavrulaki (2010) describes that manufacturers in MTS supply chains tend to push product onto retailers' shelves based on end-product forecasts.

The product flow relies heavily on distribution centres and retailers that deliver products to consumers in the most cost-efficient manner. If the volume allows it, manufacturers may also make direct-to-store distribution agreements with large retailers. The many layers and multi-ownership characteristics of MTS supply chains make efficient operations and information sharing challenging. Therefore, this type of supply chain is the most prone to the bullwhip effect.

In the context of the mining industry, mining companies tend to push products into warehouses located in ports based on production planning (Accenture, 2007). Because this industry is very capital-intensive, the mining companies produce around the clock, 24 hours a day, 7 days a week. The product flow relies heavily on distribution centres in the ports and in some cases on the intermediate sellers that deliver mineral commodities to customers (manufacturing industry) in the most cost-efficient manner. If the volume allows it, mining companies may also make direct agreements or contracts with large manufacturing companies. Typically, a mining company sells around 80% of the planned production for the year by contracts. The remaining 20% of production is sold at spot market prices. Hofstrand (2007) states that "companies that produce mineral commodities are referred to as price takers. This means that an individual producer has no control over its price. On any day, they must take what the market offers to them." Mining companies do not sell the 100% of the planned production because the uncertainties in the production process and other types of events that can stop production for a while. Examples of some uncertainties are natural conditions like the weather, a long strike in the company or in the local ports, problems with the local communities, and accidents. In addition, the many layers existing from the first to the last tier in the supply chain make information sharing more difficult.

Regarding standard products in manufacturing industry, Euthemia Stavrulaki (2010) highlights another important characteristic of MTS supply chains: only the retailer has direct contact with the end consumer. Therefore, retailers tend to have significant power in these supply chains, as these standard products are difficult to differentiate from competitors. In addition, efficiency is the main objective for both production and logistics processes of MTS supply chains. High volume production processes emphasize efficiency through automation. High volume logistics processes are also geared towards ensuring that sourcing, warehousing and transportation costs are minimized. For example, warehousing costs are reduced through the cross-docking concept, while transportation costs are minimized through the shipment of products in full truckloads. Moreover, purchasing in large volumes can further increase the efficiencies of MTS supply chains.

In a mining industry context, an end-consumer generally cannot identify which mineral commodities a final product contains, and which mining company has produced that mineral commodity. Mineral commodities are used in multiple applications. The list of applications for metals and minerals in the incorporation into products is endless. For instance, aerospace, automotive, electronics, energy generation and transmission, high-rise construction, wide-span bridges, railway tracks, weapons of war, and so on. Moreover, most manufacturing processes for most products in the world use metal equipment as an integral part of the process. By end-use, metals are found in all sectors of manufacturing, although some are particularly large-volume users, such as transportation and appliances. Construction is also important. Some high-value metals are used in very small volumes in specialized uses. Non-metallic mineral commodities are also used in manufacturing, but some mineral commodities have other distinct uses, including agriculture (e.g. phosphates and borates) and power generation (coal). In the context of mining and minerals, the term “consumer” can be used to describe any user of products containing mineral commodities. However, the most influential consumers of minerals are large manufacturing companies.

In a manufacturing context, efficiency is the primary focus for both production and logistics processes of MTS supply chains. High volume production processes emphasize efficiency through automation and large volume of production, as in a mining company. High volume logistics processes are likewise geared towards ensuring that sourcing, warehousing, and transportation costs are minimized.

However, sourcing in the context of a mining company is different than other companies in the supply chain. Usually, a manufacturing company can further increase the efficiencies of MTS supply chains by purchasing in large volumes. However, a mining company cannot purchase its main raw material, because it needs to extract it from a mineral deposit, once this deposit is discovered in nature. Therefore, minimization of costs in sourcing of a mining company depends on multiple factors. Normally, this type of company must contend with increasing costs over time. Costs increase inevitably, due to the fact that the better quality ore is extracted first, as well as the increasing distances in transporting mineral between the mine and the processing plant. This latter affects the costs and productivity of a mining company and is one of the challenges that mining industry must face, for instance mining companies in Chile right now are facing this challenge.

3.2.4 Supply chain strategy

Euthemia Stavrulaki (2010) indicates that MTS supply chains must focus on minimizing costs in the context of manufacturing industry. This is possible by emphasizing the efficient of MTS operations based on cost cutting lean principles such as JIT production. Efficient production and logistics processes are enablers of the Lean paradigm. It is possible to improve production processes by eliminating waste. The Lean concepts work best when demand is relatively stable and product variety is low, similar to MTS supply chains. Moreover, cost minimization is a key aspect to be considered in a lean supply chain. Therefore, cost and waste need to be considered in MTS supply chains and a close collaborative relationship with suppliers must be taken into account. As an example, this collaboration allows information sharing initiatives and the vendor managed inventory practices with key suppliers of raw materials. This can result in significant cost savings for both the suppliers and companies.

In the context of a mining company, there are some similarities with MTS supply chains with respect to lean capability and its emphasis on minimizing waste and costs. There are some differences, however: while lean supply chains typically mandate close collaborative relationships with suppliers (Choi & Wu, 2009), a mining company cannot just buy its product from another supplier. In addition, the lack of the key suppliers does not allow taking advantage of information-sharing among supply chain members as a strategy to reduce costs.

A comparison of MTS supply chains in the context of a manufacturing company and a mining company has been done. Emphasized here is the need for aligning the production and logistics processes of a product with the product characteristics, and matching supply chain strategy with products. Table 3-1 shows a summary of the comparison of MTS supply chains between mining and manufacturing.

Table 3-1: Comparison of characteristics of MTS supply chain in mining and manufacturing

Components MTS S.C.	Key aspects in each component	Characteristics in Mining	Characteristics in Manufacturing
Products	Demand uncertainty, Profit margin, Product variety, Order leadtime, Labor skills	Low	Low
	Product life cycle, Forecasting accuracy, Volume	High	High
Manufacturing process	Production process	Large volume	Continuous, Large volume assembly/batch
	Product design	Exploration to discover mineral raw materials	Cost conscious
	Manufacturer has direct contact with end-user	Uncommon	Uncommon
	Manufacturing processes focus	Efficiency	Efficiency
Logistics process	Number of intermediaries between manufacturer and end customer	Very Large	Large
	Bullwhip effect	Not Prominent	Prominent
	Supplier relationships	No suppliers of the main raw materials	Collaborative, High information sharing
	Logistics processes focus	Efficiency	Efficiency
S. C. strategy	Supply chain strategic capability	Lean (focus on minimize costs and waste)	Lean

Table 3-1 summarizes the main similarities and differences in MTS supply chains of a mining company and a manufacturing company. Among the major differences is the absence of raw material suppliers in the mining company and the product design. The sourcing of its ‘product’ is more complex than a purchasing arrangement. A mining company cannot take advantage of a close relationship with suppliers, which can contribute to implementing cost reduction strategies. JIT practices as traditionally known are also not possible in the sourcing of its main raw material. The minimization of costs is one of the greatest challenges in a mining company because its costs inevitably will grow over time due to the decay of the raw material quality and the increased transport distances from the mine to processing plant. Therefore, to better understand the differences, complexity, and behavior of the sourcing processes in the early part of the supply chain, it is necessary to study in detail the sourcing process of a typical manufacturing company. After that, it is necessary to perform a comparison with the sourcing process of a mining company. In the next sections, the sourcing process of both types of companies, mining and manufacturing, is analyzed.

3.3 Modes of sourcing in the manufacturing industry[3]

Purchasing has been extensively studied, mainly with a focus on measuring the performance of the administration of an organization. Many research papers has been published on this topic, and there is increased awareness of it (Koliousis, 2006). However, many authors indicate that purchasing is different from procurement, sourcing, and more generally supply management. Purchasing involves more operational decisions and less focus on strategic decisions. Procurement has been the focus of many organizations attempting to optimize their spending. Most organizations are trying to use the existing knowledge and experience regarding effective sourcing.

The sourcing process has an important impact on the supply chain performance. Any variation in the performance of this process can influence the downstream processes in the supply chain. In order to compare the characteristics of the sourcing process in a company positioned on the early part of the supply chain with another company positioned in another tier of the supply chain, a more detailed analysis of this process is performed in this section.

For a typical manufacturing company in the supply chain, sourcing and procurement is all about bringing in the company the right products, in the right quantities, in the right time, and in the right place. In general, the objectives include the following:

- Provide a continuous flow of materials.
- Improve the competitive advantage of the company.
- Achieve and sustain high quality of inbound flow by the selection of the best suppliers.
- Standardize and modularize components and/or material.

[3] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

- Purchase the materials with the least possible cost.

The sourcing and procurement function have strong interrelations with the warehousing and inventory management function as well as with the transportation function. Companies need a holistic approach of optimizing not each process in isolation, but instead ‘globally’ optimizing profits with respect to each independent function. By using this holistic approach, procurement and warehousing in the supply chain can become very advanced and highly automated (Rouwenhorst et al. 2000). As critical nodes in modern supply chain networks, the efficient and effective operation of warehouses plays an important role in determining the overall network performance (Gu, Goetschalckx, and McGinnis 2007; Rouwenhorst et al. 2000).

Gu, Goetschalckx, and McGinnis (2007) present a comprehensive overview of trends, opportunities, and challenges in warehousing. According to them, the adoption of modern management philosophies such as Just-in-Time, Just-in-Sequence, and the Lean principles increased the need to handle tighter inventory control, shorter response time, and greater product variety. However, modern information and communication technologies present the opportunity to improve the efficiency and effectiveness of warehouse operations. Among other things, this can include real-time control of operations in the warehouse, better communication and information exchange with other parts of the supply chain, and a high level of automation (Gu, Goetschalckx, and McGinnis 2007).

Another important aspect of warehousing in the supply chain is how sourcing models influence the functioning and location of stock-keeping (Fronia,Wriggers, and Nyhuis 2008). A new development is the point in time of the shift of ownership between the seller and the customer (Frühwald, Rieger, and Wolter 2005). The changeover of ownership decides which partner is responsible for storage and related costs, planning and control of stores, capital lockup, and risk of stock value loss (Frühwald, Rieger, and Wolter 2005). The two extremes are traditional inventory sourcing, where the supplier delivers according to orders, and synchronized production processes that describe a deep integration of the processes of supplier and customer. Within this concept, interim storage is no longer required because the supplier’s goods are produced for the customer according to actual demand (amount and time wise). There are many concepts for the various requirements between both suppliers and industrial customers.

In summary, sourcing and warehousing in the supply chain is mostly a tightly planned operation, trimmed for the highest efficiency and effectiveness possible. The entire operation is a result of rigorous planning, including determining the optimal location for the whole warehouse with respect to distance to customers and suppliers, and including the best integration in the available infrastructure (e.g., train tracks, harbor). In addition, important internal operations are planned from the optimal location for the individual product according to various parameters like inventory turnover ratio over material to mass and dimension of the product. Modern warehousing is based on design, not natural circumstances. The design and location is based on the optimal fit for the planned operations and products.

3.4 Characteristics of sourcing in mining[4]

Guoqing, Nailian, & Xuchun (2003) indicate that a mining enterprise is much different from the manufacturing company. Mined ore, the raw material for a mining operation, comes from nature through a series of mining operations rather than purchasing from a market. Nevertheless, parts of auxiliary materials have to be consumed in the processes (see Figure 3-2) which makes the supply chain more complicated.

The difference between the mining industry and the traditional manufacturing industry in the supply chain is the manner in which raw materials are obtained. However, compared with a supply chain management (SCM) model, some common points can be found. The cost of exploring and mining for a mining company can be regarded as the purchase cost in a manufacturing company. Similarly, the value of ore flow will increase continuously because of the input of labor, capital, and materials during the process to the finished products.

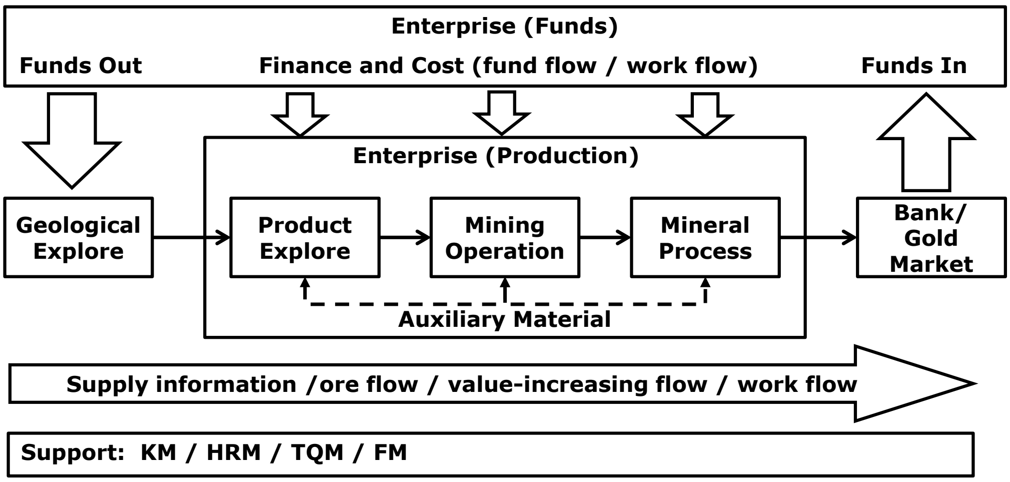

Figure 3-2: Supply chain framework for Jiaojia gold mine (Guoqing, Nailian, & Xuchun, 2003)

Regarding the auxiliary materials shown in Figure 3-2, the sourcing of spare parts and materials for some processes of mining companies is often complex and specialized. Gossamer Systems Inc. et al. (2002, p.15) indicate that controlling the purchasing of goods and materials is critical to overall profitability and vital to achieving sustainability in mining operations. The mining industry looks to maximize return on investment from capital assets. In a mining operation, downtime due to the unavailability of spare parts equates to lost production. In addition, downtime due to avoidable maintenance problems means lower returns on investment, reduced efficiencies, and lost opportunity. However, the

[4] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

availability of auxiliary materials is irrelevant if the ore does not exist. This raw material is not available for purchase in the global market, it has to be extracted from a mineral deposit in nature with a series of mining operations.

The mining industry is constrained by the mineral resource itself; the mineral resource is non-renewable and finite. Therefore, its key competition ability is its mining and controlling measures for various mineral resources. Consequently, the constraints on the early part of the supply chain exist in the mineral resources limitation and the mine restricted productivity. The early part of the supply chain in this industry used mineral resources as its primary performance driver, rather than the market. Industry sustainable development strategies and the condition of the mineral resource should be considered along with outside market forces during the supply chain decisions (Guoqing, Nailian, & Xuchun, 2003).

3.5 Comparing characteristics of sourcing in mining and manufacturing[5]

After reviewing the characteristics of the mining industry and its sourcing processes, in this section, a general comparison of the sourcing process in mining and manufacturing is performed. This comparison takes into account the difference between the mining industry and the manufacturing industry in how their raw materials are obtained or extracted. Figure 3-3 is a good demonstration of this difference.

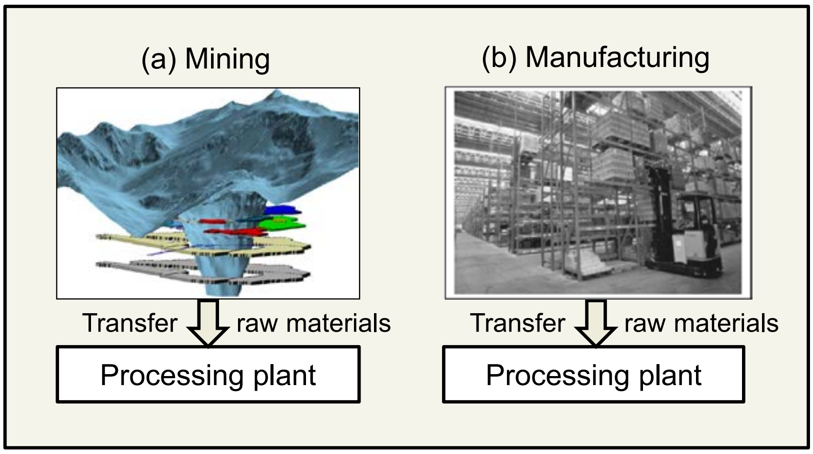

Figure 3-3: (a) ‘Sourcing’ in mining (adapted from Codelco 2011); (b) ‘Sourcing’ in manufacturing (adapted from Tardelli, Barbin, and Cesare de Tomi 2004)

In the mining industry, raw material is extracted from mineral deposits in the natural environment as depicted in Figure 3-3(a). In comparison, the manufacturing industry obtains its raw materials, to a large extent, from its warehouses and/or directly from its suppliers (see Figure 3-3b) after purchasing them on the global market. Tardelli, Barbin, and Cesare de Tomi (2004) emphasize that an important restraining factor for the production planning and scheduling is the sequencing of the mine exploitation. In order to be properly

[5] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

extracted, one specific ore block must be at the face of the open pit or underground mine, so that mining equipment can gain direct access (see Figure 3-3a). A manufacturing plant does not have this kind of restraint, as any component in a production material warehouse can be easily accessed at once and fed in to the processing plant (see Figure 3-3b). Guoqing, Nailian, and Xuchun (2003) indicate that the difference between the mining and manufacturing industries can be manifested by the differences of obtaining raw materials. However, comparing both supply chain management views, some common characteristics are also apparent. The cost of exploring and mining can be regarded as a purchase cost equivalent within the manufacturing industry. However, this comparison is only valid when the "sourcing" process of the mining industry is considered a black box in the supply chain modeling.

In the following, Table 3-2 presents the relevant comparison of specific characteristics of sourcing processes within the mining industry. Most of the unique characteristics of mining industry that were explained in chapter 2, are relevant part of the specific characteristics of the sourcing process in this industry. Sourcing is compared here to sourcing in the supply chain (manufacturing), while the manufacturing industry that includes the main differences between both industries is also shown.

The sourcing of mineral blocks through mining is achieved using processes and activities which may be considered more complex than the sourcing of raw materials from a warehouse in the manufacturing industry. However, it must be noted that only the sourcing of raw materials from a warehouse is referred to here; the design, planning, and operation itself is a highly complex task.

In order to integrate the mining industry with the manufacturing industry in the supply chain, its processes must be standardized. The process modeling using standard supply chain frameworks contributes to reducing the complexity of processes in the supply chain. The integrated SCOR and DCOR model describes the manufacturing industry using its standard processes. However, these standard processes must be applied and adapted to allow a description of mining processes that uses the same language. The EM model is the process reference model for the mining industry, so this model is the standard for the mining industry. In chapter 4, these three models are presented and their commonalities, limitations, and gaps are identified and analyzed. After that, in chapter 5 the adaptations of SCOR and DCOR models are developed in order to close the gaps identified and obtain the adapted SCOR and DCOR model to the mining industry.

Table 3-2: Comparison of characteristics of sourcing in mining and manufacturing (Zuñiga, Wuest, & Thoben, 2013)

Characteristics/ relevant aspects	Mining industry	Manufacturing industry
Main supplier	Mineral deposit (natural)	Supplier from the global market
Supplier selection	Search and find an economical mineral deposit in nature, apply for needed permission to extract (government)	Select the best supplier(s) in the global market
Availability of raw materials	Limited, determine by the mine life (depletion of natural resources)	Unlimited, determine by the global market availability
Quality of raw materials	Variable quality in mineral deposits. Also, quality decrease in time (highest quality blocks are extracted first)	Selection based on quality
Cost of raw materials	Increase in time. Include costs of exploration, development and extraction	Maintain or decrease in time, higher global competition
Capital investment to extract raw materials	Extremely high. Increased production requires finding new deposits or increasing the rate of extraction, thus new investments	Medium–low. Increase production using a higher volume of raw materials (reduce costs) with low new investments
Location of the processing plant	Fixed. Pre-determined by the natural mineral deposit location	Flexible. In most convenient location for the stakeholders (e.g., customers and/or suppliers)
Type of raw materials	Bulk, mineral rock or natural substance	Parts, or semi-elaborated product
Geological risks	High	not applicable
Operational risks	High (i.e. accidents)	Medium - Low
Economic risks	High (i.e. metal price fluctuations, tax policy, exchange money, interests, etc.)	Low-medium
Political risks	High (i.e. local communities can reject good projects, often in unstable regions)	Low
Waste/product ratio	High. An ore grade of copper around 0.7%, move high volume of waste material	Medium-low
Uncertainties	High (i.e. estimation error in parameters of deposits and processing, requires inventories)	Medium – low
Planning	Focused on mineral resource management and cost management efficiency	Focused on efficient operations and market demand and customer requirements

3.6 Summary

The sourcing process of mineral raw materials in mining has been introduced as one of the critical challenges of a supply chain. The mining company is positioned at the early part of the supply chain, and it does not have suppliers to obtain its raw materials. This restricts the possibilities to implement cost reduction strategies with suppliers. Nor JIT practices as traditionally known are possible in the sourcing of its main raw material. Moreover, cost management is another of the greatest challenges in a mining company because its costs inevitably will grow over time, due to the decay of the raw material quality and the increased transport distances from the mine to processing plant and to dumped waste.

There are considerable differences between sourcing in mining and manufacturing. The manufacturing industry obtains its raw materials, to a large extent, from its warehouses and/or directly from its suppliers after purchasing them on the global market. While in mining the raw material is still in its natural habitat and has to be extracted in the mine, in manufacturing the raw materials are stored in modern warehouses, planned out, and operated to run efficiently and effectively. Modern warehousing is based on design, not natural circumstances. When looking at mining, it is the absolute opposite. In mining, the sourcing operations have to adjust to the naturally given design and location.

In the next chapters, the discussion will be how process modeling by using standard supply chains frameworks such as SCOR and DCOR models can be applied and adapted to describe the mining processes. The process modeling using standard supply chain frameworks contributes to reduce the complexity of the processes. In addition, it contributes to improve the integration and transparency of the processes in the supply chain. The integrated SCOR and DCOR model allows a description of the processes of manufacturing industry by using its standard processes. The EM model allows a description of the processes of mining industry because this model is the standard for mining industry. However, in order to describe the mining processes by using an accepted language in the supply chain, the commonalities, limitations, and gaps of these three models must be identified and analyzed. After that, the adaptations of SCOR and DCOR models need to be performed in order to close the gaps identified.

4 Process modeling approaches

In previous chapters, the differences in sourcing processes of manufacturing and mining industries were highlighted. In this chapter, the EM model in mining and the SCOR and DCOR models in manufacturing are presented and described. The EM model is a standard process model in the mining domain. The SCOR model is the standard for the annotation of supply chain processes in the supply chain domain for manufacturing industry, and the DCOR model is being accepted as a reference in the product design chain domain for the manufacturing industry (see Figure 4-1).

In order to improve, simplify, and standardize business processes across the supply chain, companies can adopt the Integrated Supply Chain (ICS) framework using DCOR and SCOR models (Nyere, 2006). DCOR and SCOR are design and supply chain management tools which can be adapted to any business process under study. The adoption of these models helps improve competitiveness in the supply chain, and can result in better cooperation between supply chain partners (Supply Chain Council, 2007).

In this chapter, some approaches and examples are analyzed in more detail, for a better understanding about how the SCOR and DCOR models could be applied and adapted in modeling the mining processes. SCOR and DCOR models are particularly interesting for industrial contexts that share similarities in processes, namely: Exploration, Engineering Design, Construction, and Extraction.

In this chapter, the similarities and differences between the sourcing processes of the EM model in mining and the existing applications and adaptations of SCOR and DCOR models in other industrial environments are analyzed. From this analysis, the gaps between the existing literature about SCOR and DCOR applications in similar environments and the mining processeses are identified. This will lay the foundation for the following chapter 5, which will present an adaptation of the SCOR and DCOR models to the mining processes.

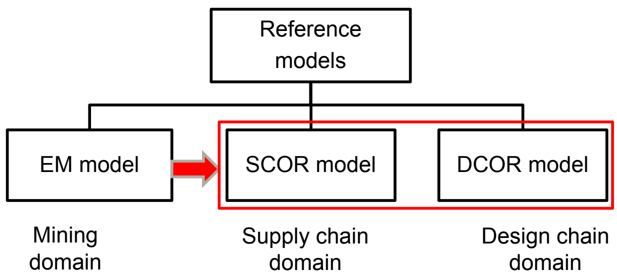

Figure 4-1: The EM model and the SCOR and DCOR models

4.1 Characteristics of the EM, SCOR, and DCOR models and the adaptation approach

In this section, the EM, SCOR and DCOR models are described and the characteristics of these specialised models are analysed. Then, the proposed approach for applying and adapting the SCOR and DCOR models is presented. This will lay the foundation for the following sections, which present a review of existing applications of SCOR and DCOR models in the mining processes and other industrial contexts.

4.1.1 The EM model

EMMMV (2010) indicates that the Exploration and Mining Business Reference Model (EM model) is an industry business process model, defining the standard business activities for organisations that operate in the exploration and mining sectors with a focus on metals and minerals. The model is the first deliverable from The Open Group's EMMMv™ Forum in the year 2010. The model provides a categorisation of the business activities applicable to the sector, so that mines and their suppliers and partners are in a position to speak a common language when they are considering the support of specific activities or processes in the business. The main objectives of the EM model are to (EMMMV, 2010):

- Provide an overarching standard for business activities in the exploration and mining sectors focused on all metals and minerals.
- Provide a common definition for describing business processes (activities) in the industry.
- Create a common understanding of the information that will be required to execute the business activities.
- Enable sharing through understanding, amongst exploration and mining organisation and internally within these organisations.

The EM model is specifically defined so as not to extend its focus beyond the mining industry. For example, companies in the following industries are encouraged to use this model, including mining, refining, engineering support, consulting organisations, and application companies.

The Open Group forum is responsible for delivering the applicable models and standards for the exploration and mining industry, focusing on metals and minerals, and thus owns the EM Model. The forum is a collaboration between organisations in the exploration, mining, metals, and minerals industry sectors and the suppliers to these industries.

EMMMV (2010) highlights the EM model should always be used as a reference and does not attempt to replace process analysis and definition activities within the enterprise. Using this model, an organisation can do a process mapping exercise and have a better understanding of the operational activities they should expect to find and own within the various areas of the business.

The processes of the EM model

This model has a specific structure where processes are categorised into three different levels of processes. Figure 4-2 shows the first level processes (Level 1), which are the 'enterprise processes' and they are depicted by the vertical boxes in Figure 4-2. These core enterprise processes are Exploration (or Discover), Engineering Design, Construction, Extraction (or Exploit), Processing (or Beneficiate), Distribution (or Sell), and Rehabilitate, and they describe the sequential nature of the exploration and mining business. This sequential nature does not imply that the sequence will always be followed rigorously, but merely that in most cases the activities will occur in this sequence.

The 'Development' (or Establish) enterprise process of the EM model is split into two main processes, ‘Engineering Design’ and ‘Construction’ (EMMMV, 2010 p.22). These processes are relevant in the development of a mine and share similarities with other industrial contexts. The processes of exploration and engineering design are an essential part of a mining project, be it a currently operating one, a new ‘Brownfield’, or a new ‘Greenfield’ mining project. Thus, this distinction is depicted by the green and brown boxes underlying these two enterprise processes and is made because of the detailed deliverables and or processes that may differ for a particular state or location. In addition, the 'Rehabilitate' process of the EM model is not considered because this process is applicable when the mine has finished the operations.

The second-level processes are the 'value chain processes' and they are contained within the vertical box. The third-level processes are the 'business processes'. In Figure 4-2 the Level 3 procesess of the extraction process are shown. Additionally, the EM model includes the 'Enterprise Support' processes, which are separated from the core enterprise processes within the exploration and mining business since these support the operation of the business and do not constitute a core process focused on creating value within the enterprise (EMMMV, 2010, p. 45).

In Section 2.3, the processes of the EM model were presented in greater detail. It is also important to note that the EM model provides a definition and description of the processes at all three levels. However, there are the following limitations of the EM model:

- This model does not include information on the key performance indicators (KPIs) and best practices for the mineral raw materials industry.
- It is focused only in the mining domain.
- It does not use a standard, generic and compatible language which can be accepted in the entire supply chain.
- There is limited research published on applications of the EM model.

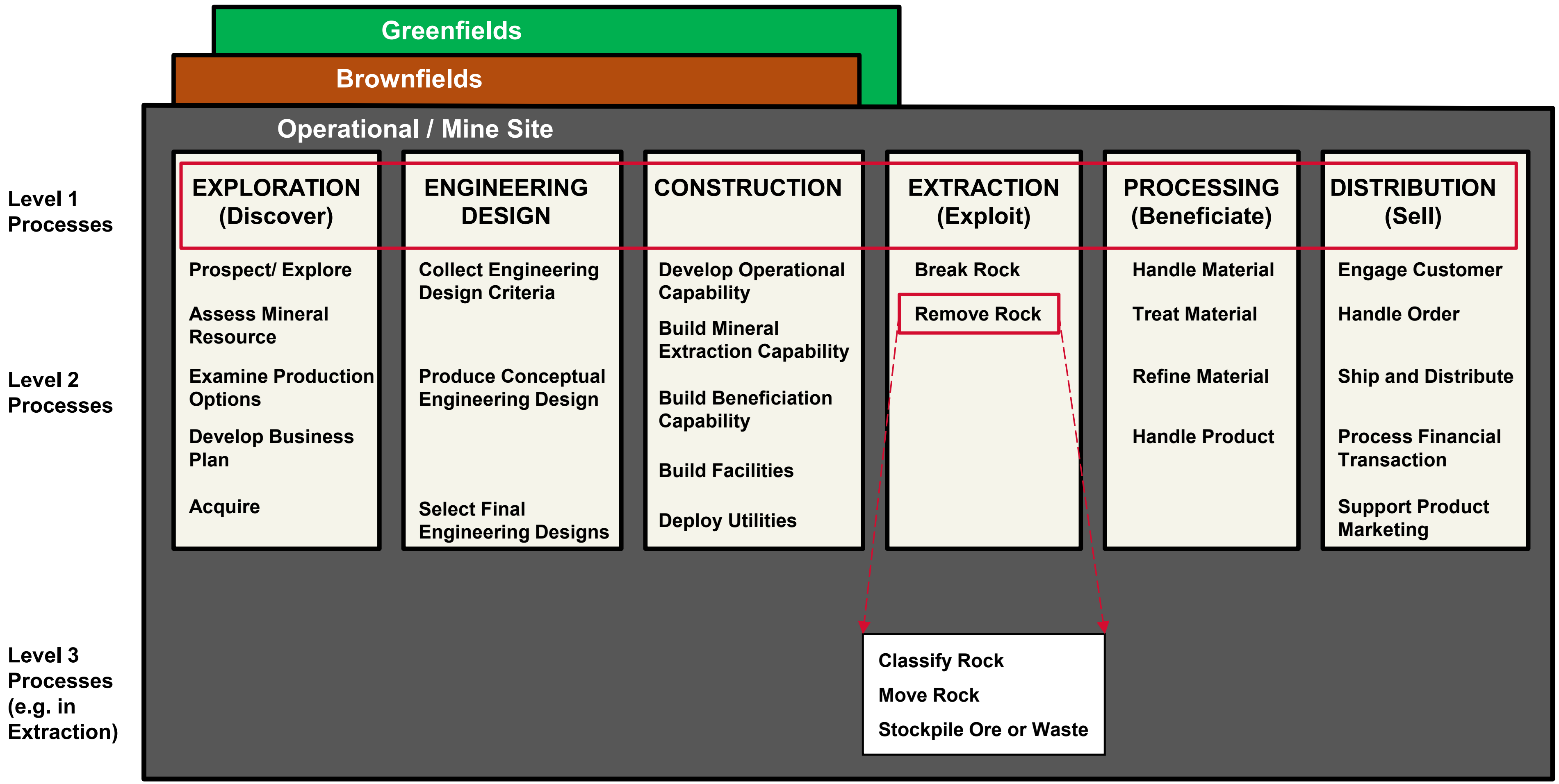

Figure 4-2. The Levels 1, 2, and 3 processes of the EM model (Adapted from EMMMV, 2010)

4.1.2 The SCOR and DCOR models

DCOR and SCOR models are part of an integrated standard framework for modeling business processes in design and supply chains (SCC, 2010; Nyere, 2006). The processes involved in this framework can be applied for modeling the specific characteristics of any type of industry. For instance, these processes can be applied for modeling the specific characteristics of the sourcing process in the mining industry, as this process is the most critical process in the early part of the supply chain.

The Supply Chain Council (SCC) created in 1996 the Supply-Chain Operations Reference (SCOR®) model. SCC established the SCOR process reference model for evaluating and comparing supply-chain activities and performance. The SCOR-model provides a unique framework that links business process, metrics, best practices, and technology into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities. In addition, SCC created the Design Chain Operation Reference (DCOR) model (SCC, 2006) because the SCOR model does not address product development, research and development (SCC, 2010 p.11).

4.1.2.1 The SCOR model description

The SCOR model is organized around the five primary management processes of Plan, Source, Make, Deliver, and Return (shown in Figure 4-3). By describing supply chains using these process building blocks, the model can be used to describe supply chains using a common set of definitions. As a result, disparate industries can be linked to describe the depth and breadth of virtually any supply chain. It is important to note that this model describes processes not functions. In other words, the model focuses on the activity involved not the person or organizational element that performs the activity (SCC, 2010).

SCOR defines three detail levels of process (See Figure 4-3). Level 1 describes supply chain processes at the most general level. It is assumed that all supply chains are composed of five basic types of processes: Plan, Source, Make, Deliver, and Return. The Plan process is a management process. Each supply chain process must be managed. Thus, if a company has a Source Process, it must also have a Plan Source process to manage it. Complex supply chains are made up of multiple combinations of these basic processes.

Level 2 provides for variations in the Level 1 processes. These are not sub processes, as such, but variations in the way the processes can be implemented. Each of the Level 1 processes currently has three variations. In analyzing a process, first it decides that there is a sourcing process, Level 1 Process, and then decides which of three, Level 2 variations of sourcing process it is. These variations are S1, Source Stocked Products, S2, Source Made-to-Order Products, or S3, Source Engineered-to-Order Products. Figure 4-3 shows all of the current Level 2 variations, inside their respective Level 1 processes. It must be considered that there are two slight variations in the Return Process itself.

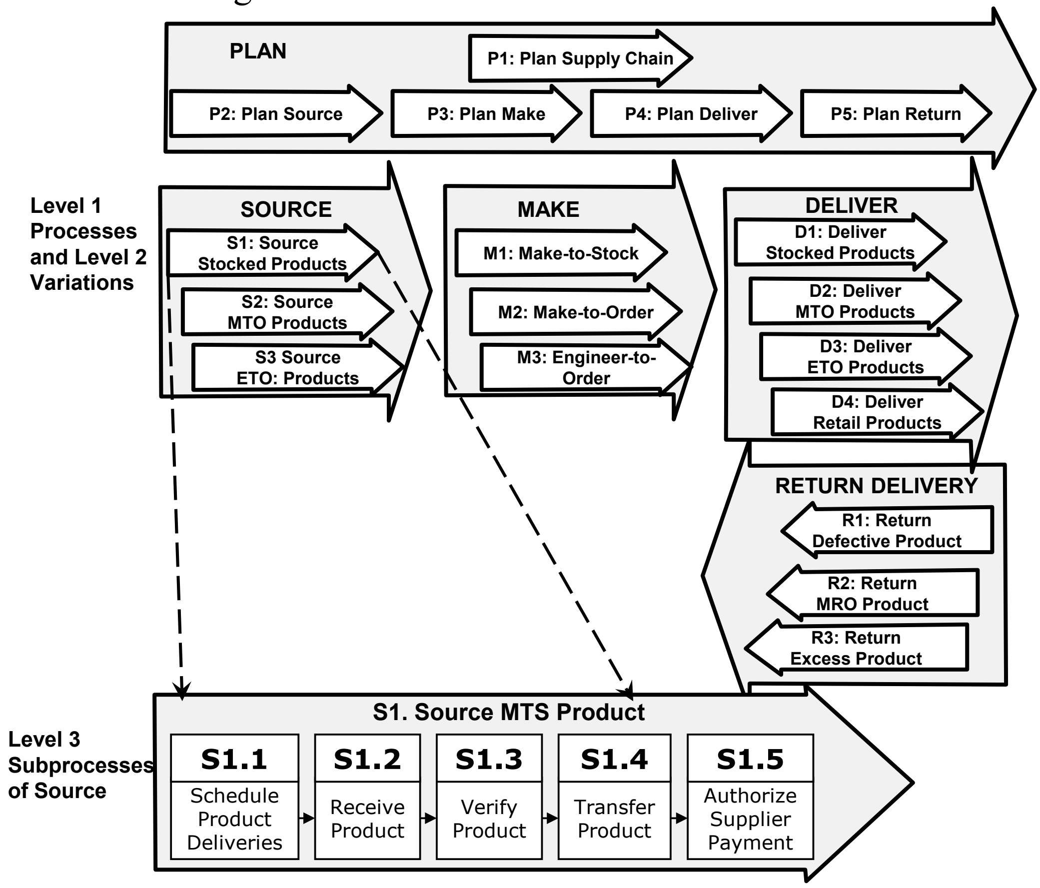

Figure 4-3. The five basic SCOR Levels 1, 2, and 3 processes (Adapted from SCC, 2010)

Each Level 2 process is further defined by a set of sub processes or activities that illustrate the basic sequence of steps involved in implementing the process. In fact, in SCOR, the Level 3 processes are sub processes of the Level 1 processes, and are the same, no matter the variation. In general, this level defines the processes elements within and between companies. Figure 4-3 shows the Level 3 activities that are included in one Level 2 process: S1, the Source MTS Products. Level 4 processes are beyond the scope of the SCOR framework. It is assumed that each company will have its own procedures for implementing each of the Level 3 sub processes defined by the SCOR framework and that it is not useful to try to standardize Level 4 sub processes (Harmon, 2003).

4.1.2.2 The DCOR model description

Supply Chain Council created the Design Chain Operation Reference (DCOR) model (SCC, 2006) because the SCOR model does not address product development, research and development (SCC, 2010 p.11). DCOR and SCOR models are part of an integrated standard framework for modeling business processes in the design chains and supply chains (SCC 2010; Nyere 2006). The processes involved in this integrated framework can be adapted for modeling the specific characteristics of the sourcing process in the mining industry.

The SCOR process categories are constructed around 'Stocked Product', 'Make to Order Product', and 'Engineer to Order Product'. In DCOR, within the Research, Design, and Integrate processes, the common internal structure (see Figure 4-4) focuses on three environments: 'Product Refresh', 'New Product' and 'New Technology' (Nyere, 2006). These three environments or categories need to be analyzed to be adapted to the mineral commodity context. This analysis is described in section 4.3.1.

SCC (2006) indicates that the DCOR model contains five basic management processes: Plan, Research, Design, Integrate, and Amend. These processes provide the organizational structure of the DCOR-model (see Figure 4-4). In addition, SCC (2006) describes a set of standard notations that is used throughout the Model. P depicts Plan elements; R depicts Research elements; D depicts Design elements; I depicts Integrate elements; and A depicts Amend elements. In order avoid confusion when using both the SCOR and DCOR models, a distinction is made between the processes' names to identify them as belonging to SCOR or to DCOR. For instance, the naming convention for DCOR Plan Design Chain is PP; for Plan Research, PR; for Plan Design, PD; for Plan Integrate, PI; and for Plan Amend, PA.

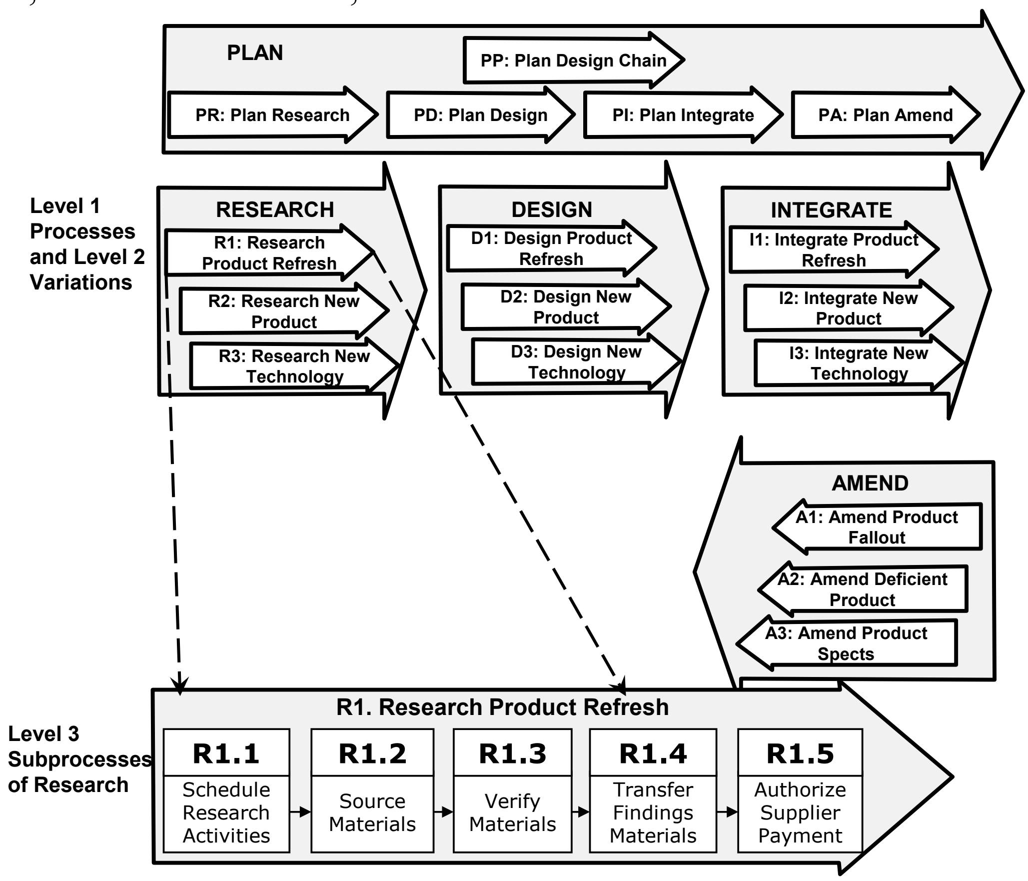

Figure 4-4. The five basic DCOR Levels 1, 2, and 3 processes (Adapted from SCC, 2006)

4.1.3 Proposed approach for applying and adapting the SCOR and DCOR models in the mining domain

A general view of the proposed approach for applying and adapting the SCOR and DCOR models to the mining processes of the EM model is based on the following methodology (see Figure 4-5):

1) *Identify commonalities and gaps between the processes of the EM model and the processes of the SCOR model*. Reference process models, such as the SCOR model go a long way into identifying common processes, activities, and KPIs in the context of the supply chain in the manufacturing industry. In a similar way, but outside the supply chain context, the EM model is the reference process model in the mining domain. The commonality between the EM model and the SCOR model essentially deals with the following question: "How to model business processes that are similar to one another in many ways, yet differ in some other ways from the mining domain to the supply chain domain?" (La Rosa, M. & Dumas, M., 2008). In order to identify the commonality between the EM model and the SCOR model, the content analysis is applied to the mining industry, the EM model, and the SCOR model. The commonalities between the processes of construction and extraction of the EM model and the processes of the SCOR model are then analyzed. After that, the differences in the gaps between these processes are identified.
2) *Identify commonalities and gaps between the processes of the EM model and the processes of the DCOR model.* In order to identify the commonality between the EM model and the DCOR model, it is necessary to understand what these process models share, what are their differences, and why and how these differences occur. To do this, the content analysis is applied to the mining industry, the EM model, and the DCOR model. The EM model represents the common practice in the mining domain, and the DCOR model represents the common practice in the design chain domain. The commonalities between the processes of exploration and engineering design of the EM model and the processes of the DCOR model are analyzed. Then, the differences in the gaps between these processes are identified.
3) *Adaptation of SCOR logic to represent the mining processes.* The SCOR model provides a foundation for describing the processes and defining the terminology in an already accepted framework. The input from the processes of construction and extraction of the EM model is used for the adaptation of the processes of SCOR Levels 2 and 3. The SCOR model is applied to represent the construction process that shares commonalities with construction in the mining. After that, the SCOR model is adapted to close the gaps in the construction process in the mining industry. In a similar manner, the SCOR is adapted to close the gaps identified in the extraction process.
4) *Adaptation of the DCOR logic to represent the mining processes.* The input from the processes of exploration and engineering design of the EM model are used for the adaptation of the categories and processes of DCOR Levels 2

and 3. The categories of the DCOR model are adapted to the semantics in the mining domain in order to close the identified gaps. Similarly, the processes of DCOR Levels 2 and 3 are adapted to close the gaps in the processes of exploration and engineering design.

5) *If adaptation is unfeasible, study weather other models can be extended to fit the mining process.* While the SCOR and DCOR models adaptability in the mining processes is impossible, the next step must be to study whether other design and supply chain models can be extended or altered to fit the mining processes requiring adaptation.

The letters P, R, D, I, and A indicated in Figure 4-5 represent the name of the processes of DCOR model: Plan, Research, Design, Integrate, and Amend. Similarly, the letters P, S, M, D, and R represent the name of the processes of the SCOR model: Plan, Source, Make, Deliver, and Return. Finally, the small letter "m" is "mining"—for example, "mR" of the mDCOR represents the adapted research process of the adapted DCOR model in mining.

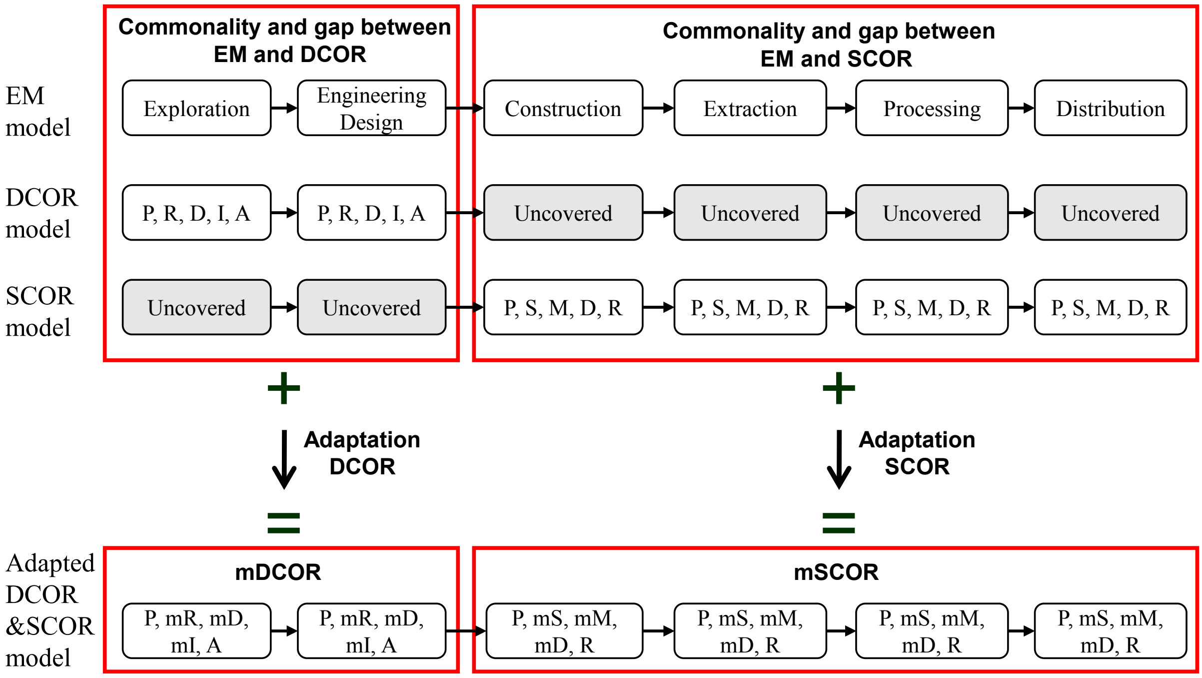

Figure 4-5: Proposed approach for applying and adapting the SCOR and DCOR in mining

4.2 Applications of SCOR model

The SCOR model was originally designed to fit the requirements to model the processes within a manufacturing environment. Hence, the manufacturing and related processes were extensively studied, and a wide selection of literature describing various successful applications of the SCOR model within the manufacturing industry can be found (Fronia, Wriggers, & Nyhuis 2008; Hwang, Lin, & Jung 2008; Han & Chung-Yee 2007; Vanany, Suwignjo, & Yulianto 2005).

However, limited research has been published on SCOR model applications in the mining industry in order to describe this early part of the supply chain.

The mining industry and its processes show many atypical characteristics, which do not fit easily with the existing SCOR model. Existing applications of SCOR models to the construction industry should be studied in more detail because it has similarities with the construction process of the sourcing process in the mining industry. This is elaborated in this chapter. Regarding the extraction process, there is no evidence of any application of the SCOR model to this process. Existing SCOR model applications in other industrial environments, however, could provide a guide to adapting SCOR model to the extraction process. This is analyzed in section 4.2.2.

4.2.1 SCOR model applications in construction industry

There exists some research on applications to the supply chain in the construction industry (O'Brien, London, & Vrijhoef 2002; Dainty, Briscoe, & Millett 2001). Also, SCOR applications to this industry can be found (Cheng 2009; Venkataraman 2007). The existing applications of the SCOR model to this industry are important guides for adapting the SCOR model to the construction process in the context of the mining industry.

Construction projects typically involve tens to hundreds of companies, supplying materials, components, and a wide range of construction services (Dainty, Briscoe, & Millett, 2001). Modeling the structure of participants involved in a construction supply chain can help understand the complexity and the organization of a supply chain (O'Brien, London, & Vrijhoef, 2002). Venkataraman (2007) indicates that the SCOR model can be applied to describe a project supply chain. They explain that in a project supply chain context, the planning process encompasses all aspects of planning, including the integration of the individual plans of all supply chain members, into an overall project supply chain plan. For example, in the sourcing process the focus is on all processes related to procurement, such as identifying, selecting, and qualifying suppliers, contract negotiation, and inventory management.

The application of the SCOR model to the construction industry that is proposed by Cheng (2009) has certain similarities to the construction process in the field of mining. Cheng (2009) indicates that construction supply chains are complex in structure and often composed of a large number of participants who work together in a project-based temporary manner. In addition, he indicates that the SCOR model is suitable for modeling various construction supply chains of different complexities because the SCOR model is generic and can be used to model supply chains of various types and scales. To illustrate this, he applies the SCOR model to a specific case, a construction project of a two-storey high-school student center. Specifically, the Mechanical, Electrical, and Plumbing (MEP) supply chains of the project were studied retrospectively and modeled based on the information from the documents provided by, and the interviews conducted with, the general contractor, subcontractors, and suppliers. Even when the buyer-supplier relationships in a construction project differ from project to project, organization to organization, and product to product, similar patterns emerge. Thus, similar patterns can be found in the construction process in the context of a mining project.

Cheng (2009) states that, although the supply chain modeling is demonstrated only with the MEP supply chains, the model can be potentially applied and extended to other kinds of supply chains in construction projects of various scales and types. He uses SCOR model for modeling only the suppliers of materials of the construction process. However, the construction site itself needs to be described in more detail by the SCOR model. The construction site is effectively an ad-hoc factory, temporarily created to manufacture a prototype product. Therefore, this proposal is selected as the starting point to apply and adapt the SCOR model to the construction process of the mining industry, where the complexity of the material supply management in a project of this scale can be even more complex. This complexity will depend of the type of project to be developed: Greenfield, Brownfield, or Operational.

Figure 4-6 shows the conceptual view of the construction supply chain, which has the following three components:

- The supplier (***engineering design process***), which provides the design drawings and general and detailed specifications.
- The ***construction process*** includes two main components, the suppliers of materials and the construction site. The general contractor and subcontractors perform the construction activities specified by the engineering design process. These construction activities must meet the customer's requirements.
- The customer can be a company or a process. For example, in the context of mining industry, the customer could be the ***extraction process***. This process receives the product, which in this case is a site with a stock of mineral blocks to be extracted.

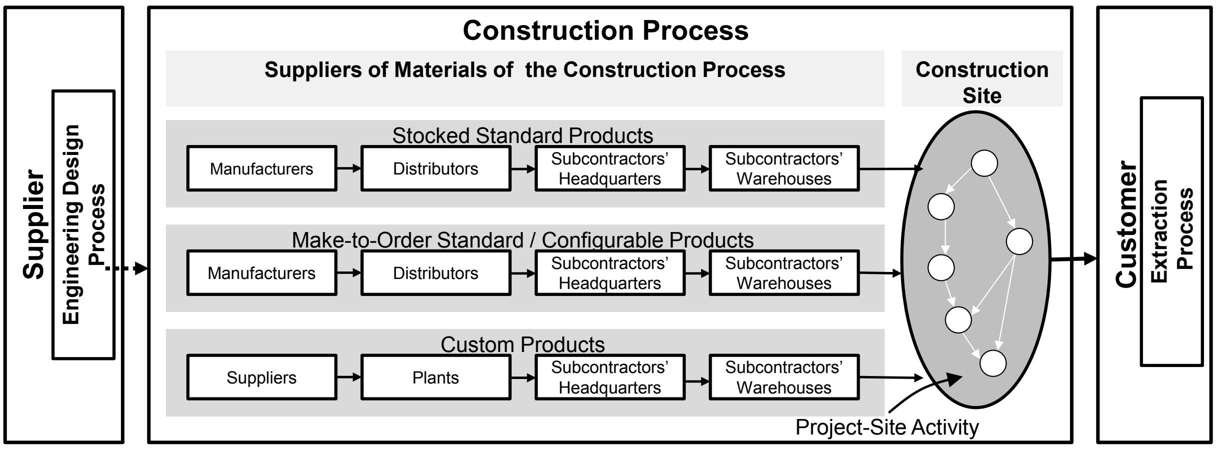

Figure 4-6: The construction process supply chain (Adapted from Cheng 2009; O'Brien, London, & Vrijhoef 2002)

The interactions along the supply chains show three major patterns of the construction supply chain: for stocked standard products, for make-to-order standard/configurable products, and for custom products. The relevant aspects to consider for the SCOR Level 2 and Level 3 modeling of the material flows for these three types of construction supply chains have been developed by Cheng (2009). Because of the similarities of these models with the construction process in the context of mining industry, they are shown in this section. In the next chapter 5, SCOR Level 2 and SCOR Level 3 modeling will be adapted to a mining construction site, taking into account Cheng's (2009) proposal.

4.2.1.1 Describing the supply of construction materials using the SCOR Level 2 model

Cheng (2009) indicates that the supply chain of materials necessary for the construction process can be classified into three types of products: Stocked Standard Products, Make-to-order Standard/Configurable Products, and Custom Products. These are the types of products that are required in the activities that are performed on the construction site. Construction supply chains for stocked standard products and make-to-order standard/configurable products involve the general contractor, subcontractors, distributors, and manufacturers. In contrast, members of supply chains for custom products usually consist of the general contractor, subcontractors, plants, and material suppliers. The SCOR level 2 model for these three types of products and the construction site is developed as follows (see Figure 4-7).

For ***Stocked Standard Products***, the information flows start from S1 of subcontractors' headquarters to D1 of distributors. Usually, these products are maintained in stocks in suppliers' inventory prior to the receipt of a customer's order. There are two alternative material flow paths from distributors:

- Products are often delivered from D1 of distributors to S1 of the construction site at the time designated by the subcontractors.
- In specific cases, products are delivered from D1 of distributors to S1 of subcontractors' warehouses because subcontractors prefer to deliver the products to the construction site at the time they are required.

These types of products are produced by manufacturers and are sent to S1 of distributors. Supply chains of this type are inventory driven.

For ***Make-to-order Standard / Configurable Products***, the information flows start from the subcontractors' headquarters (S2), where purchase orders are sent from S2 of subcontractors' headquarters to D2 of distributors. In most cases, distributors serve as an intermediary between subcontractors and manufacturers. In general, these products are not maintained in stock prior to the receipt of a customer's order. There are two alternative material flow paths from manufacturers:

- The products can be delivered directly from D2 of manufacturers to S2 of the construction site.
- The products can be delivered from D2 of manufacturers to S2 of subcontractors' warehouses.

In some specific cases, some subcontractors communicate with their manufacturers to learn about the state of their orders (from S2 of subcontractors' headquarters to D2 of manufacturers).

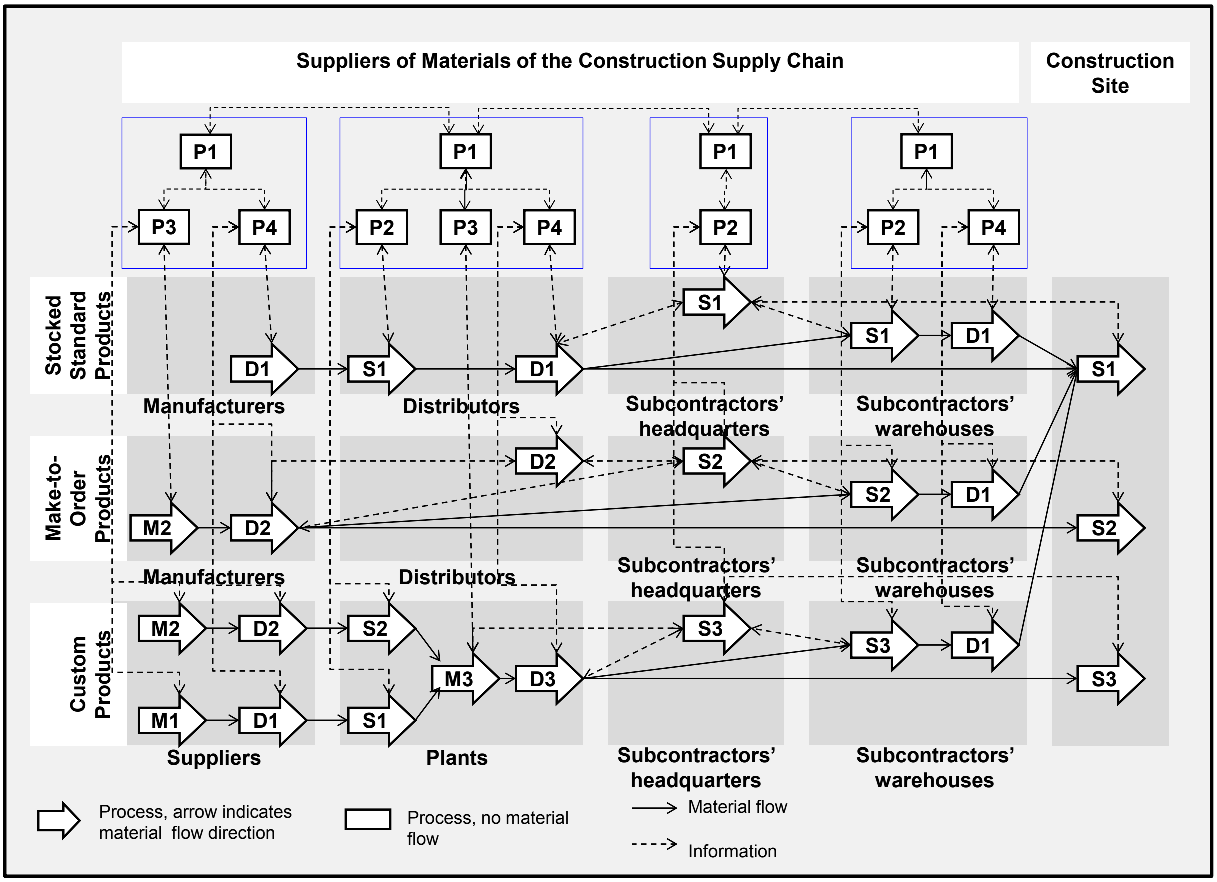

Figure 4-7. SCOR Level 2 model for a typical construction supply chain which involves the suppliers (Adapted from Cheng, 2009)[6]

For ***Custom Products***, the information flows start from S3 of subcontractors' headquarters to D3 of plants. A plant represents a business unit for the engineering and production of the custom products. To make the custom product, the plants need to buy products, the raw materials, from the suppliers. To do this, the plants buy stocked standard products (from S1 of plants to D1 of suppliers) and standard/configurable products (from S2 of plants to D2 of suppliers). There are two alternative material flow paths from plants:

- The products can be delivered directly from D3 of plants to S3 of the construction site.

[6] All processes of the SCOR model use the notation "s", for example, P1 is sP1, S1 is sS1, etc. however, within this paper, the "s" is left out as it does not provide any additional benefit

- The products can be delivered from D3 of plants to S3 of subcontractors' warehouses.

The subcontractors communicate with the plants to check the production progress and to schedule the delivery (from S3 of subcontractors' headquarters to M3, and D3 of plants). Supply chains of custom products are driven by the customer's requirements and specifications.

4.2.1.2 Describing the supply of construction materials using the SCOR Level 3 model

The SCOR Level 3 model specifies the business processes involved in the supply chain, while the SCOR Level 2 model provides an overview of information flow and material flow along the supply chain. Figure 4-8 shows the SCOR Level 3 model for the supply of materials to the construction site which is proposed by Cheng (2009). This SCOR Level 3 model represents the construction supply chain for stocked standard products required at the construction site. Following the same example, SCOR Level 3 models can be constructed for make-to-order standard and for custom products. Figure 4-8 describes a complex map of the processes involved in the supply chain, which includes manufacturers, distributors, sub-contractors' headquarters, sub-contractors' warehouses, and the construction site. The connections among these processes of the SCOR Level 3 model are analyzed following the instructions provided in the SCOR model version 10 (SCC, 2010).

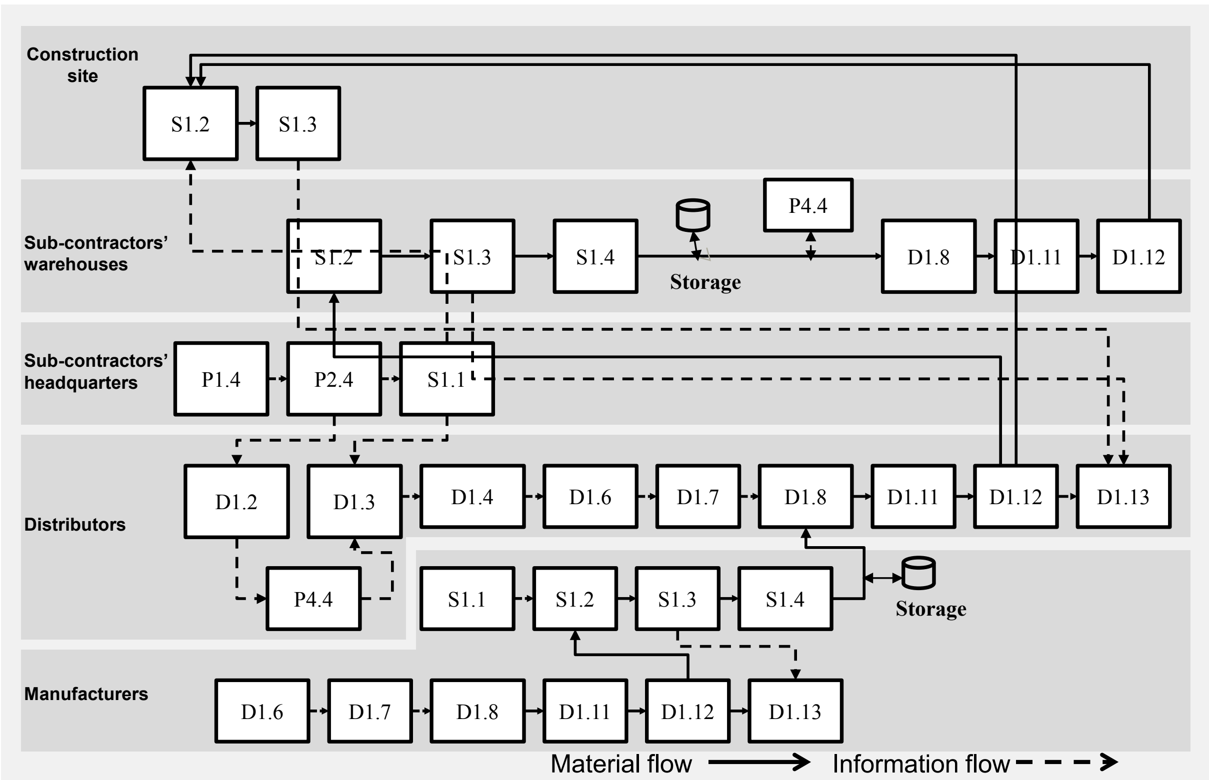

Figure 4-8: The SCOR Level 3 model for a construction supply chain for stocked standard products (Adapted from Cheng 2009, p.93)

In order to improve the comprehension and understanding of the SCOR Level 3 model, some additional objects are introduced in this model by Cheng (2009). These objects are part of the Business Process Modeling Notation (BPMN) (Object Management Group, 2015). This is a standard for business process modeling that can help define process interactions and facilitate communication in the process design and analysis phase. BPMN models can also act as a blueprint for subsequent implementation. There are four basic categories of elements in BPMN models – flow objects, connecting objects, swimlanes, and artifacts. For the present research the most relevant is the gateway. A gateway determines forking and merging of paths depending on the conditions expressed.

A gateway is used to control the divergence and convergence of multiple Sequence Flows. Thus, it will determine branching, forking, merging, and joining of paths. Icons within the diamond shape indicate the type of flow control behavior. Each type of control affects both the incoming and outgoing flow. The types of control include:

- Exclusive decision and merging (see Figure 4-9)
- Parallel forking and joining (see Figure 4-10).

An exclusive decision (gateway) restricts the flow such that only one of a set of alternatives may be chosen during runtime. This decision represents a branching point where alternatives are based on conditional expressions contained within the outgoing sequence flow. BPMN uses the term "merge" to refer to the exclusive combining of two or more paths into one path, also known as an OR-Join. A merging exclusive gateway is used to show the merging of multiple flows. If all the incoming flow is alternative, then a gateway is not needed. Exclusive gateways can also be used as a merge (see Figure 4-9b) for alternative sequence flow.

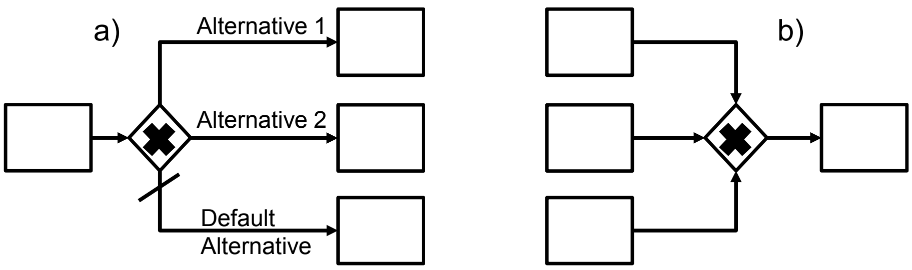

Figure 4-9: a) An exclusive decision (gateway), b) An exclusive merge (gateway)

Parallel Gateways provide a mechanism to synchronize parallel flows and to create parallel flow. These gateways are not required to create parallel flow, but they can be used to clarify the behavior of complex situations where a string of gateways are used and parallel flow is required. The parallel gateway must use a marker that is in the shape of a plus sign and is placed within the Gateway Diamond (see Figure 4-10) to distinguish it from other gateways.

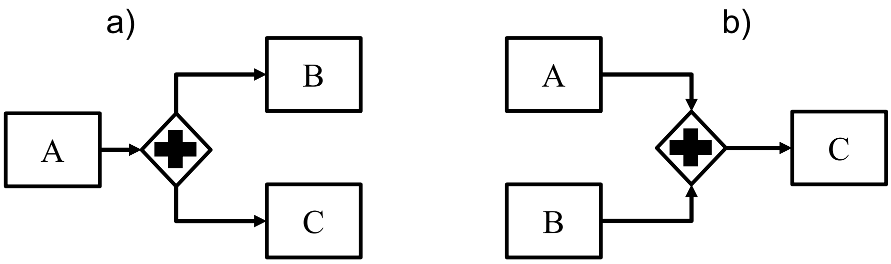

Figure 4-10: a) A parallel gateway (fork), b) The joining of parallel paths

BPMN uses the term “fork” to refer to the dividing of a path into two or more parallel paths, also known as an AND-Split (see Figure 4-10a). It is a place in the Process where activities can be performed concurrently, rather than sequentially. BPMN uses the term “join” to refer to the combining of two or more parallel paths into one path, also known as an AND-Join or synchronization (see Figure 4-10b). A Parallel Gateway is used to show the joining of multiple flows.

The SCOR Level 3 model using some objects of the BPMN model

The SCOR Level 3 model for a typical supply chain for stocked standard products shown in Figure 4-8 can be represented using BPMN (Figure 4-11). The SCOR Level 3 model for make-to-order standard/configurable products is shown in Figure 4-12. The SCOR Level 3 model for custom products is shown in Figure 4-13. The subcontractor’s headquarters, warehouse, and the construction site are separated by lanes. Each figure shows the subcontractor, the distributors, the manufacturers, the plants, and the suppliers.

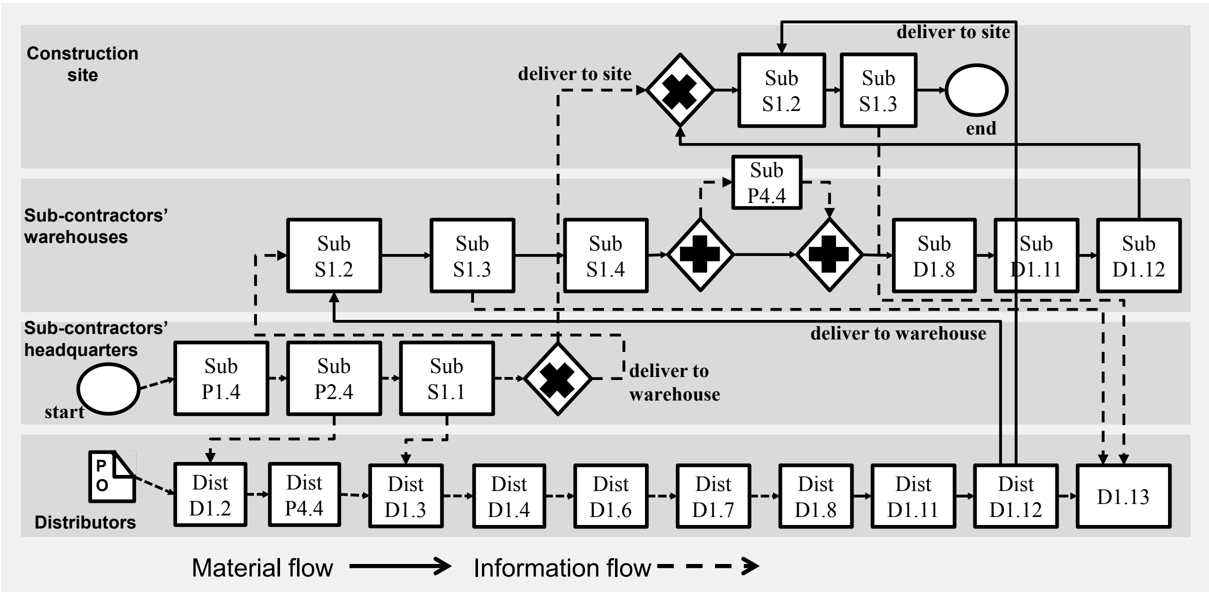

Figure 4-11: BPMN representation of the SCOR Level 3 model for stocked standard products (Cheng 2009, p.97)

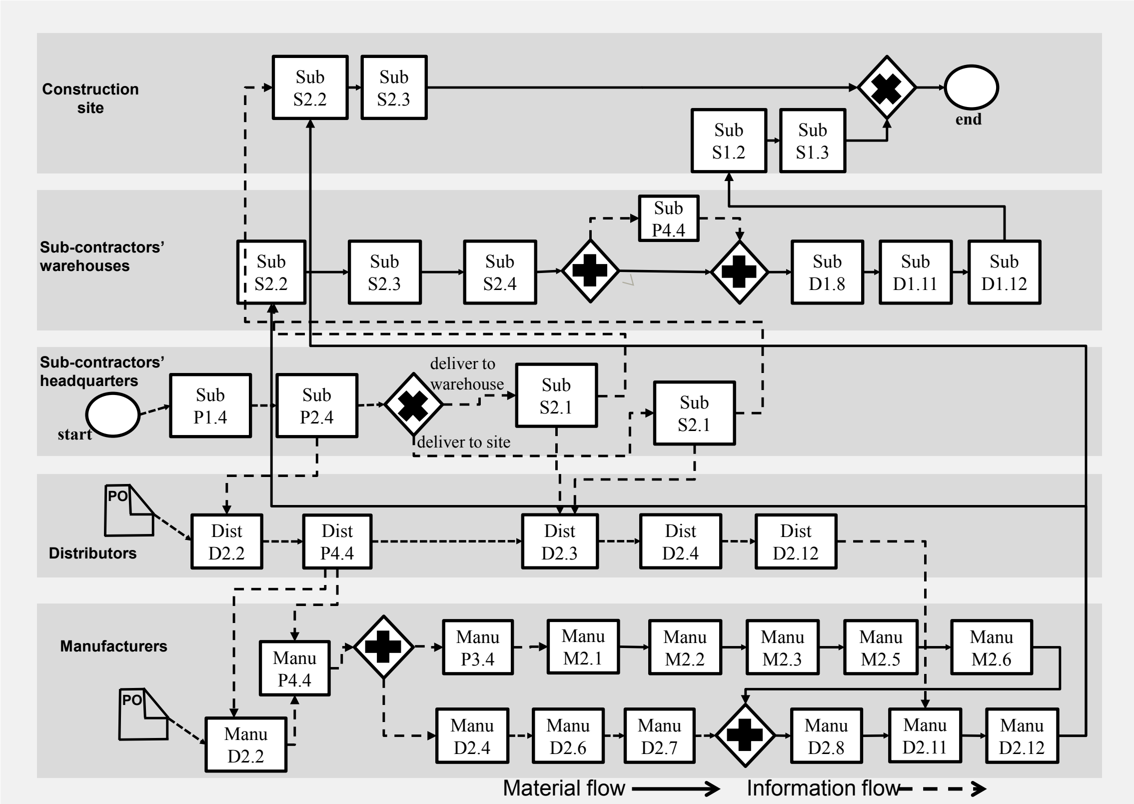

Figure 4-12: BPMN representation of the SCOR Level 3 model for make-to-order (Cheng 2009, p.97)

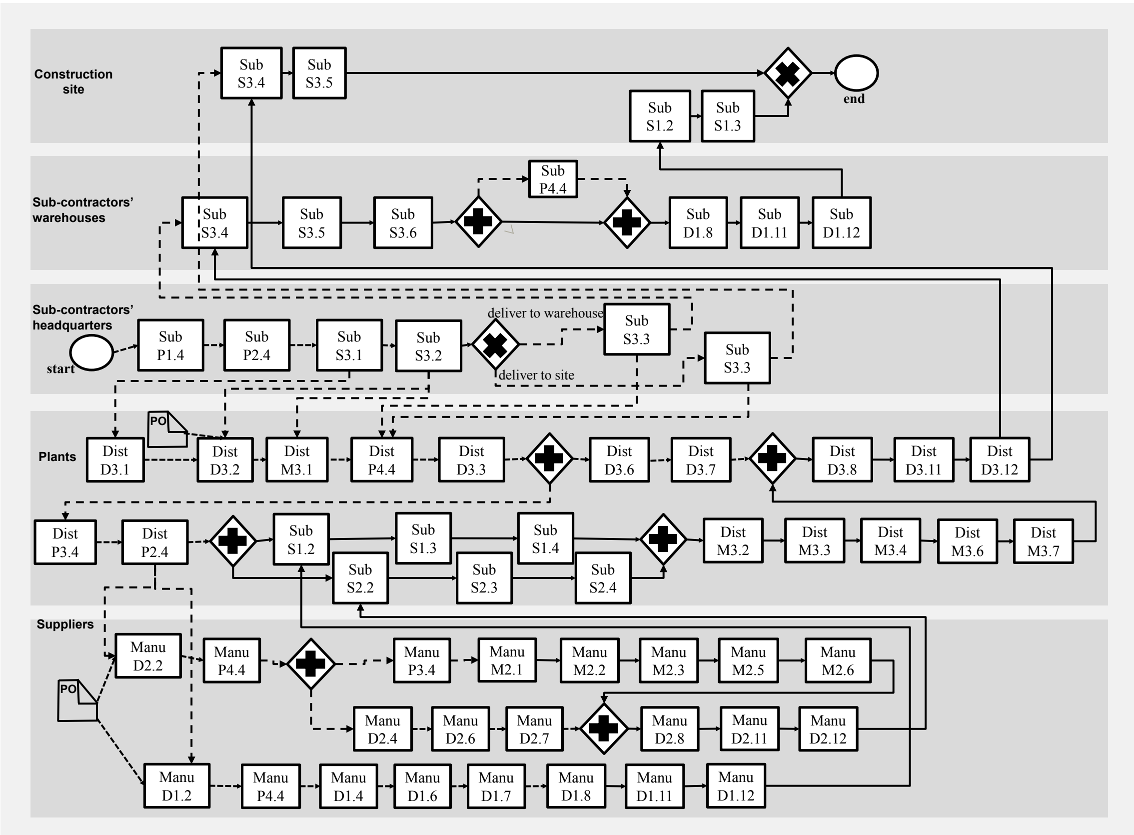

Figure 4-13: BPMN representation of the SCOR Level 3 model for custom products (Cheng 2009, p.98)

4.2.2 SCOR model applications in industrial contexts similar to the extraction process

The SCOR model has been widely used in recent years to analyze and reconfigure operations in the supply chain context. In this research work it is relevant to understand how the SCOR model has been applied and extended in other industrial environments with some similarities to the sourcing process in mining industry. The SCOR model was designed to model the processes of manufacturing environment. Nowadays, the SCOR model has emerged as a quasi-standard business reference model in manufacturing industries. As indicated in the previous chapters, there are important differences in the sourcing process of a manufacturing company and a mining company (Tardelli, Barbin, and Cesare de Tomi, 2004). Therefore, it must take into account these differences in the adaptation of the SCOR model to the extraction process. In this section the literature on applications of SCOR model in industrial contexts that have similarities to the extraction process is analyzed. Moreover, taking into account the existing applications of SCOR model the gaps with the extraction process are discussed in section 4.4.1.2.

4.2.2.1 Manufacturing environment

In the context of manufacturing environment, the first difference relates to the raw material supplier in manufacturing and mining. The manufacturing company can produce a product when it finds the right supplier of raw material in the global market, and it has production plants and distribution centers in the best possible location. In contrast, the extraction process begins operations only once it finds its supplier of raw materials, a mineral deposit. In addition, the production plant and equipment required in each of the processes should be available. As a fundamental requirement, the production facility must be located in the same place as the mineral deposit.

The second difference relates to the storage and retrieval of raw material to feed the processing plant. In the manufacturing company, raw material can be stored in a warehouse after being purchased in the global market (Gu, Goetschalckx, and McGinnis 2007; Rouwenhorst et al. 2000). Then, the raw material can be taken from the warehouse to be transferred to the production plant when it is required. However, in the context of the extraction process, the raw material is hidden under the surface of the earth in a mineral deposit (Tardelli, Barbin, and Cesare de Tomi, 2004). Other processes need to be performed prior to achieving the extraction of the raw material and its transfer to the processing plant. Given the above, it is clear that the extraction of raw materials from a mineral deposit in the mining industry is more complex than ‘sourcing’ raw materials from a warehouse in manufacturing industry.

In addition, the extraction process bears resemblance to the construction process. This similarity is because extraction is an extension of the construction process. Typically, the extraction process uses heavy equipment similar to that of a construction company to perform similar activities, such as the breaking of rocks and moving those rocks to predefined destinations. In addition, similar technology is used, and varies based on whether the mine is open pit or underground. For example, an open pit mine uses drills, shovels, loaders, and trucks. Underground mine equipment has similar functionality, but it is smaller because it must work in confined spaces in the tunnels. Given these similarities between construction and extraction, the existing literature on applications of SCOR model to the construction industry are relevant to applying and adapting this model to the extraction process.

Furthermore, there are certain similarities between the extraction process and the manufacturing process related to delivering a product. Simply put, the extraction process ‘produces’ a product which is transferred and delivered to a customer (processing plant). During the extraction process, the rock is ‘produced’ (ore and waste) and it is loaded onto trucks and moved to predefined destinations. The mineral can be sent to the processing plant or sent to an intermediate stockpile between the mine and plant. Waste is transferred to a dump. In contrast, with construction, there is no transfer and delivery as such to the customer, who must go to the site where the product was manufactured and use the product (i.e. building, bridge, block area, roads, etc.).

Additionally, the SCOR model has been applied in the context of geographic information systems (GIS), where spatial and related non-spatial data are considered as its raw materials (Schmitz, 2007). In the extraction process, the raw materials are different in comparison with the raw materials of the manufacturing industry and the GIS environment. Therefore, in order to compare the implications of these differences in the SCOR model application, the analysis is done below.

4.2.2.2 Geographic information systems (GIS) environment

In the PhD thesis of Schmitz (2007) an application of the SCOR model in the context of Geographic Information Systems (GIS) is developed. For this application, an equivalence with a typical supply chain in the context of manufacturing industry was needed. In comparison with the manufacturing environment, in the GIS environment there is no flow of materials among the processes. Data is the raw material and its transformation creates the products that are required by customers (see Figure 4-14). The analogies drawn in this research are as follows:

- Raw materials: various data sources – spatial and related non-spatial data from suppliers.
- Warehouse: data warehouses.
- Product: a GIS product (map) is a commodity created from sourced raw materials.
- Inventory: available data layers in a data warehouse or other storage devices.

- Distribution centre: an Internet or FTP site from which GIS products can be downloaded. An enterprise-wide data server is also a distribution centre.
- Transport: data via Internet, Intranet, WAN/LAN or on CD-ROM, DVD or RHD which are transported personally or via a courier company acting as a third party logistics (3PL) provider for the GIS unit.

Taking into account this research study an equivalence in the context of the extraction process is developed.

- Raw materials: mineral block from mineral deposits (suppliers).
- Warehouse: a warehouse now becomes a warehouse of rocks (located in the mine).
- Product: a product (mineral rock) is a commodity created from sourced raw materials (mineral block).
- Inventory: an available stock of blocks in the mine.
- Distribution centre: the dispatch centre, which coordinate all the activities to remove the rock (ore and waste) to different destinations (Modular Mining Systems, 2015).
- Transport: the rock (ore and waste) is transported using trucks or other type of transport.

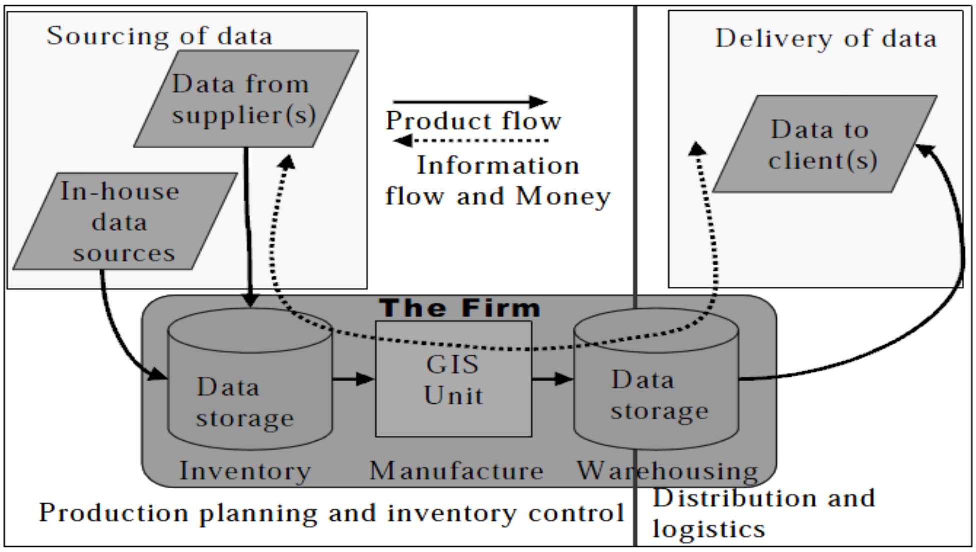

Figure 4-14: Geographic Information Systems (GIS) supply chain (Schmitz, 2007)

In the PhD thesis of Schmitz (2007) the SCOR model was applied in the context of GIS without making changes to the processes of this model. This leads to the conclusion he has done analysis and translation of the semantics used in the context of GIS to the SCOR model annotation. The contribution of his research work was applying a standard language in manufacturing (SCOR model) to a different domain (GIS). This application of SCOR model to GIS contributes to integration of the supply chain of GIS products with other supply chains of products that are based on the SCOR model. In addition, this work demonstrates how to perform an analysis and translation of the semantics used in another industrial context (GIS) to an equivalent in the manufacturing industry, ie the SCOR model. This approach is chosen for the analysis of the extraction process in the mining domain.

4.2.3 Link between the processes of construction and extraction

This link is for the connection between the 'Deliver' process of the SCOR model in the construction site, and the 'Source' process of the SCOR model in the extraction process. In literature there is no specific proposal for this connection in the mining context. However, in the context of manufacturing industry, some alternatives and proposals for applications of the SCOR model for the link (Deliver-Source) have been analyzed. Fronia, Wriggers, & Nyhuis (2008) indicate that the process categories described in Level 2 of the SCOR model do not allow a clear depiction of the processes which occur in the field. In particular, the link between the 'Deliver' process of the previous enterprise and the 'Source' process of the following company is not sufficiently distinguished. In sourcing for example, the SCOR model only differentiates three process categories Source Stocked Product, Source Make-to-Order Product, and Source Engineer-to-Order Product. In the industrial practice, however, these process categories can exist in extremely different forms. As a result, Fronia, Wriggers, & Nyhuis (2008) suggest adding six standard process models for Source Level 2 (see Figure 4-15). These are inventory sourcing, standard parts management, consignment concept, contract warehouse concept, synchronized production processes, and individual sourcing. In comparison to those natives to SCOR, these six models are shown to be advantageous, distinguishing more clearly among different modes of procurement. Consecutively, they have shown how these new models were detailed on SCOR Level 3 and 4.

Looking at the six standard process models of Fronia, Wriggers, & Nyhuis (2008), two among them, 'Inventory Sourcing' and 'Consignment Concept', show similarities to the sub-processes shown in Figure 2-13. The Inventory Sourcing bears some resemblance to the sub-process 'Build Mineral Extraction Capability' shown in Figure 2-13, in which the construction process generates a stock of mineral blocks. The 'Consignment Concept' bears some resemblance to the rest of the sub-processes in the construction process, as is shown in Figure 2-13, for example as described in 'Build Beneficiation Capability'.

- With traditional Inventory Sourcing the supplier (construction process) delivers according to orders. The change-over of ownership occurs with the delivery of the goods (i.e. a stock of mineral blocks). The customer thus carries the costs and risks involved with storing and provision. Furthermore, materials are consciously stored in advance, in order to ensure a high level of availability for subsequent manufacturing processes (i.e. extraction process).
- In Consignment Concept, the change-over of ownership to the customer occurs at the point in time when the materials (buildings, infrastructure, etc.) are

removed directly at the place of use. This means that the storage and provision of goods are the responsibility of the supplier. Consequently, the supplier remains the owner of the goods until the customer uses them. The supplier has to ensure that a specific, pre-defined minimum stock level is maintained.

Translating the 'Consignment Concept' to apply to the mining industry, customers are required to go to the place and use the product because there is no possibility of transporting the product to another place. This means that construction process (supplier) delivers a processing plant (construction product) with some capacity for which it was built. The customer/client receives the plant and uses the plant to test whether it meets the specifications requested. In the context of mining, the construction process remains the owner of the processing plant up until the point in time at which the customer is completely satisfied with the operation of the plant, and proceeds to final acceptance of the product.

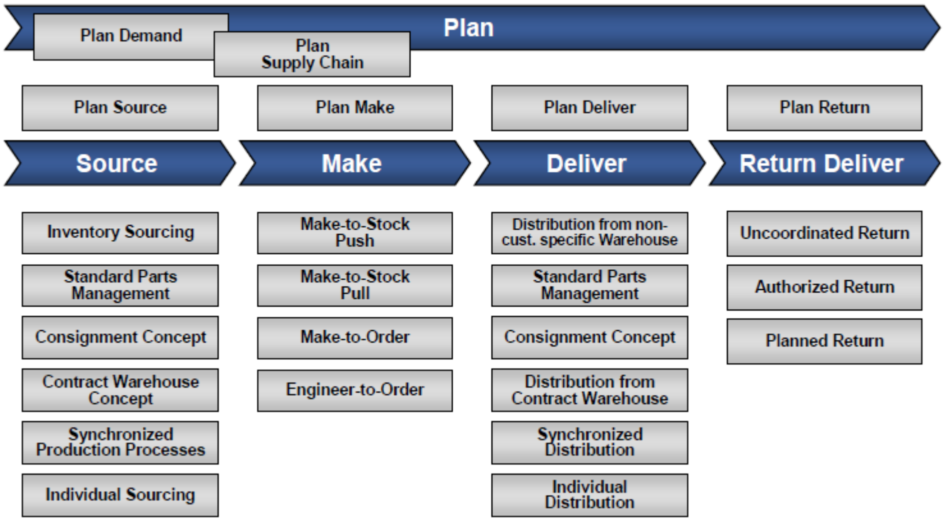

Figure 4-15. Standard process models – an enhancement of the SCOR model (Fronia, Wriggers, & Nyhuis, 2008)

4.3 Applications of DCOR model

The DCOR model defines the business activities between customer requirements and the design or specification of a product to meet customer demand. The purpose of DCOR is to standardize the definition of product development and R&D, particularly for New Product Development (NPD) processes for offering a common language among design chain partners. The DCOR model borrows heavily from SCOR in terms of language, presentation, and layout. Similarly to SCOR, the DCOR model includes performance attributes, best practices and metrics (SCC, 2004).

The DCOR model is designed and maintained to support design chains of various complexities and across multiple companies. The council has focused on three process levels and does not attempt to prescribe how a particular organization should conduct its business or tailor its information flow. Every organization using the DCOR model to improve its design chain needs to extend the model, at least to Level 4, by using organization-specific processes, systems, and practice (Lyu et al., 2006).

There is limited research evidence of DCOR applications to the processes of mining industry. However, a review of literature both academic and professional yielded some relevant discussion on the application of DCOR in other industrial enviroments. These DCOR applications are part of the inputs for the DCOR adaptations to the processes of exploration and engineering design in mining industry to be developed in the next chapter. In this section some exemplary industrial applications of the DCOR model are presented, and the most appropriate approaches for mining are selected.

4.3.1 DCOR model applications in different industrial environments

A literature review revealed some applications of DCOR in different industrial environments. Chen et al. (2006) applied the DCOR model to the design chain planning model for the technical fabric industry. The DCOR model was adopted in establishing an optimized operation model in the sector. It effectively coordinates collaborative design processes among systems; minimize planning, RD, design, integration, and cycle time needed for improvement.

Wu, Yeh, & Fang (2006) used the DCOR model, and integrated the concepts of design chain, collaborative product design (CPD), and collaborative product commerce (CPC) to develop a collaborative design chain system in the product lifecycle. The model has a hierarchical structure resembling DCOR's four levels: business, cooperative, process, and operational. The case study showed the importance of information sharing and management.

Lyu, Chang, Cheng, & Lin (2010) developed an approach that extends the DCOR to the mould industry. The M-DCOR was designed for evaluating, positioning, and implementing to improve design chain in the mould industry. Based on DCOR model, design level 4 processes are used for mould development. A case company integrates design chain from mould material preparation and mould development to the product manufacturing assembly lines of manufacturers. They implemented a Web-base system to strengthen information exchange between mould providers.

Juan, Ou-Yang, & Lin (2009) proposed a process-oriented multi-agent systems (MAS) development approach to support the cooperation requirements in a concurrent new product development (CNPD). CNPD processes are defined using a modified 3rd level of the DCOR model (process element level) and represented using e-Business Scenario Diagrams. This approach is acting in two phases: the process-oriented cooperation requirements analysis phase, and the MAS specification design phase. In a complete CNPD process, different cooperation requirements take place at different stages and need different workgroups to be involved.

From the applications of DCOR model in the abovementioned industrial contexts, the following items are evident:

- The DCOR model applications are focused on product design.
- The DCOR model is used to support the cooperation activities of the providers or workgroups that participate in the product design.
- The semantics used in product design create difficulties in applying the DCOR model in the mining industry environment.

In order to highlight the relevance of the semantics in the application of DCOR model, a similar experience exists in the adaptation of SCOR model to the service industry. In the context of the service industry, the limiting factor of the semantics is the definition and use of the “MAKE” process. The “MAKE” definition in the SCOR model is the process of manufacturing that adds value to a product. Barnard (2006) indicates that the conversion of the “MAKE” process of SCOR to service semantics creates a situation that is lost in translation. The “MAKE” process in the service industry does not have a direct translation. In addition, Barnard (2006) adds that the “RETURN” process is another process that is not in any services setting. He states that the physical return of a service is highly improbable because once a service is rendered the service is consumed, thus invalidating the semantic and process descriptions in relation to services.

In section 4.4.2, the limitations of the DCOR model in semantics when this model is applied in the mining domain is discussed.

4.3.2 Existing approaches of DCOR model applications

Hunsche (2006) explains how the DCOR model can be used to describe the development of the MP3 product. This approach is a good example how two processes or workgroups can work in collaboration to produce a product. In the context of mining there are two processes, exploration and engineering design, which need to work together to design a new mine project. This approach is chosen to apply and adapt the DCOR Level 2 model to the processes of exploration and engineering design.

In the MP3 example that is shown in Figure 4-16, Hunsche (2006) indicates that the company has a dedicated R&D team focused on audio compression technology. The work of this team is driven by the overall product roadmap. The Plan processes a link to the DCOR processes. Research and Design are driven by this plan. The MP3 player team works off the same product roadmap. One of the key design elements for the player is the audio compression technology. The research for the MP3 player encompasses the linkage to the work of the MP3 compression team. The MP3 compression team works with the MP3 player team to “integrate” the technology into the MP3 player design. Thus, Integrate processes link to Research processes (see circle 1). The activities between the teams are coordinated in the Plan processes (see circle 2). The research process for the MP3 player needs to take place. The MP3 technology must match the requirements for the player. The requirements include costing, form (compression), fit (can it be integrated in the product), function (quality-loss), etc.

In the DCOR model, the 'Research' process includes the process of collecting and formatting the inputs to the transformation process. The 'Design' process is the transformation process. In Design the 'raw materials', for example ideas, technology and components, are integrated in the design of the 'product.' The final design needs to be released into the company. The 'Integrate' process is the delivery of this design into the supply chain, marketing, sales, and support.

From the literature review of relevant papers abovementioned in section 4.3.1, the approach that is proposed by Juan, Ou-Yang, & Lin (2009) is chosen to apply and adapt the DCOR Level 3 model to the processes of exploration and engineering design. This approach presents an application of the DCOR Level 3 model to the concurrent new product development (CNPD). This approach is chosen for the following reasons:

- The approach takes into account the organizational aspects as it allows showing more clearly the cooperation and coordination activities among different workgroups.
- In this approach, the main activities of product development are described using the process elements of DCOR Level 3 model. These main activities are assigned to each of the workgroups involved in the product development.
- This approach has some similarities with mining projects development to create a mineral commodity. These similarities are the following:
    - the workgroups in the organization involved in a project
    - the activities of cooperation and coordination between the workgroups
    - takes into account the requirements arising from the organization
    - considers the requirements and specifications that occur in the processes elements of the DCOR model
    - integrates the process elements of DCOR model with organizational aspects in products development

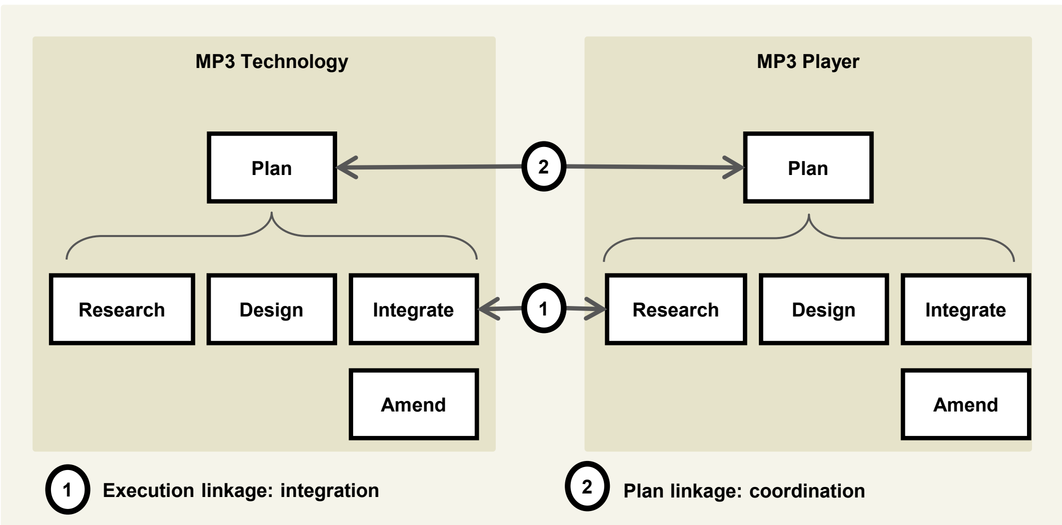

Figure 4-16. DCOR Level 1 model for MP3 product development (Hunsche, 2006)

Figure 4-17 describes the modified DCOR Level 3 model proposed by Juan, Ou-Yang, & Lin (2009), which will be applied and adapted to the mining domain in section 5.2.2.2 and section 5.2.3.2.

As Figure 4-17 shows, the Y-axis is tagged with the names of participant workgroups. To the right of workgroups, the standard notation of DCOR's New Product is used to specify the workgroup's tasks and cross-workgroup information flows. In addition, a circle is used for the cooperation-activity. The procedure for defining CNPD process is as follows:

- *Step 1*. Designate participant workgroups. The number and name of workgroups participating in a CNPD process would differ depending on the company's practices. Thus, a company should refer to its organizational structure and designate the names of participant workgroups from upstream to downstream on the Y-axis. The top workgroup is always the initiator of the CNPD process.
- *Step 2*. Specify the main-activity managed by each workgroup. This is a set of tasks that the workgroup should perform to complete the stage. The process elements of DCOR's New Product can be used to represent these tasks. The process elements are listed using DCOR's standard notation on the right-side of the workgroup name and aligned from left to right according to their executing sequence. Additionally, the input/output information of the process elements which vertically flows among workgroups should also be retrieved from DCOR's New Product and depicted on the diagram to connect relevant process elements.
- *Step 3*. Specify the required cooperation-activities interacted between workgroups. CNPD emphasizes that upstream workgroups should cooperate with downstream workgroups in their own stages to simultaneously consider all desired characteristics for downstream stages. A company should specify where the cooperation-activities will occur. The vertical cross-workgroup information flows depicted in step 2 have shown the likely place for cooperation-activities. However, it still needs the company to confirm the need for a cooperation-activity and to note the cooperation-activity name beside the tagged circle.

Figure 4-17 is a Modified DCOR Level 3 model used by Juan, Ou-Yang, & Lin (2009) to define the CNPD process for an empirical case, Y Corp. Four workgroups, including Marketing (M), Product Design (PD), Component Design (CD) and Industrial Engineering (IE), are involved in the new product development of Y Corp. Workgroup M starts the CNPD process with customer requirements and then works with the Product Design (PD), Component Design (CD) and Industrial Engineering (IE) to come to a consensus about the requirements. Next, based on the requirements, workgroup PD defines, creates, analyzes, tests, and releases the form, fit, and function of a new product prototype. Meanwhile, it gets a confirmation about the product prototype design from workgroup IE and gets the consensual component requirements from workgroup

CD. Afterward, workgroup CD satisfies all component requirements through the identification of sources of supply, sourcing, and validation of materials against product requirements. Finally, workgroup IE creates and verifies the product pilot and releases the product definition and documentation to supply chain and selling chain execution.

From the above information, Y Corp. can first designate the names of workgroups from Marketing to Industrial Engineering on the Y-axis (Step 1). Next, by mapping the process elements of DCOR's New Product (compiled in Table **4-1**) to workgroups' tasks, process elements I2.1–I2.3, D2.1–D2.6, R2.1–R2.6, and I2.4–I2.7 are assigned to workgroups M, PD, CD, and IE, respectively. Afterward, the input/output information vertically flowing among workgroups (as shown in Table 4-2) is retrieved from DCOR's New Product and depicted on the diagram to connect relevant process elements (Step 2). As Figure 4-17 shows, there are seven cross-workgroup information flows which indicate a likely place for cooperation-activities. However, four early cooperation-activities, including Module Req. Coordination, Component Req. Coordination, Prototype Req. Coordination, and Pilot Design Req. Coordination, are finally specified on the diagram (Step 3) and the desired CNPD process is derived. It is mainly charged with receiving, decomposing, and distributing requirements.

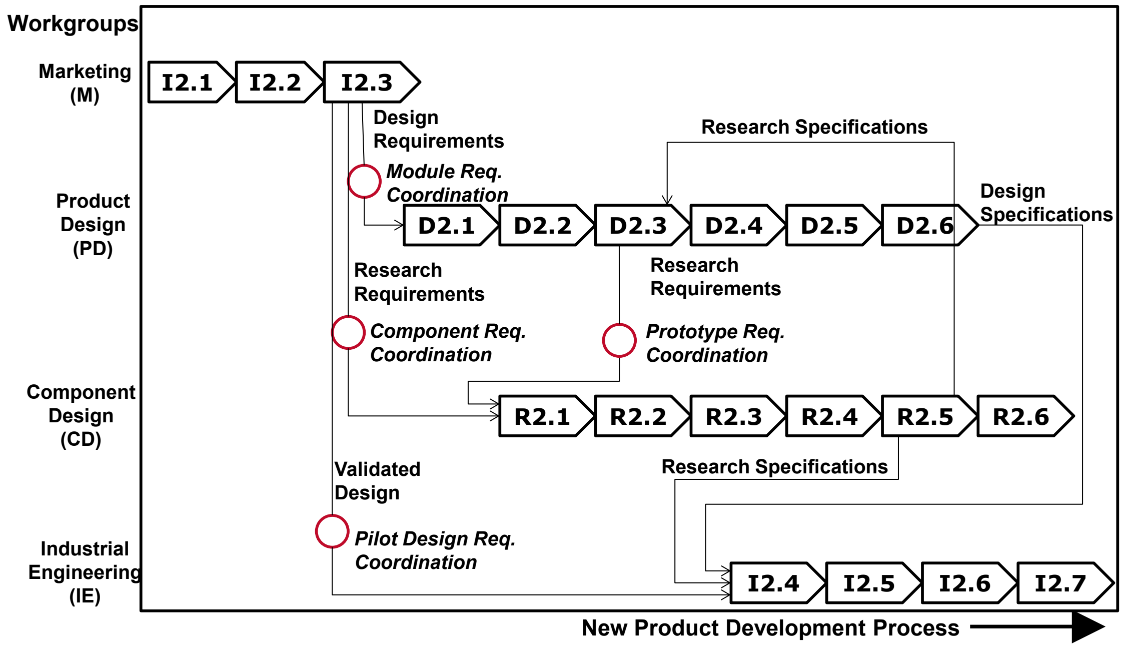

Figure 4-17. Modified DCOR Level 3 model (Modified D-L3-M) for Y Corp.'s CNPD process definition (Juan, Ou-Yang, & Lin, 2009)

In the approach proposed by Juan, Ou-Yang, & Lin (2009) shown in this section, requirements and specifications in DCOR model are very important to describe the design of a product. In the next section, the requirements and specifications are explained in more detail because they must be considered in applying and adapting the DCOR model to the processes of exploration and engineering design in mining industry.

Table 4-1: Process elements of DCOR's New Product (SCC, 2004)

R	Research	D	Design	I	Integrate
R2.1	Receive & Validate Request	D2.1	Receive, Validate & Decompose Request	I2.1	Receive & Validate Request
R2.2	Schedule Research Activities	D2.2	Schedule Design Activities	I2.2	Decompose Request
R2.3	Source Materials	D2.3	Develop Prototype	I2.3	Distribute Requirements
R2.4	Verify Materials	D2.4	Build & Test Prototype	I2.4	Receive & Validate Design
R2.5	Transfer Findings / Materials	D2.5	Package Design	I2.5	Pilot Design
R2.6	Authorize Supplier Payment	D2.6	Release Design to Integrate	I2.6	Package Product
				I2.7	Release Product

Table 4-2: Cross-workgroup information flow retrieved from DCOR's New Product (Juan, Ou-Yang, & Lin, 2009)

Input/Output	Description/Definition
Design Requirements	Design requirements are the translation of a set of functional requirements into design specifications that meets both the enterprise and customer expectations.
Research Requirements	Research requirements related to design needs, including forecasts and actual orders and backorders.
Validated Design	A design of product which ensures performance and conformance to defined specifications and requirements.
Design Specifications	Design Specification will: a) Define the technical scope of the product. b) Define the expected use and purpose of the product. c) Define relationships with existing products. d) Describe the design of the product.
Research Specifications	Research specifications: Product Description, Raw Materials, Equipment Required, Production Consideration, Production Process, Merchandising Considerations, Estimated Shelf-Life.

4.3.3 Requirements and specifications in DCOR model

In the DCOR model a ***'requirement'*** can be driven by the company or by customers. The requirements define necessary objectives which must be met or define what the project is ultimately supposed to do. Most requirements are defined in functional terms, leaving design and implementation details to the developers. The requirements may include what a company wants in a product, to include performance, reliability objectives in fine detail, some aspects of user interface, support services, and product data. In addition, user requirements describe the needs, goals, and tasks of the end user. The system requirements can refer to the requirements that describe the capabilities of the system on which the product will function or can refer to the requirements that describe the product itself as a system. In the context of a mining company, the research requirements are more focused on discovering and assessing new mineral deposits. These requirements must meet the enterprise's expectations.

In the context of a mining company, the research requirements can be driven by the company and they define the objectives of what a mining project must do. For example, the requirements include discovering and assessing new mineral deposits. These requirements must meet the enterprise's expectations. The design requirements are the translation of process requirements into design specifications that meet the enterprise's expectations.

In DCOR model a ***'specification'*** is an explicit set of requirements to be satisfied by a material, product, or service. Specifications are a component of product data. Specifications are critical inputs in the Supply Chain, for instance for users of the SCOR model. In Make we produce to specification (e.g. in construction process), or in Repair we return the item to specification. Specifications originate and are managed and changed in the Design Chain. What is key for the DCOR model is that specifications for products, assemblies, subassemblies, components, parts, processes, and materials are outputs of the three execution processes of DCOR model, Research, Design, and Integrate. These execution processes generate the following forms of specifications:

Research process: The research specifications are the following: product description, raw materials, equipment required, production consideration, production process, merchandising considerations, and estimated shelf-life result from the research execution processes. In the context of the exploration process of a mine project, the research specifications can include characteristics of mineral rocks, size of mineral deposit, mineral deposit characteristics, estimated mine life, ore-grade, geological information, etc.

Design process: The design specifications define the technical scope of the product, define the expected use and purpose of the product, define relationships with existing products, and describe the design of the product. In the context of a mine project, the design specifications can include: define the technical scope of the mine project, define the expected use and purpose of the project, define relationships with existing mine projects, and describe the design of the mine project.

Integrate process: The product specifications are produced in this process as detailed product information including, but not limited to, key features, compatible options, part numbers, and technical specifications.

Specifications are used in design, manufacturing, and engineering and they are critical for suppliers, purchasers, and users of materials, products, and services to understand and agree on all requirements. A spec may also be a type of a standard which is often referenced by a contract or procurement document. It provides the necessary details about the specific requirements. Specs can be written by the government (e.g. Mil Std), standards organizations (ASTM, ISO, CEN, etc.), trade associations, corporations, and others.

A spec might include drawings, photos, or tech illustrations; safety considerations and requirements; certifications required; environmental considerations and requirements; quality requirements, sampling (statistics), inspections, and acceptance criteria. Also, a spec includes terminology and definitions to clarify the meaning of the spec; descriptive title and scope of the spec; date of the last revision and revision designation; person, office or agency responsible on the spec for updates or deviations; etc.

In the context of a mine project, the validated design is a design of a mine project which ensures performance and conformance to defined specifications and requirements.

4.4 Gap analysis between processes of EM model, and SCOR and DCOR models

In the context of process modeling, gap analysis focuses on the gaps between the processes of the SCOR and DCOR models, and the mining processes of the EM model. Gap analysis involves comparing what is in the processes in the mining domain (EM model) with what should be in the annotation of the mining processes in the supply chain domain (SCOR model) and the design chain domain (DCOR model). In this section the gap is identified. This is the foundation for the next chapter where the ways of bridging the gap are discussed.

4.4.1 Gap analysis between the SCOR model and the mining processes of the EM model

Comparing the mining processes of the EM model with the execution processes of the SCOR model, there are similarities and differences between both model processes. The similarities occur within the ‘make’ and ‘deliver’ processes of the SCOR model, and within the ‘processing’ and ‘distribution’ processes of the EM model, respectively. This means that the processes of the EM model can be relatively easily described by using the SCOR model, without need of adaptation. However, a large difference between the ‘source’ process of the SCOR model and the ‘sourcing’ process of the EM model exists. This ‘sourcing’ process includes the exploration, engineering design, construction, and extraction processes of the EM model. Because most of the traditional frameworks of supply chain modeling are focused on the manufacturing industry, they do not include this type of ‘sourcing’ process. The ‘source’ process of the SCOR model focuses on purchasing/procurement, which is different from the ‘sourcing’ process in the mining industry. For example, Figure 4-18 shows the ‘source’ process of the SCOR Level 2 model for stocked product ‘S1’ which includes the following process elements (SCC, 2010): schedule product delivery (S1.1), receive product

(S1.2), verify product (S1.3), transfer product (S1.4), and authorise supplier payments (S1.5). In contrast, the 'sourcing' process of the mining industry includes exploration, engineering design, construction, and extraction processes. Thus, the main difference between the two is the way raw materials are obtained. Consequently, there is a gap between what the SCOR model defines as the 'source' process and how the 'sourcing' process actually works within the mineral raw materials industry.

This research focuses on applying and adapting the SCOR model annotation to the extraction and construction processes. These processes are part of the 'sourcing' process described within the EM model. The exploration and engineering design processes, also part of the 'sourcing' process in the EM model, are not in the focus of the SCOR model. Specifically, SCC (2010, p.11) indicates that the SCOR model does not address sales and marketing, product development, research and development, and some elements of post-delivery customer support. The exploration and engineering design processes are more similar to product development processes or research and development processes and are best suitable to the DCOR model (SCC, 2006). Therefore, this research also focuses on applying and adapting the DCOR model annotation to the exploration and engineering design processes.

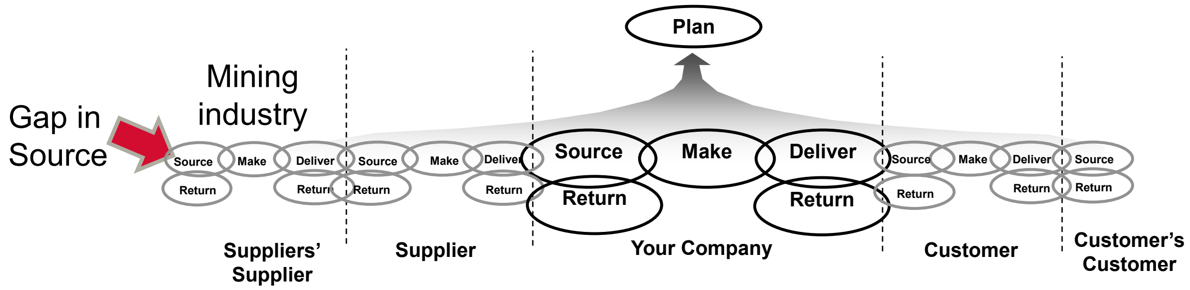

Figure 4-18: Gap in the 'Source' process of the SCOR model

4.4.1.1 Gap analysis between the processes of SCOR and the construction process

The applications of the SCOR model described by Cheng (2009) do not include a complete description of the construction site. He only describes the 'Source' process of SCOR model that is shown in Figure 4-19 which represents the supply of materials for the construction site. This 'Source' process of SCOR model is analogous to the sub-process 'Develop Operational Capability' shown in the EM model in Figure 4-19. In the context of mining, this process includes receipt, verification, and transfer of materials to the construction site.

Figure 4-19 shows the sub-processes of the construction process in the EM model. These sub-processes were defined and described in section 2.3.1.3. A distinction is made between those sub-processes oriented to describe the product and those oriented to create a link with suppliers and customers. It is important to consider whether the SCOR model application to the construction industry, which is proposed by Cheng (2009), fits with sub-processes of the EM model in Figure 4-19.

Cheng (2009) does not describe the 'Make' and 'Deliver' processes of the SCOR model depicted in Figure 4-19. The ‘Make’ process of the SCOR model allows a description of product manufacturing. At the construction site, everything needed for the construction products indicated in Figure 4-19 can be manufactured using the construction process. These construction products are as follows: build mineral extraction capability, build beneficiation capability, build facilities, and deploy utilities. The construction of these products depends of the project to be developed: Greenfield, Brownfield, or Operational. For example, for a Greenfield project, extraction, beneficiation, and utility facilities must be built anew, as there are no pre-existing facilities nearby. In contrast, in a Brownfield project there are facilities nearby, some of them can be used and others need to be built. In the case of an ongoing, operational project, certain updates or enhancements are necessary, for example installing a larger plant to process ore rock, or developing a new phase in the current mine.

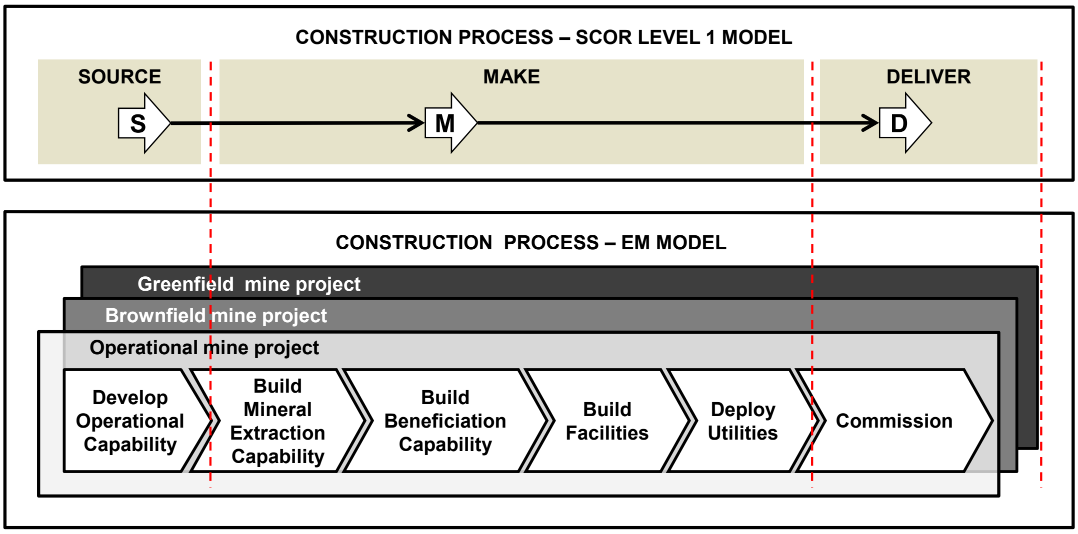

Figure 4-19: Gap between the EM-model and the SCOR Level 1 model in the construction process

In applying the SCOR model to the construction site, the ‘Make’ process is similar to any ‘Make’ process of a manufacturing company, which can be described by SCOR model. This similarity exists because a temporary manufacturing company is installed on the construction site (Cheng, 2009). However, the most significant difference occurs in the ‘Deliver’ process of SCOR model, this difference is explained by the particular characteristics of a construction product compared to other manufactured products. For example, the facilities which are built remain at the construction site and cannot be physically sent to another location to be delivered to the customer, as in most manufactured products. In construction, there is only a formal transfer of the product which involves a change of responsibility. The product passes from one owner to another owner of the product, and the product remains in the same place. This 'Deliver' process of the SCOR model is analogous to the sub-process ‘Commission’ shown in the EM model in Figure 4-19.

In addition, a gap is identified in the SCOR model in relation to the provision of engineering design documentation and specifications, which must be supplied by the ‘Engineering Design’ process. This link between the processes of engineering design and construction is analyzed in the section 4.4.3.

4.4.1.2 Gap analysis between the processes of SCOR and the extraction process

A gap in the literature has been observed between SCOR model and the extraction process of the EM model. In Figure 4-20 the essence of a supply chain for the extraction process is shown. This figure reflects the similarities mentioned above with Figure 4-14. (1) Extract or access the raw materials found in the stock of mineral blocks. The construction process supports this extraction. (2) Convert these raw materials, the mineral blocks in specific products, which are mineral rock and waste material. (3) Lastly, the products are delivered to a final customer or any pre-defined destination. The mineral rock is delivered to the processing plant, the waste is delivered to a dumped waste, and sometimes mineral rock is delivered to a stockpile to be stored until a new decision changes the destination to the processing plant.

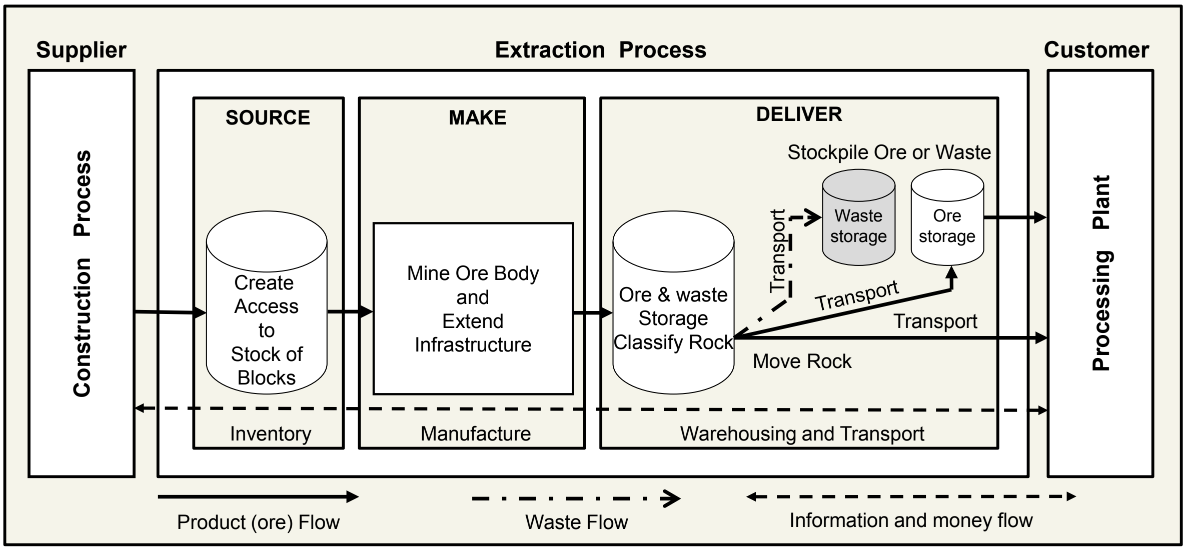

Figure 4-20: The extraction process supply chain (adapted from Zuñiga, Wuest, & Thoben, 2013)

The extraction process containing the components of a supply chain, namely sourcing, manufacturing, and delivering, are shown in Figure 4-21. The SCOR Level 1 model covers these components within its macroprocesses Source, Make, and Deliver. Also, a real description of the extraction process is shown in the base of the Figure 4-21 (extraction process – mining industry), which describes the extraction process as-is in a mining company. In addition, Figure 4-21 integrates the sub-processes of the EM model in order to translate these processes to the SCOR model annotation.

Because the physical return of a mineral rock is highly improbable, there is no 'Return' process of SCOR model in the extraction process. This is because once an extraction is rendered, the materials must be delivered to some pre-define destinations to continue the exploitation of the mine. Moreover, this chain is traditionally characterized by a forward flow of materials and a backward flow of information.

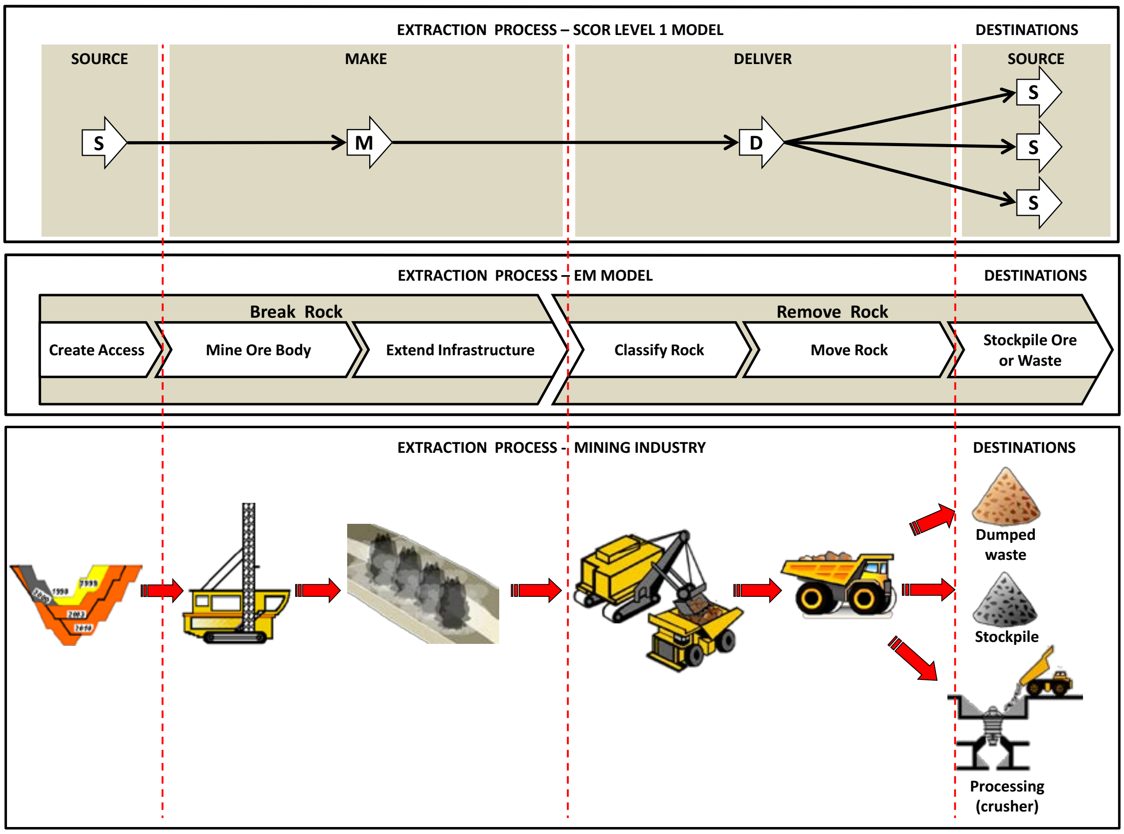

Figure 4-21: Gap between the EM-model and the SCOR Level 1 model in the extraction process

As shown in Figure 4-20, the construction process delivers an area or a site, which represents a stock of mineral blocks in the mine site. This stock cannot be transferred as-is from the site because it adheres to the mineral deposit in the mine site, forcing the extraction process to relocate to the site in order to break it and remove it. Given the above, a manufacturing equivalence exists, indicating that the extraction process receives a stock of raw materials in the form of a mineral block. However, these blocks need to be removed from the mineral deposit using the extraction process. The extraction includes drilling blocks, and uses explosives to break rock and thus achieve a final product, the broken rock. The product is rock pieces of a size suitable to feed the processing plant. Again, analyzing similarities to manufacturing, the stock of rocks may represent a warehouse of finished products localized in nature (the mine), which contains mineral rock and waste. This stock of material must be removed from the warehouse and sent to different predefined destinations (client).

Therefore, the approach that is proposed by Schmitz (2007) in the application of SCOR to GIS environment is used in applying and adapting the SCOR model to the extraction process. This approach is chosen as a base to apply and adapt the SCOR Level 2 model to the extraction process. This approach presents an application of the SCOR Level 2 model to the Geographic Information Systems (GIS) supply chain.

In addition, given a certain similarity between the construction process and the extraction process, the existing applications of SCOR Level 3 model in construction process proposed by Cheng (2009) is chosen. Section 4.2.1.2 shows the existing literature on application SCOR Level 3 model to construction process. This application is used as a base to apply and adapt the SCOR Level 3 model to the extraction process.

In chapter 5, the Level 2 and Level 3 of SCOR model are adapted and used to annotate the mining operations in the extraction process.

4.4.2 Gap analysis between the processes of DCOR and the processes of exploration and engineering design of the EM model

The DCOR model has limitations when applied to the mining industry. One of the most important limitations is semantics. A clear example are the categories of the DCOR model. In a way similar to SCOR process categories are constructed around ‘Stocked Product’, ‘Make to Order Product’, and ‘Engineer to Order Product’. In DCOR, within the Research, Design, and Integrate processes, the common internal structure focuses on three environments or categories: ‘Product Refresh’, ‘New Product’, and ‘New Technology’ (Nyere, 2006). These categories are applicable in the context of product development. Figure 4-22 shows these three categories and the execution processes of DCOR model, Research, Design, and Integrate.

In the context of the mining industry, the categories product refresh, new product, and new technology are not common and do not have a direct translation in this industry. The terminology of ‘new product development’ is not applicable to the context of the mining industry because it is not possible to create a ‘new mineral commodity’ which is different from the existing one. In this industry, obtaining the main raw material to produce the mineral commodity is the most important and complex task. The term ‘new mine project development’ has a similar meaning when used to indicate that a new mineral deposit must be developed to produce a mineral commodity (product). The level of newness in a mine project depends of the level of complexity and risk of an exploration activity. This indicates that categories of the DCOR model must be adapted considering the semantics used in the mining domain. In addition, the connotation of semantic definitions incorporated in each of the processes of the DCOR model need to be analyzed and adapted in the mining context. Therefore, the most appropriate categories to adapt the DCOR model are, 'Operational mine project', 'Brownfield mine project', and 'Greenfield mine project'. The adaptation of the categories of the DCOR model are presented in section 5.2.1.

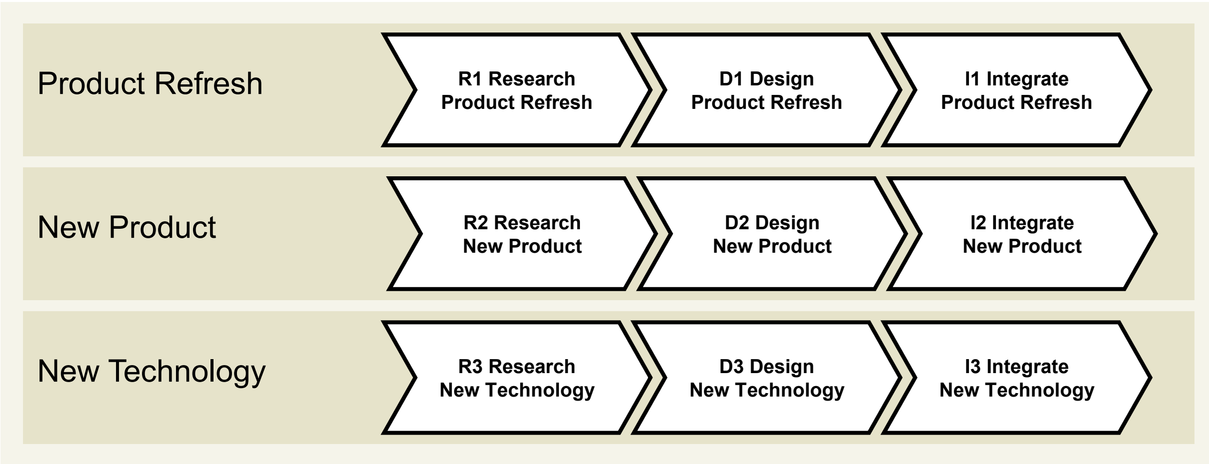

Figure 4-22. The categories and execution processes of DCOR in the context of product development (Nyere, 2006)

A gap has been observed between the DCOR model and the processes of exploration and engineering design. To describe these processes by the DCOR model, the following adaptations are required.

- *Adaptation of the DCOR model categories to the mining domain.* The categories of the DCOR model must be adapted considering the semantics common in the mining domain. The most appropriate categories to adapt the DCOR model are 'Operational mine project', 'Brownfield mine project', and 'Greenfield mine project'.
- *Adaptation of the execution processes (Research, Design, and Integrate) of the DCOR Level 2 model to the processes of exploration and engineering design.* The connotation of semantic definitions incorporated in each of the processes of the DCOR Level 2 model need to be adapted to the processes of exploration and engineering design. In this adaptation, the new categories for the DCOR model need to be considered. For this adaptation the approach that is proposed by Hunsche (2006) is used (see Figure 4-16). This approach is a good example how two processes or workgroups can work in collaboration to produce a MP3 product.
- *Adaptation of the DCOR Level 3 model to the processes of exploration and engineering design.* For this adaptation the approach that is proposed by Juan, Ou-Yang, & Lin (2009) is used. This approach is chosen to adapt the DCOR Level 3 model to the processes of exploration and engineering design in the mining domain. This approach presents an application of the DCOR model to the concurrent new product development (see Figure 4-17).

4.4.3 Gap analysis in the link between the SCOR model and the DCOR model

Hunsche (2006) indicates that the linkage between the SCOR and DCOR is an unanswered question for many of the council's members and, more importantly, for practitioners. The SCOR model has long been considered to cover all aspects of supply-chain management. But, at the same time, it expands the view of the SCOR model by integrating DCOR. The best way for practitioners to answer the question is to use the SCOR and DCOR frameworks on a project. The way a company organizes its processes will clarify the integration of supply and design processes. Thus, it is required to prove it in practice.

In the context of mining, the link between the processes of engineering design and construction need to be analyzed. A gap is identified in the SCOR model in relation to the provision of engineering design documentation, which must be supplied by the 'Engineering Design' process. This process contributes key information regarding design and technical specifications, which are necessary for the acquisition of materials and to build the product in the construction site. It is required to identify the process element of DCOR model, which is linked with the M3.1 process element of the SCOR model. This gap needs to be studied in more detail in the existing adaptation of the DCOR model to the 'Engineering Design' process.

The adaptations of the SCOR model proposed by Cheng (2009) describe the first sub-process 'Develop Operational Capability' shown in the EM model in Figure 4-19. The SCOR model adaptation is set with the supply of materials to the construction site by different suppliers. The 'Engineering Design' process is not described as a supplier in Cheng's (2009) model.

The SCOR model version 10 describes the interaction between the M3 process and the engineering design process (see the M3.1 process element in Figure 4-23). M3.1 is named as 'Finalize Production Engineering,' and it is defined as "Engineering activities required after acceptance of order, but before product can be produced. They may include generation and delivery of final drawings, specifications, formulas, part programs, etc. In general, the last step in the completion of any preliminary engineering work done as part of the quotation process" (SCC, 2010).

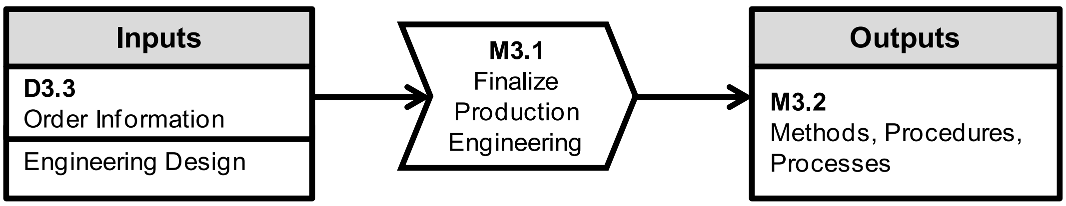

Figure 4-23: Finalize Production Engineering process element M3.1 (SCC, 2010)

Figure 4-23 shows that there are two inputs and a single output for M3.1. In addition to order information, Engineering Design is the second of the two inputs for this function. Methods, Procedures, and Processes comes out of M3.1, and is defined as: “Methods, procedures, and processes required to produce distinct items, such as parts that retain their identity through the transformation process and are intended to be completed after receipt of a customer order, including custom products that are designed, developed, and produced in response to a specific customer request” (SCC, 2010). What this means is that in the case of a mine project, design specifications come from the ‘engineering design process’. It is necessary to adapt the process element of the DCOR model, which, in turn, connects to the M3.1 process element of the SCOR model. This gap needs to be closed by combining the adaptation of the SCOR model to the construction process and the adaptation of the DCOR model to the ‘Engineering Design’ process. This is developed in the next chapter.

Based on the gaps identified in this chapter, the proposed adaptation of the processes of the SCOR and DCOR models to the mining processes is developed in the next chapter.

4.5 Summary

Regarding to the mining processes, the standard framework in mining, the EM-model, does not use a standard, generic, and compatible language which can be accepted in the entire supply chain. The mining industry and its processes show many atypical characteristics, which do not comply easily with the existing SCOR and DCOR models. There is a limited research focused on the mining processes by applying and adapting the SCOR and DCOR models. In addition, in the existing applications of SCOR model (e.g. Cheng 2009; Zhou et al. 2011), researchers assume the ‘availability’ of raw materials. Nevertheless, the availability of raw materials depends of the processes. This is a critical aspect that need to be considered in the mining domain and therefore in the entire supply chain that depends of mineral raw materials. It has been observed in the literature review a low level of 'awareness' about limitation of raw materials.

Comparing the processes of the EM model with the execution processes of the SCOR model, there is a variation between what the SCOR model defines as the ‘source’ process and how the ‘sourcing’ process actually works within the mining industry. Because this sourcing process is a critical challenge for mining, this research focuses on the gap between the processes of SCOR model and the processes of extraction and construction of the EM model. In addition, this research focuses on the gap between the processes of DCOR model and the processes of exploration and engineering design of the EM model.

The existing application of the SCOR model to the construction industry has been studied because it has similarities with the construction process in mining industry. A gap in the literature has been observed between the processes of the SCOR model and the construction process of the EM model. An adaptation of the SCOR model to the construction site is required. Moreover, the existing approaches of SCOR model applications in other exemplary industrial domains contributes to the analysis of how to apply and adapt the SCOR model to the extraction process. There is a gap between the processes of the SCOR model and the extraction process. The adaptations required are the level 2 and level 3 of the SCOR model, and the link between the processes of construction and extraction.

There are limited research publications of DCOR applications to the processes of exploration and engineering design in the context of the mining industry. However, a review of literature yielded some relevant discussion on the application of DCOR in other industrial environments. Important adaptations of DCOR include making changes to the categories and processes of the DCOR model according to the semantics used in the mining domain. These changes include the levels 2 and 3 of DCOR model in order to better model the processes of exploration and engineering design of the EM model. In addition, the gap in the link between SCOR and DCOR needs to be closed by combining the adaptation of the SCOR model to the 'Construction' process and the adaptation of the DCOR model to the 'Engineering Design' process.

5 Adaptation of SCOR and DCOR models to the sourcing process in the mining industry

On the basis of the research problem studied in detail in chapter 4 and the gaps that were identified, chapter 5 initiates the adaptations of the SCOR and DCOR models to the sourcing process of the early part of the supply chain in the mining industry. In order to close the gaps identified, an adaptation of the integrated SCOR and DCOR framework for solving the problem is developed in this chapter.

Some adaptations of the processes of Level 2 and 3 of the SCOR model are developed for the construction site to solve the existing gap between SCOR model and the construction process. Moreover, some adaptations of the processes of Levels 2 and 3 of the SCOR model are required for modeling the extraction process. After this, the link between the processes of construction and extraction can be modeled by using the adaptations of SCOR model.

The existing gap in the processes of exploration and engineering design can be closed by the adaptation of the DCOR model in the mining domain. The application of the DCOR model in other industrial environments allows adaptation of the DCOR model for modeling these mining processes. The categories of DCOR need to be aligned with the semantics used in mining. After this adaptation, the processes of Level 2 and 3 of the DCOR model can be adapted for modeling the processes of exploration and engineering design. Finally, the gap in the link between the SCOR and DCOR models can be closed by combining the adaptations developed for the SCOR model in the construction process and the DCOR model in the engineering design process.

5.1 SCOR model adaptation to the processes of construction and extraction

The gap between the SCOR model and the processes of construction and extraction are developed. To describe these processes using SCOR model, the following adaptations are required:

- Adaptation of the Levels 2 and 3 of the SCOR model to the construction site.
- Adaptation of the Levels 2 and 3 of the SCOR model to the extraction process.
- Adaptation in the link between the processes of construction and extraction.

5.1.1 Adaptation of the Levels 2 and 3 of SCOR model to the construction site

The construction process in the context of the mining industry was defined in section 2.3.1.3. The existing adaptations of the SCOR model in the literature review are shown in section 4.2.1 and the gap in this process is the construction site, which was analyzed in section 4.4.1.1. The SCOR Level 2 model developed for the construction site is shown in Figure 5-1. This includes the SCOR processes

S1, S2, S3, M3, D3, and DR2. The supply of products or materials to the construction site is described by the processes of SCOR Level 2 model S1, S2, and S3 of the construction site, as shown in Figure 5-1. There are different alternatives for materials flow to the construction site for each type of material that is required by the M3 process. These processes are described as follows.

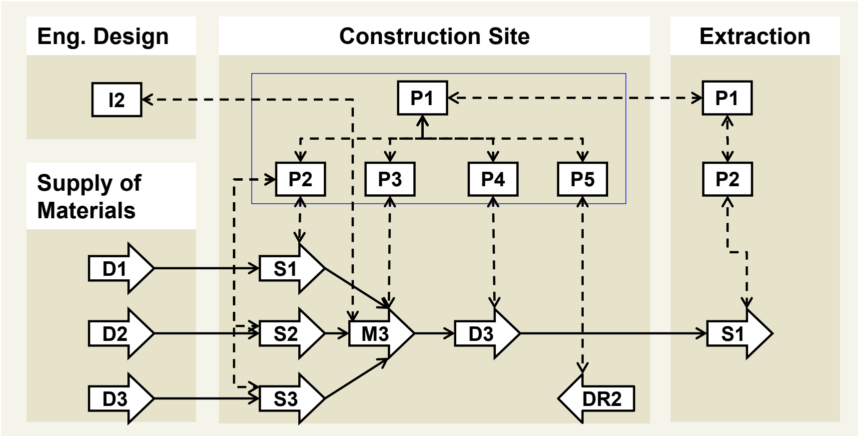

Figure 5-1: The SCOR Level 2 model for the construction site

The 'S1', 'S2' and 'S3' processes in the construction site. These processes were described in detail in section 4.2.1.1, Figure 4-7. Briefly described below is the supply of materials to the construction site, which is explained in more detail in the abovementioned section. The Stocked Standards products come from D1 of distributors to S1 of the construction site. In the other case, these products come from D1 of distributors to S1 of subcontractors' warehouse because the products are delivered to the construction site at the time they are required. In the same way, the Standard/Configurable Products come from D2 of manufacturers to S2 of subcontractors' warehouses because the products are delivered to the construction site at the time they are required. Custom Products come from D3 of plants to S3 of subcontractors' warehouses. In a similar way to the above process, products are delivered to the construction site from subcontractors' warehouses at the time they are required. In the S2 and S3 processes of the construction site, the materials flow comes from the manufacturers and plants to the construction site, respectively.

The engineer-to-order (M3) process. This process performs the manufacturing activities to produce products (e.g. build mineral extraction capability, build beneficiation capability) based on the requirements of a customer and the specifications of the engineering design process. The interaction between the M3 process and the engineering design process is produced using the M3.1 process element shown in Figure 5-2. This process element was defined in section 4.4.1.1. The M3.1 process element of the SCOR model has two inputs, Order Information and Engineering Design. In the case of a mine project, design specifications come from the ‘engineering design process’. M3 process develops the necessary work at the existing mine (operational project) to reach the ore body and ensure sustained supply of ore to the processing plant. For example, in open pit mine, this is called ‘pre-stripping’, which involves removing the rock with no commercial value (sterile) which is covering the mineral reserves. In underground mining, this is called ‘development’. Normally, in a new open pit or undergroung mine (Greenfield or Brownfield project), the construction is performed in parallel, aimed at establishing for example the following facilities:

- Extraction (crushers, workshop equipment maintenance, etc.)
- Processing (processing plant)
- Transportation (roads, highways, railways, ports, airports, etc.)
- Energy supply (high voltage lines, power plants)
- Staff (camps, offices, hospitals, clinics, etc.)

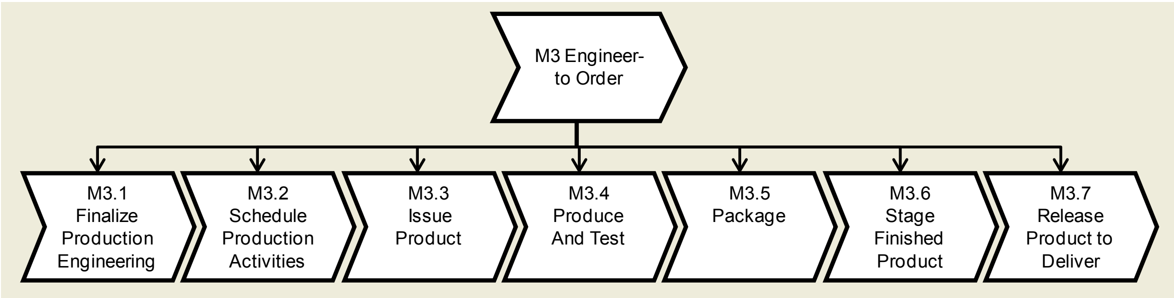

Figure 5-2: Engineer to order value chain for new product (SCC 2010)

The deliver engineer-to-order product (D3). This process delivers a product (mine project) that is partially or fully designed, redesigned, manufactured, and/or assembled from a bill of materials or recipe that includes one or more custom parts or ingredients. In the context of a new mine project (Greenfield or Brownfield), this process includes the activities such as receiving project (mine site) and delivers the project to the customer. The process of receiving at a mine site allows verification that the project was delivered complete and that the project meets its quality and delivery terms. The reception of the project by the customer verifies that the project is fully functional upon completion. Therefore, in context of the construction site, the deliver process includes: Run Pilot Operation and Handover to Operations. Run Pilot Operation proves, on a trial basis, the mining and processing capabilities against the design specifications, including trouble-shooting, before commissioning. The output for this process is proven operational capability. Handover to Operations is the formal transfer of an operational mining environment from the project team to operational management. The output for this process is the operational mine.

The deliver return MRO product (DR2). This process includes the return of some products or company assets for maintenance, repair and overhaul (MRO) for the purpose of servicing, repairing, or upgrading them. This is done because of the occurrence or anticipation of risk of failure. For example, equipment has been installed at the processing plant, where it is in use; the supplier of this equipment and the construction contractor are responsible for its normal performance, which is determined by contracts. In a period of time, the equipment needs to be checked by the construction process for maintenance, repair, and overhaul (MRO) for servicing, repairing, or upgrading it.

The material flow in the construction process has been shown in the SCOR Level 2 model. This model includes the SCOR Level 2 model for the construction site, which is not included in the model developed by Cheng (2009). No relevant differences with respect to the processes of SCOR model have been detected. Because this process is relevant in mining industry, the construction process is described in more detail utilizing Level 3 of the SCOR model. The model developed for the construction site is depicted in Figure 5-3.

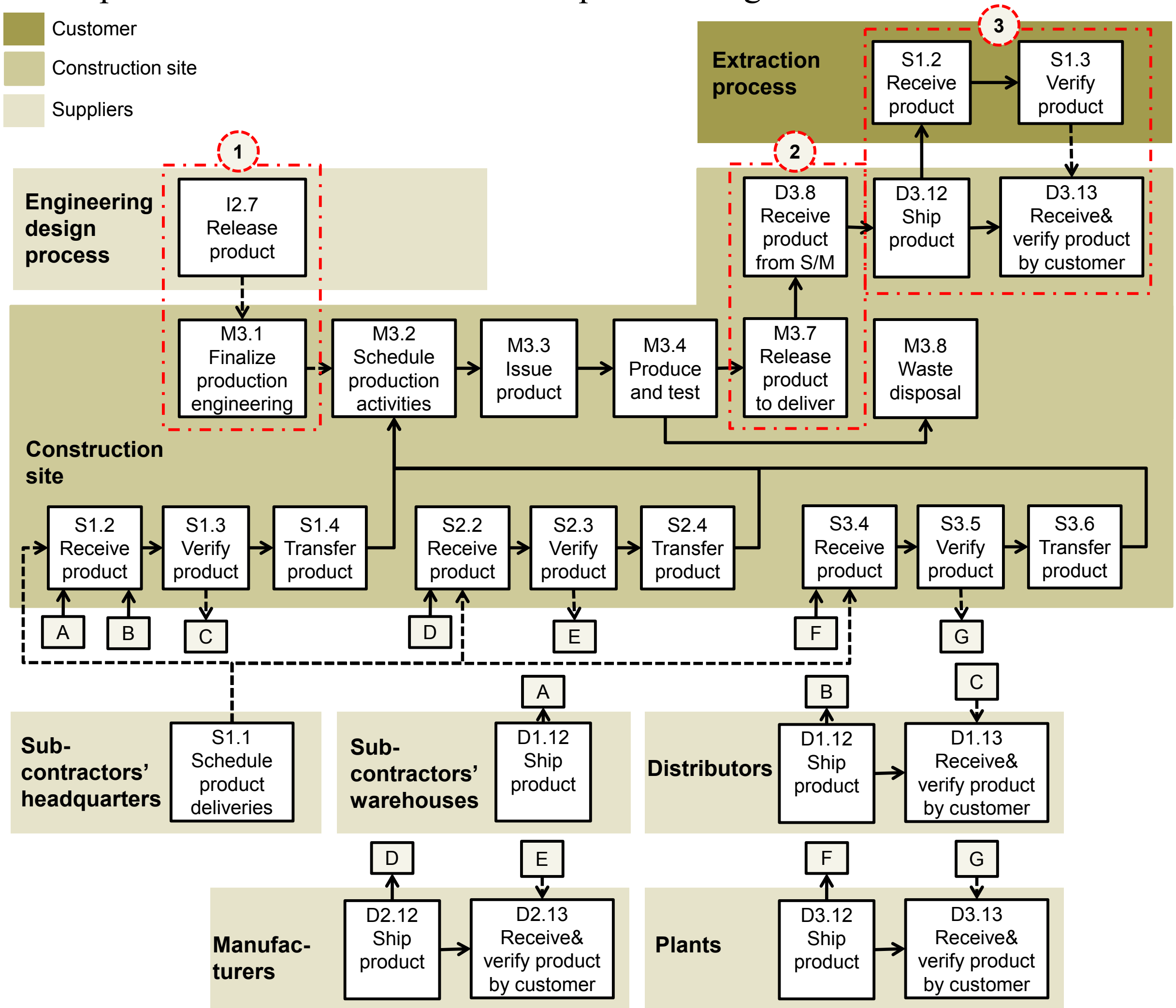

Figure 5-3: The SCOR Level 3 model for the construction site

Figure 5-3 shows the SCOR Level 3 model for a supply chain of the construction site in the mineral raw materials industry. The SCOR Level 3 model can be analyzed, starting from the circle with a number 1. In the circle with number 1, the engineering design process releases the product, which is the specifications of the construction site to the process element M3.1. Then, the schedules production activities are defined (M3.2), given the plans for the production (construction) of the specific construction site in the mine. The scheduling of the operations must be performed in accordance with these plans. Next, the issue materials process element (M3.3) includes preparation of the materials to be used in the production (construction) process. Then, the M3.4 process element produces access to the stock of mineral blocks and tests its quality. The result of this process element is the access to a site with a stock of mineral blocks, which are ready to be extracted by the extraction process.

In the circle with a number 2, the process element M3.7 releases the product, the site to the D3.8 process element. This process (D3.8) in turn receives this site from M3.7. After that, in the circle with a number 3, the construction site delivers a product, which is a site in the mine. The process element D1.12 transfers this site from the construction site. S1.2 is the process element of the extraction process, which receives this site from the D1.12. The process element S1.3 of extraction verifies those blocks to be extracted and classifies them. Then, D3.13 of the construction process receives the reception and verification of the site with the blocks through the extraction process.

The construction site has been described by using the Levels 2 and 3 of the SCOR model. For modeling the construction site there is no change to the processes of SCOR model. Therefore the existing gap in the construction site has been closed. In the next section the adaptation of the SCOR model to the extraction process is developed.

5.1.2 Adaptation of the SCOR Level 2 model to the extraction process[7]

The extraction process was defined in section 2.3.1.4. There is no existing adaptation of SCOR model to this process in the literature review. Given this, adaptations of the SCOR model in similar industrial environments were analyzed in section 4.2.2. The gap in the extraction process was analyzed in section 4.4.1.2. To close this gap, the SCOR Level 2 model is developed for the extraction process (see Figure 5-4). This process includes the SCOR processes S1, M1, and D1. These processes are explained as follows:

Source stocked product (S1). This process manages the stock of mineral blocks, in other words, the raw materials for the extraction process. This stock of mineral blocks represents the mineral resource inventory of a mine project. The extraction process receives this stock of blocks when the construction process has both developed the mine and delivered the stock of blocks (process element D3). The viable blocks are then transferred (assigned) within the extraction process according to the sourcing plan ‘P2’. That way, the extraction process has a certain

[7] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

amount of available blocks in the mineral resource inventory for product manufacture (mineral rock).

Make-to-stock (M1). This process represents the 'break rock' process indicated in the EM model in Figure 4-21. The product of this process is the mineral rock, and the waste material (sterile). In this case, M1 is a plan-driven process as mineral rock is generally produced in accordance with a planned schedule following production plan 'P3'. In the context of the extraction process, this process includes the test of the product in order to classify the ore grade in the rocks and the sterile material. These materials are stored on a stockpile (transiently), in an open place located in the place where they are produced, before being delivered to a predefined destination.

Deliver stocked product (D1). This represents the process of delivering product which, in this case, is made based on two things: planned demand of the processing plant, and inventory re-ordering parameters according to the production plan requirements. D1 is the 'remove rock' process depicted in the EM model in Figure 4-21. Additionally, this process includes all activities involved in the delivery process of a product from storage to the predefine destinations (processing plant, stockpile, dumped waste) via a transport system (see Figure 5-4 and Figure 5-5). The intention of delivering stocked product is to have the mineral rock available when the customer requires it, to prevent the processing plant from stopping due to lack of raw material. The D1 process delivers mineral rocks according to the delivering plan 'P4'. The source stocked product (S1) of the processing plant then receives the mineral rock from the extraction process and transfers it to the processing plant. Thus, the processing plant has the mineral rock for product manufacture (e.g. copper concentrate, copper cathodes) according to the production plan.

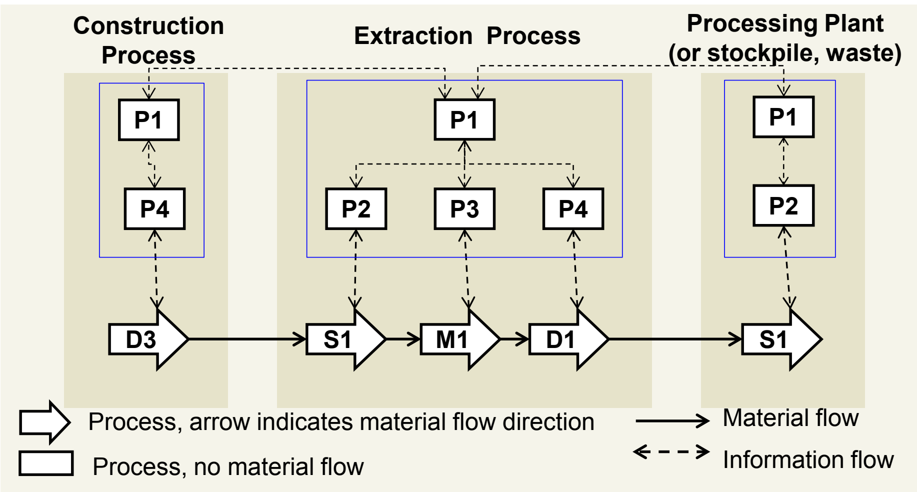

Figure 5-4: The extraction process using the SCOR Level 2 model

The material flow in the extraction process has been shown in the SCOR Level 2 model. No relevant problems or differences in respect to the processes of SCOR model have been detected. In the following section, the extraction process, highly relevant to the whole modeling, is described in more detail utilizing Level 3 of the SCOR model.

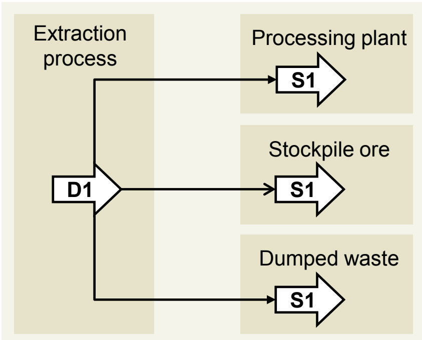

Figure 5-5: The 'Deliver' process in extraction process and predefine destinations

5.1.3 Adaptation of the SCOR Level 3 model to the extraction process[8]

SCOR Level 3 is mapped in order to identify further problems or differences within the extraction process. To describe this process, the approach of adaptation of the SCOR Level 3 model shown in Figure 5-3 is used as an approach to adapt to the extraction process. Figure 5-6 shows the SCOR Level 3 model developed for the extraction process in the mineral raw materials industry. The following are the process elements of the SCOR model related to the product flow, from supplier to predefined destinations.

The SCOR Level 3 model can be analyzed, starting from the construction process (the supplier). The construction site delivers a product, which is a site with access to the mineral blocks in the mine. The process element D3.12 transfers this site from the construction site. S1.2 is the process element of the extraction process, which receives this site from the D3.12. The process element S1.3 of extraction verifies those blocks to be extracted and classifies them. Then, D3.13 of the construction process receives the reception and verification of the site through the extraction process (S1.3). After that, S1.4 transfers this site with a stock of mineral blocks to initiate the schedule of production activities M1.1, which follows the delivery plan (P4.4) and production plan (P3.4). Then, the schedules production activities are defined (M1.1), given plans for the production of specific mineral rock in specified quantities and planned availability of required blocks. The scheduling of the operations must be performed in accordance with these plans (P4.4 and P3.4). Next, the issue materials process element (M1.2) includes the preparation of the materials to be used in the production (extraction) process. Then, the M1.3 process element produces the mineral rocks and tests its

[8] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

quality in order to classify the type of rocks. This process produces mineral rocks and waste materials.

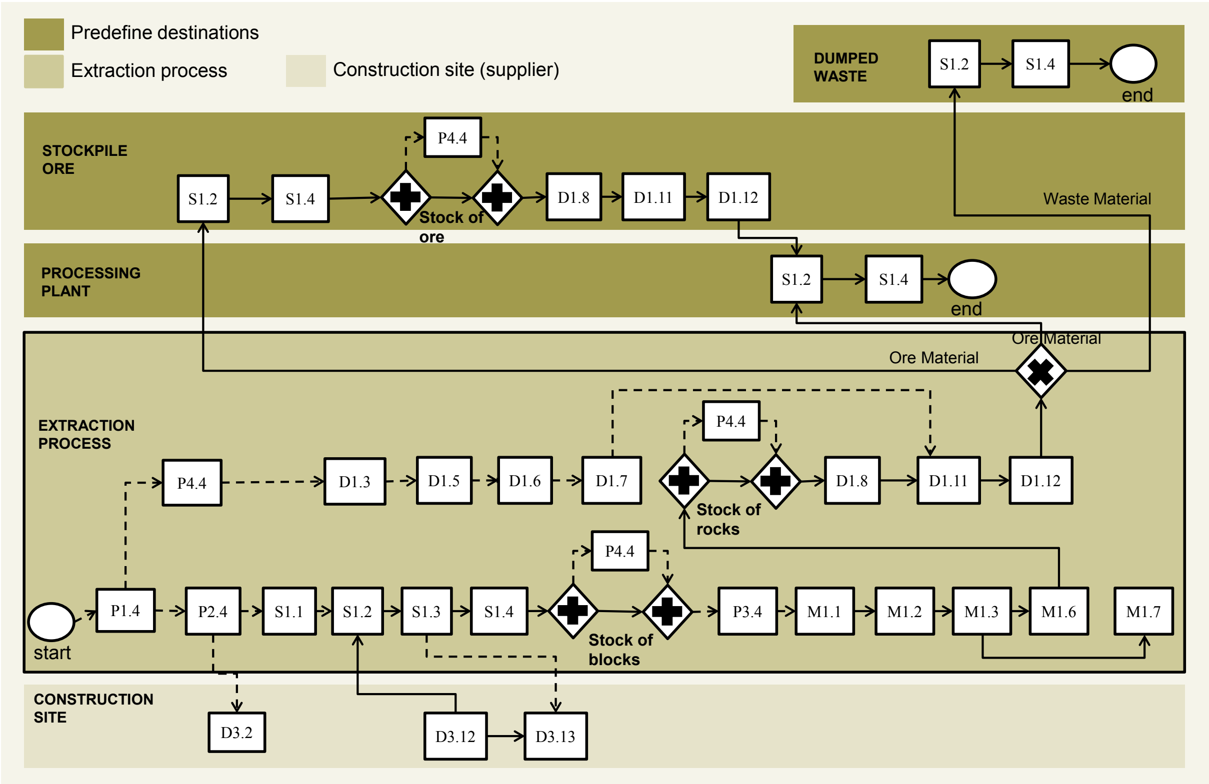

Figure 5-6: SCOR Level 3 model of the extraction process

Figure 5-7 shows the ‘Make’ process of SCOR model in the extraction process. The process elements M1.3 and M1.6 are highlighted because they produce and release the product that is produced in this process, respectively. The product includes the mineral rock and the waste material (sterile). These materials are in the ‘stock of rocks’ that is shown in Figure 5-7. The process element M1.6 releases the product to the D1.8 process element. This process (D1.8) in turn receives the mineral rocks from M1.6. Next, as it is shown in Figure 5-6, the product is loaded (D1.11) into the transport system according to the indications given by the D1.7 process element, and its information is generated. After that, the product is shipped, as is indicated by the process element D1.12 (see Figure 5-8). The process element ‘S1.2’ of the processing plant receives the product from D1.12 according the schedule’s product deliveries that were defined by process element ‘S1.1’ of the processing plant. Moreover, the process element D1.12 ships the product (different types of materials) to predefined destinations, the processing plant, the stockpile ore, and the dumped waste. The process elements ‘S1.2’ of these predefine destinations receive the material from ‘D1.12’.

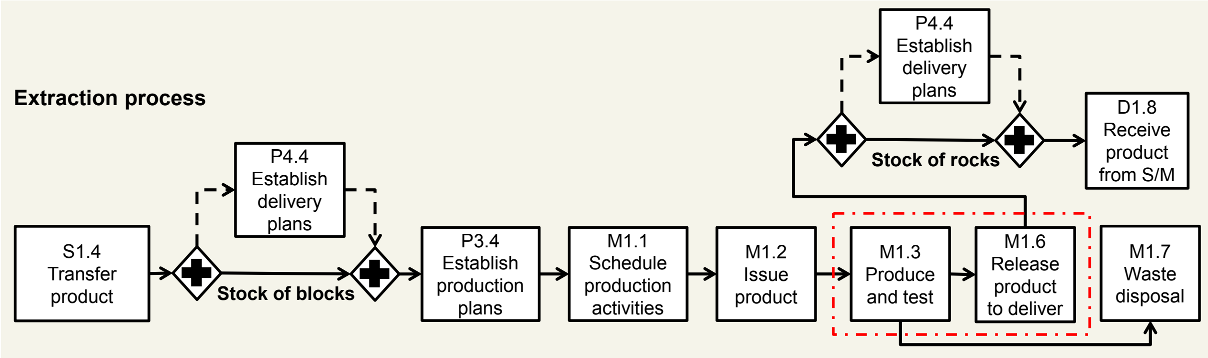

Figure 5-7: The 'Make' process in extraction using the SCOR Level 3 model

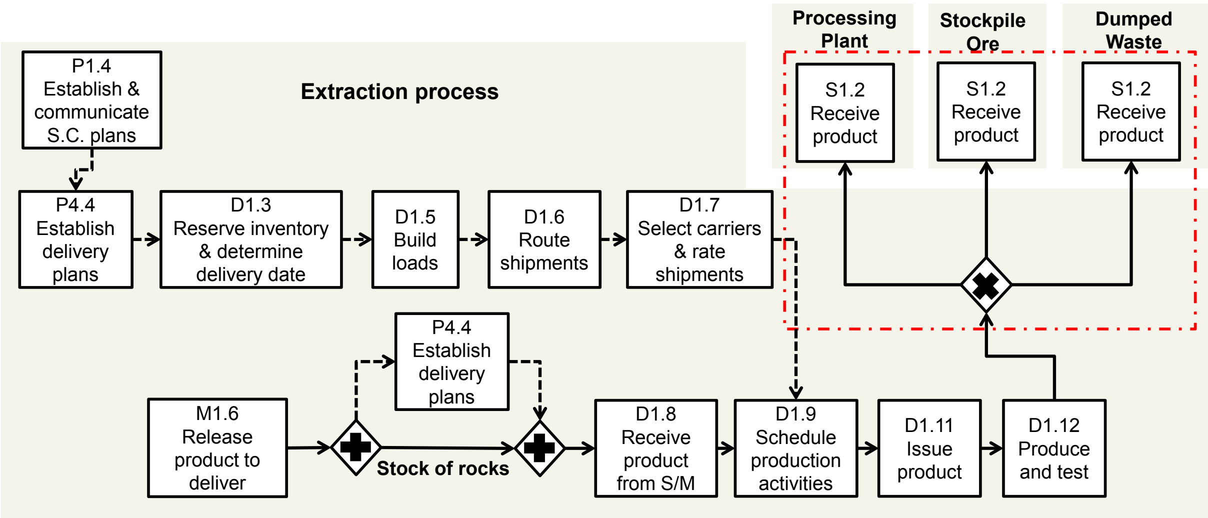

Figure 5-8: The 'Deliver' process in extraction using the SCOR Level 3 model

The following are the process elements of the SCOR model related to the selection of the appropriate transportation system of the product for delivering to the predefine destinations:

Reserve inventory and determine delivery date (D1.3). Inventory of mineral rock (both on hand and scheduled) is identified and reserved for a delivery date which is committed and scheduled. This process element has interactions (shared information) with other process elements to optimize the transport of mineral rock from the extraction process to the processing plant and other destinations. For example, this process receives the information of the sourcing plan (P2.4) relating to the blocks to be extracted, the production plan (P3.4) relating to the mineral rocks to produce, and the delivery plan (P4.4) relating to the delivery dates of the processing plant, among others. The inputs and outputs of the process element 'D1.3' are described in more details in SCC(2010; p.363).

Build loads (D1.5). Transportation modes are selected, and loads are built for efficiency. For example, the loads of mineral rocks and sterile are built specifically for each day and week.

Route shipments (D1.6). Loads are consolidated and routed by mode, lane, and location. For example, 1.000 tons/hr. of mineral rocks are assigned to transport from shovel No. 1 to crusher No. 1. At the same time, 2.000 tons/hr. of waste materials are assigned to transport from shovel No. 1 to waste dump No. 2.

Select carriers and rate shipments (D1.7). Specific carriers are selected for lowest cost per route, and shipments are rated and tendered. For example, to minimize cost of transportation, trucks type 'A' are assigned to shovel No. 1 to transport mineral rocks to crusher No. 1. They are assigned to operate optimally, taking into account their capacities, as well as the waiting time of the trucks in the queues of the shovel and crusher.

The extraction process has been described by using the Levels 2 and 3 of the SCOR model. There is no change to the processes of the SCOR model for modeling the extraction process. Therefore the existing gap in the extraction process has been solved by using the existing SCOR model. In the next section the adaptation of the SCOR model in the link between the processes of construction and extraction is developed.

5.1.4 Adaptation of the SCOR model in the link between construction and extraction

This link is for the connection between the 'Deliver' process of the SCOR model in the construction site, and the 'Source' process of the SCOR model in the extraction process. In the construction process in mining industry, the extraction process (customer) is required to go to the place and use the product because there is no possibility of transporting the product to another place.

In the context of a new mine project (Greenfield or Brownfield), the construction process (supplier) delivers an open pit mine or underground mine, and a processing plant (construction product) with some capacity for which it was built. The extraction process receives the mine and the plant. After that, it uses the mine and the plant to test whether they meet the specifications requested. In the context of mining, the construction process remains the owner of the processing plant up until the point in time at which the customer is completely satisfied with the operation of the plant and proceeds to final acceptance of the construction product.

In an existing mine project (Operational), the construction process (supplier) delivers a new phase of the mine with a stock of mineral blocks (inventory), which is ready to be extracted by the extraction process. After that, the extraction process proceeds to accept the stock of mineral blocks if it meets the specifications requested.

The construction process is the supplier for the extraction process as shown in Figure 5-9. The construction site delivers a product, which is a site with the access to the mineral blocks in the mine. The process element D3.12 transfers this site from the construction site to the process element S1.2 of the extraction process, which receives this site. This transfer occurs in the same place because the extraction process needs to go to the mine and extract the minerals blocks. The process element S1.3 of extraction verifies those blocks to be extracted and classifies them. Then, D3.13 of the construction process receives the reception and verification of the site through the extraction process (S1.3). After that, S1.4 transfers this site with a stock of mineral blocks to initiate the schedule of production activities (extraction).

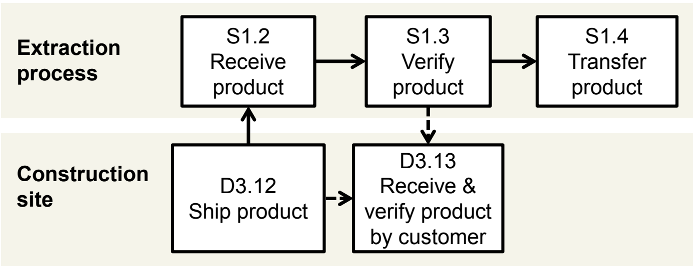

Figure 5-9: The link between construction and extraction in SCOR Level 3 model

The link between the processes of construction and extraction has been described by using the SCOR Level 3 model. There are no changes to the processes of the SCOR model, ‘Deliver’ and ‘Source’, for modeling this link. In the next section the adaptation of the DCOR model in the processes of exploration and engineering design is developed.

5.2 DCOR model adaptation to the processes of exploration and engineering design

In section 2.1.3 the mine life phases were described and the needs to develop new mine projects was highlighted. The types of mine projects to be developed are Greenfield, Brownfield, and Operational. They were described in section 2.2 and explained with a case example of a Brownfield mine project applied in Codelco-Chile company.

There is no adaptation of the DCOR model to the processes of exploration and engineering design. The existing adaptations of DCOR model in other industrial contexts were shown in section 4.3. The gap between the DCOR model and the processes of exploration and engineering design was analyzed in section 4.4.2. To describe these processes using the DCOR model, the following adaptations are developed in this section.

- Adaptation of the DCOR model categories to the mining domain.

- Adaptation of the levels 2 and 3 of the DCOR model to the processes of exploration and engineering design.

Mining companies focus on the mine design to produce a product (mineral commodity) by using the results created by the exploration process. The tighter the collaboration between the processes of exploration and the engineering design, the better the design of the entire mine. These processes can be described by an adaptation of the DCOR model. To do so, the categories of the DCOR model must be adapted from the product development context to the mining project development.

5.2.1 Adaptation of the DCOR model categories to the mining domain

Figure 5-10 depicts the approach of the DCOR categories adaptation to the mining domain. This figure presents the EM model with three categories: Operational mine project, Brownfield mine project, and Greenfield mine project. In addition, Figure 5-10 shows the three categories of the DCOR model, which are applicable in the context of product development. In this context, these categories can be explained using the execution processes of the DCOR model: Research (R1, R2, R3), Design (D1, D2, D3), and Integrate (I1, I2, I3). However, in the context of mining, these categories need to be adapted to the semantics of the mining domain. For this adaptation, some commonalities between the development of a new mine project and the development of a new product need to be considered.

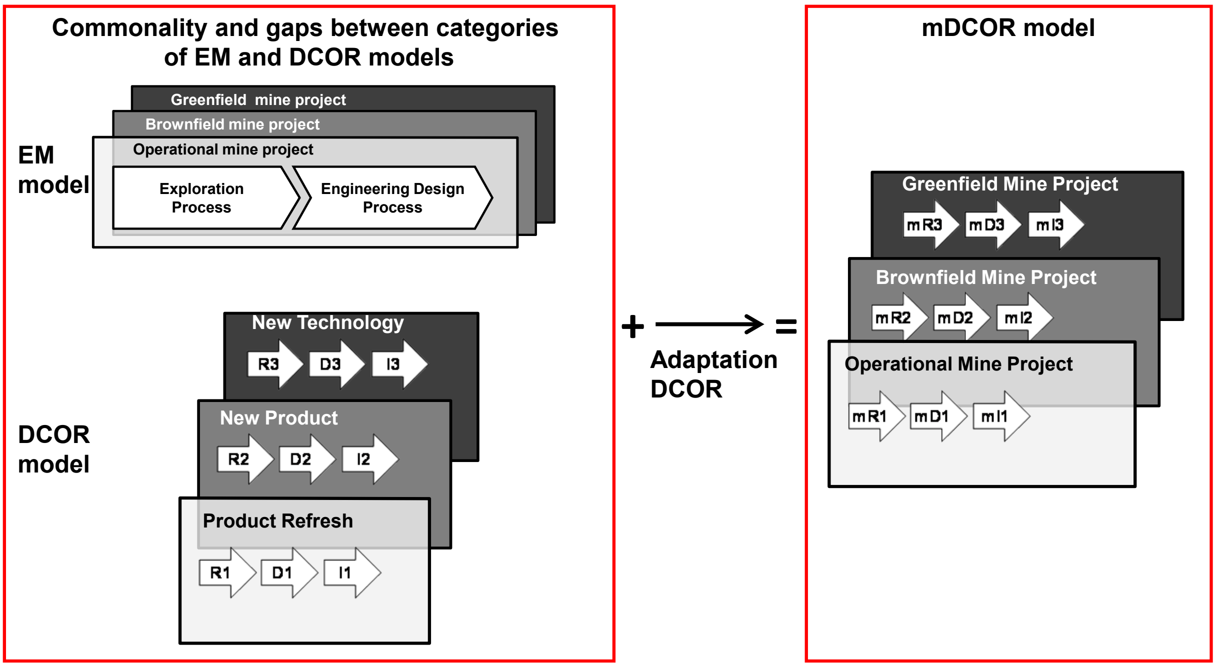

Figure 5-10: Approach for adapting the categories of the DCOR to the mining domain

In the context of mining, Figure 5-10 depicts the mDCOR model which is the adapted DCOR model in the mining domain. Figure 5-11 depicts the three categories: Operational Mine Project, Brownfield Mine Project, and Greenfield Mine Project. All DCOR execution processes have a small 'm' preceding the former process ID. For example: R1 (Research Product Refresh) is now mR1 (Research Mine Project). The small 'm' represents 'mining' or mineral commodity. These categories are adapted taking into account the mine project development to produce a mineral commodity, for instance: copper, gold, alumni, zinc, coal, etc. Each of these categories is explained by using examples and comparisons of the commonalities between the categories of the EM model and the categories of the DCOR model, as follows.

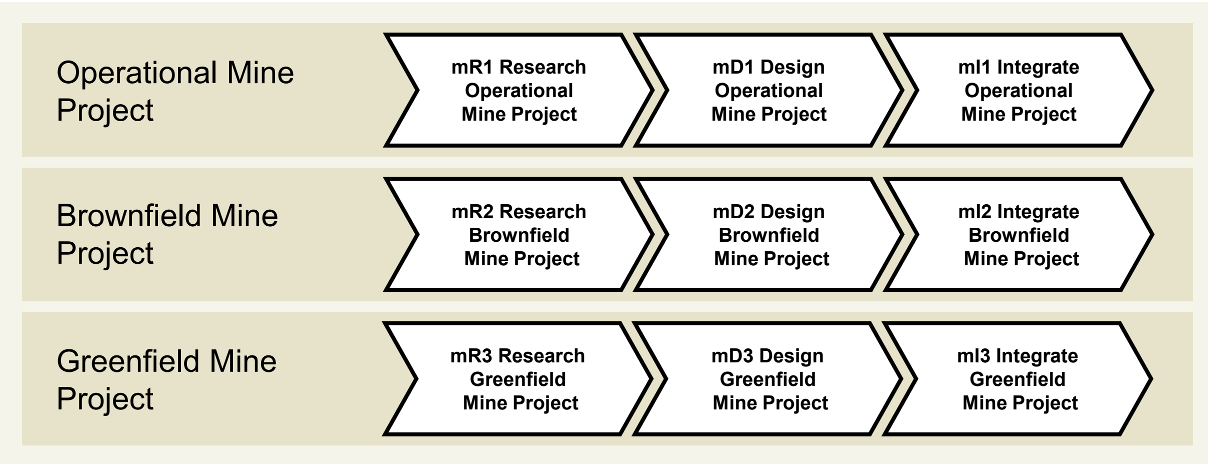

Figure 5-11: The DCOR Level 2 model in the context of the mine project development

5.2.1.1 Adaptation of the category 'Operational mine project'

Nyere (2006) indicates that Product Refresh relates to an existing product (see Figure 5-12). For example, in the automotive industry, this would equate to introducing "next year's" model when a company spends 15 months to incrementally improve upon an existing model. In the technology area, product refresh may span three to four months. The time spent to introduce an updated version of the product depends on the type of product and industry.

In the mineral commodity context, Operational mine project relates to an existing mine project in a specific location and operation. This is done to expand a mineral resource that has already been found and developed on the property of an existing mine (Prospectors and Developers Association of Canada 2006). At an operational level, exploration involves the day-to-day enhancement of the level of confidence in the geological model. The outputs at operational level for exploration are operational budget/updated short-term exploration plans, routine updated geological models, and definition of ore reserves (EMMMV, 2010). If the exploration is done in the existing mine the identification for this project is an Operational mine project. After the exploration, the Operational project includes the processes of engineering design and construction. The engineering design for an operational project is done to expand the exploitation of mineral resources in an existing mine which is in operation. The results of the engineering design process are the engineering design, and the mining layout designs, including all mining technical inputs. These results allow initiating the construction process, which in this case may represent the development of a new phase in the open pit mine site or an update of the existing infrastructure or equipment in the processing plant. The results of the construction process are the access to the mineral blocks in some specific location in the mine site (phase), and/or the improvements and optimization of the existing facilities and infrastructure.

For example, in the copper mining industry, this would equate to introducing a new development phase for the mine exploitation. This new development phase may take around two years in an underground mine to build the access in the current operations. In open-pit exploitation, mine project refresh may span three or more months. In addition, operational mine project may include optimization projects in the processing plant for productivity improvements.

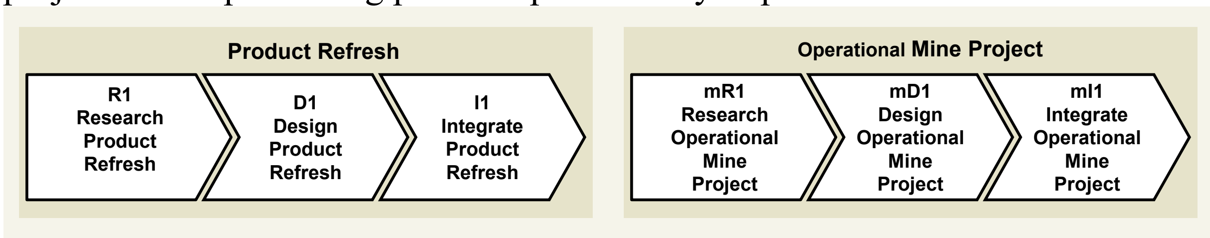

Figure 5-12: Adaptation of the category 'Product Refresh' of DCOR model to the 'Operational Mine Project'

5.2.1.2 Adaptation of the category 'Brownfield mine project'

Continuing with the example of Nyere (2006), wherein he states that New Product relates to the development of a new product (see Figure 5-13). As an example, it equates to an automotive manufacturer introducing a totally new product, e.g., a truck, when the company has only produced passenger vehicles to date. This may take as long as seven years. In the U.S. Department of Defense, it takes even longer to introduce a new weapon system. Normally, this new product is produced near the current operations, with some additional infrastructure, to take advantage of existing infrastructure.

In the mineral commodity context, Brownfield mine project equates to a mine producer introducing an extension by a new mine project near the current operations. It aims to extend an existing mine's operating life and to take advantage of existing infrastructure. Brownfield exploration does not deliver more than incremental growth as existing mineral deposits are depleted (Hronsky, Suchmel and Welborn 2009, p.29). Brownfield exploration is lower risk in comparison with Greenfield exploration, and therefore the investments are lower in the development phase. After the exploration, the Brownfield mine project includes the processes of engineering design and construction. The engineering design for a Brownfield mine project is done to extend an existing mine's operating life. The results of the engineering design process are the final (approved) engineering design, and the final mining layout designs, including all mining technical inputs (e.g. ventilation and rock engineering). These results allow initiating the construction process, which in this case may represent the development of a new extension of the mine in the existing district, for example, a new open pit or underground mine. The results of the construction process are access to the new open pit mine or underground mine, and new extension of the processing plant.

Take for example the development of an underground copper mine, when the company has only produced in an open pit to date. Another example: the development of a new open-pit mine '2' near the current operations in the open-pit mine '1', when the company has only produced in the open-pit mine '1' to date. This new development may take as long as seven years or more. In the case example that is shown in section 2.2.1, the time of development of the underground mine project 'New Mine Level El Teniente' of Codelco-Chile was around 19 years, from 1999 to 2018. The exploration process (exploration and feasibility studies) took around 12 years, from 1999 to 2011. The development process that includes engineering design and construction (investment phase) took around 7 years, from 2011 to 2018. The transference of this Brownfield mine project to the extraction process (operation phase) is estimated to begin in 2017 and this transference process is going to finish in 2018. After that, the extraction process is going to operate this project until the end of the mine's life. In a copper mine company the development time in an underground mine is longer than an open pit mine development of similar production level.

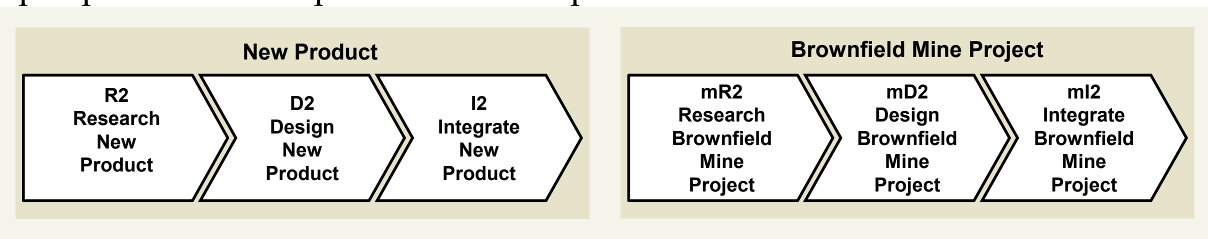

Figure 5-13: Adaptation of the category 'New Product' of DCOR model to the 'Brownfield Mine Project'

5.2.1.3 Adaptation of the category 'Greenfield mine project'

In this case, Nyere (2006) indicates that New Technology relates to the development of a new technology and a new product (see Figure 5-14). By using the same example, a company may be operating in a space where they have never operated before, such as fuel cell technology, to continue the automotive example. Obviously, the cycle time (time to market) will be progressively longer as companies refresh, introduce new products, and employ new technologies. Correspondingly, it costs less to refresh than to introduce new products (higher) and new technologies (highest). In this case the product is produced in a new infrastructure.

In the mineral commodity context, Greenfield mine project equates to a mine producer introducing a new mine project in a new location. In this context, a mining company may be operating in a space or location where it has never operated before (e.g. in a new region or district), using the appropriate technology for the specific requirements of the new mine project. Greenfields exploration refers to the activity undertaken in unexplored or incompletely explored areas. Its key purpose is to discover new mineral deposits in new areas, typically away from the immediate vicinity of existing mines. Greenfields exploration provides the foundation of the resources sector and is how all major mines begin. It is imperative to ensuring the discovery of new resources and maintaining a pipeline of new resource projects. Without ongoing Greenfields exploration activity, there is no opportunity to replace depleting resources (Hronsky, Suchmel and Welborn 2009, p.29). If the exploration is succesfull, the identification for this project for the next stages is a Greenfield mine project. After the exploration, the Greenfield mine project includes the processes of engineering design and construction. The engineering design for a Greenfield mine project is done to develop a new mine in a new location. The results of the engineering design process are the final engineering design, and the final mining layout designs, including all mining technical inputs. These results allow initiation of the construction process, which in this case may represent the development of all the infrastructure required for a new mine in a new district. The results of the construction process are all the access to the new open pit mine or underground mine and the new processing plant.

In a similar way, the time to market will be progressively longer as companies develop a operational mine project, introduce new mine project extension (Brownfield), and employ new mine project in new district with its technologies (Greenfield). Regarding costs, and Operational mine project costs less than introducing a Brownfield mine project (higher) or a Greenfield mine project (highest) (Mackenzie & Cusworth 2007; Whiting & Schodde 2006).

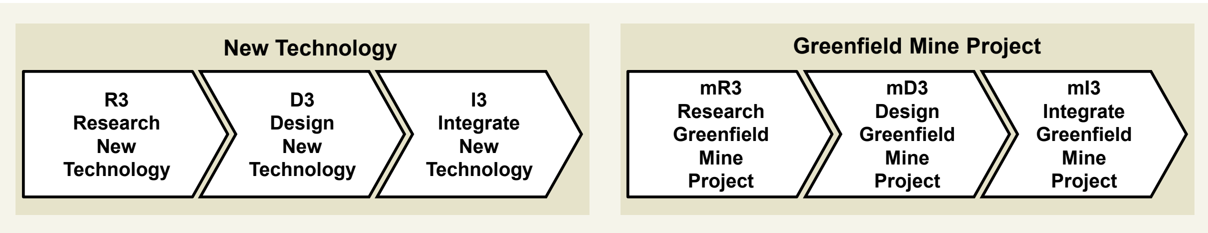

Figure 5-14: Adaptation of the category ‘New Technology’ of DCOR model to the ‘Greenfield Mine Project’

Greenfields are high-risk, but high-reward, projects that create long-term option value if new deposits are discovered. Brownfield exploration is lower risk, but is unlikely to deliver more than incremental growth, and the Brownfield exploration opportunities in any one location will ultimately be depleted. The success rate for exploration is extremely low for Greenfield exploration (Prospectors and Developers Association of Canada 2006, p.6).

The processes of the DCOR model need to be adapted to be suitable for modeling the processes of exploration and engineering design. Each of these processes is analyzed and adapted for the three categories. In section 5.2.2, the adaptation of the DCOR model applied to a Brownfield mine project is developed. The adaptation of the DCOR Level 2 model applied to the processes of exploration and engineering design of an Operational mine project, is developed in section 9.1 in the Appendix. In addition, the adaptation of the DCOR Level 2 model of a Greenfield mine project is described in section 9.2 in the Appendix.

5.2.2 Adaptation of DCOR model to the exploration process of a Brownfield mine project

The main processes of the DCOR model are adapted for a suitable description of the processes of exploration and engineering design in the context of the mining industry. For this adaptation the existing definitions of the DCOR processes are an important input (SCC, 2006). These existing definitions are in the context of product development and they are adapted to be applicable to the processes of exploration and engineering design.

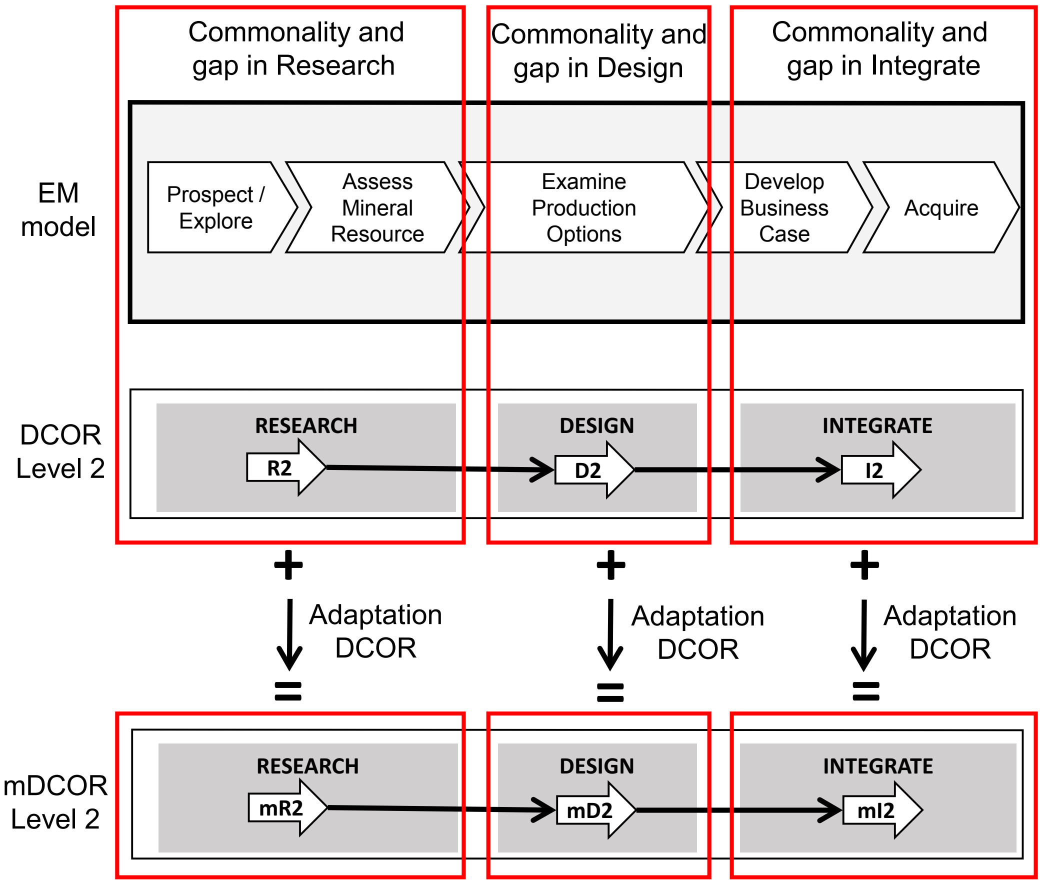

Figure 5-15: Approach for adapting the processes of DCOR to the exploration process of the EM model

Figure 5-15 depicts the approach for adapting the processes of DCOR model to the exploration process of the EM model in the context of a Brownfield mine project. This figure presents the sub-processes of the exploration process of the EM model. In addition, Figure 5-15 shows three execution processes of the DCOR Level 2 model: R2, D2, and I2. In the context of mining, these processes need to be adapted to the semantics of the mining domain. For this adaptation, the commonalities between the mining processes of the EM model and the processes of DCOR model need to be considered. Then, the adapted processes of mDCOR Level 2 can be obtained by considering the commonalities and variations between the mining processes of the EM model and the processes of DCOR model.

In this section, the definitions and descriptions of the exploration process are taken into account. These definitions and descriptions are indicated in section 2.3. In addition, these adaptations consider the type of mine projects described in section 2.2 and the adapted categories of the mDCOR model indicated in section 5.2.1.

5.2.2.1 Adaptation of DCOR Level 2 model to exploration process

Figure 5-16 depicts the processes of the DCOR Level 2 model to the exploration process of a Brownfield mine project. The Brownfield mine project involves the processes research (mR2), design (mD2), integrate (mI2), and amend (mA3). These processes are applied in the exploration process. The adaptations of these processes are analyzed as follows.

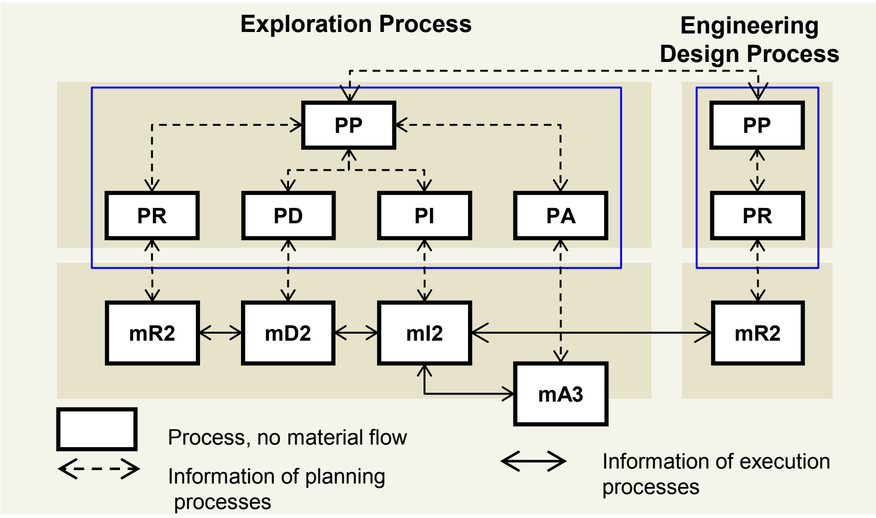

Figure 5-16. Adaptation of DCOR Level 2 model to the exploration process of a Brownfield mine project

Research Brownfield mine project (mR2). In the context of exploration, mR2 encompasses the processes of prospection, exploration, and assessment of mineral resources that are carried out in a new mine project near an existing mine. The purpose of these processes is the identification and decomposition of research topics to locate the presence of economic deposits near an existing mine, considering their attributes of structure, density, grade, and tonnages. From this, information to establish their nature, extent, and grade is obtained and synthesized. The output of the mR2 process is the evaluation and publishing of research findings regarding geologic and mineralogical data with spatial attributes, and a geologic model used as the basis for design and mine planning. In addition, the mR2 process includes the identification of sources of supply, sourcing, and validation of materials/products against requirements. Furthermore, this process is driven by the research plan (PR).

Design Brownfield mine project (mD2). In the context of the exploration process, mD2 encompasses the definition, creation, analysis, testing, and release of process, size, and function for the most convenient production options of a new mine project near an existing mine. This process involves the design and feasibility of a technical mine, and the beneficiation plan, at an appropriate level of confidence. The process is focused on improving levels of confidence in Brownfields projects. The output of the mD2 process is the technical mine plan (i.e. volume and product profiles over time). This process is driven by the mR2 process.

Integrate Brownfield mine project (mI2). In the context of the exploration process, the mI2 process encompasses the synthesizing of the design definitions and decomposition of the design definitions into develop business plan, releasing the business case and the new mine definitions to enable a decision making regarding a new mine project near an existing mine. Also, the mI2 process includes acquiring all the necessary rights. The develop business plan is focused on the analysis (including options) and creation of the financial viability plan associated with the establishment of a new mine project in a particular site in order to be able to make a go/no-go decision. The output of the mI2 process is a documented business case to enable a decision making, bankable feasibility study for internal project proposal for capital cost-related decisions. In addition, the process of acquiring involves the securing of all the necessary rights applicable to mine a particular site. This includes: mineral rights, environmental impact assessment (EIA), approved environmental plan, surface rights, access rights, approved social and labor plan, and water rights. In this case, the outputs are the secured rights and sufficient information to make an investment decision.

Amend mineral commodity specs (mA3)

In the context of exploration, this process includes the activities associated with Specification Change. The process is triggered by the gathering of an issue and commodity specifications. The process culminates with publication of a Specification Change Order (SCO). The process should encompass the requisite reviews and approvals.

The main processes of the DCOR Level 2 model have been adapted to be suitable for modeling the exploration process. The adaptation of the DCOR Level 2 model has been applied to a Brownfield Mine Project. The same procedure has been done in the adaptation of the DCOR Level 2 model applied to the others two categories, which are described in sections 9.1 and 9.2 in the Appendix. Because of the relevance of the exploration process in mining industry, the DCOR Level 3 model for this process is analyzed in the next section.

5.2.2.2 Adaptation of DCOR Level 3 model to exploration process

The Brownfield mine project involves the processes elements of DCOR Level 3, mR2.1-mR2.6, D2.1-D2.6, and I2.1-I2.7. These adapted process elements are applied in the category of a Brownfield mine project of the exploration process. The adaptations to the definitions of these process elements are described in section 9.3.

Figure 5-17 shows the adapted DCOR Level 3 model to describe the exploration process for a Brownfield mine project. Four workgroups are involved in the development of a Brownfield mine project. These workgroups are: Project Management (PM), Prospection/Exploration and Assessment (PEA), Exploitation Options Design (EOD), and Feasibility Studies (FS).

Workgroup PM initiates the development process with the customer's requirements (e.g. customers can be owners, stakeholders). The tasks for PM are represented by the process elements I2.1-I2.3 shown in Figure 5-17. PM works with Prospection/Exploration and Assessment (PEA) to reach a consensus on customer requirements (research requirements). After that, and based upon the requirements, PEA identifies and decomposes the research topics to locate economic mineral deposits. The tasks for PEA are represented by the process elements R2.1-R2.6 which are shown in Figure 5-17. When PEA gets a potential mineral deposit, the results on research specifications are delivered. These results provide the geologic and mineralogical data with spatial attributes and a geologic model for the next workgroup (EOD). The workgroup EOD can use this information as the basis for planning and mine design.

Once PEA workgroup obtains certain results that meet customer requirements, PM works with the EOD workgroup to reach a consensus on customer requirements and to begin main activities. For this, EOD must take into account the results on the research specifications obtained by PEA. The tasks for EOD are represented by the process elements D2.1-D2.6 that are shown in Figure 5-17. Based on the research specifications provided by PEA, EOD workgroup defines, creates, analyzes, tests, and releases the proposal about the process (e.g., the extraction method to extract ore from the mine), size (e.g., the ore tonnages to extract per day), and function (e.g., waste treatment according to regulations and requirements of the communities). This proposal presents the most convenient options for mineral resource exploitation by a new prototype of mine.

After the EOD workgroup has reached certain results, PM works with the FS workgroup to reach a consensus on the customer's requirements and to initiate its main activities. This is done based upon the results that were delivered by the workgroups PEA (Research specifications) and EOD (Design specifications). The tasks for FS are represented by the process elements I2.4-I2.7 shown in Figure 5-17. The FS workgroup embraces the synthesis of design definitions and decomposition of design definitions in developing the business plan. This plan focuses on the analysis and creation of the financial viability plan. Finally, workgroup FS releases the project definition and documentation in order to make a go/no-go decision.

From the above information, a mining company can first designate the names of workgroups from Project Management to Feasibility Studies on the Y-axis (Step 1). Next, by mapping the process elements of DCOR (depicted in Figure 5-17) to workgroups' tasks, process elements I2.1–I2.3, R2.1–R2.6, D2.1–D2.6, and I2.4–I2.7 are assigned to workgroups PM, PEA, EOD, and FS, respectively. Afterwards, the input/output information vertically flowing among workgroups (as shown in Table 5-1) is retrieved from DCOR and depicted in the diagram to connect relevant process elements (Step 2). As Figure 5-17 shows, there are six cross-workgroup information flows which indicate a place likely for cooperation-activities. However, three early cooperation activities, including Prospection/Exploration and Assessment Requirements Coordination, Exploitation Options Design Requirements Coordination, and Feasibility Study Requirements Coordination are finally specified on the diagram (Step 3), and the desired Development process of a Brownfield mine project is derived. It is mainly charged with receiving, decomposing, and distributing requirements.

Table 5-1. Cross-workgroup information flow retrieved from the adaptation of the DCOR Level 3 model to the exploration process

Input/Output	Description / Definition
Research Requirements	Research requirements related to discovering and assessing new mineral deposits. These requirements must meet the enterprise's expectations.
Design Requirements	Design requirements are the translation of process requirements into design specifications that meet the enterprise's expectations.
Validated Design	A design of mine project which ensures performance and conformance to defined specifications and requirements.
Research Specifications	Research specifications: Mineral Rocks, Size of Mineral Deposit, Mineral Deposits Characteristics, Estimated Mine Life, Ore-Grade, Geological Information, etc.
Design Specifications	Design Specification will: a) define the technical scope of the mine project; b) define the expected use and purpose of the project; c) Define relationships with existing mine projects; and d) describe the design of the mine project.

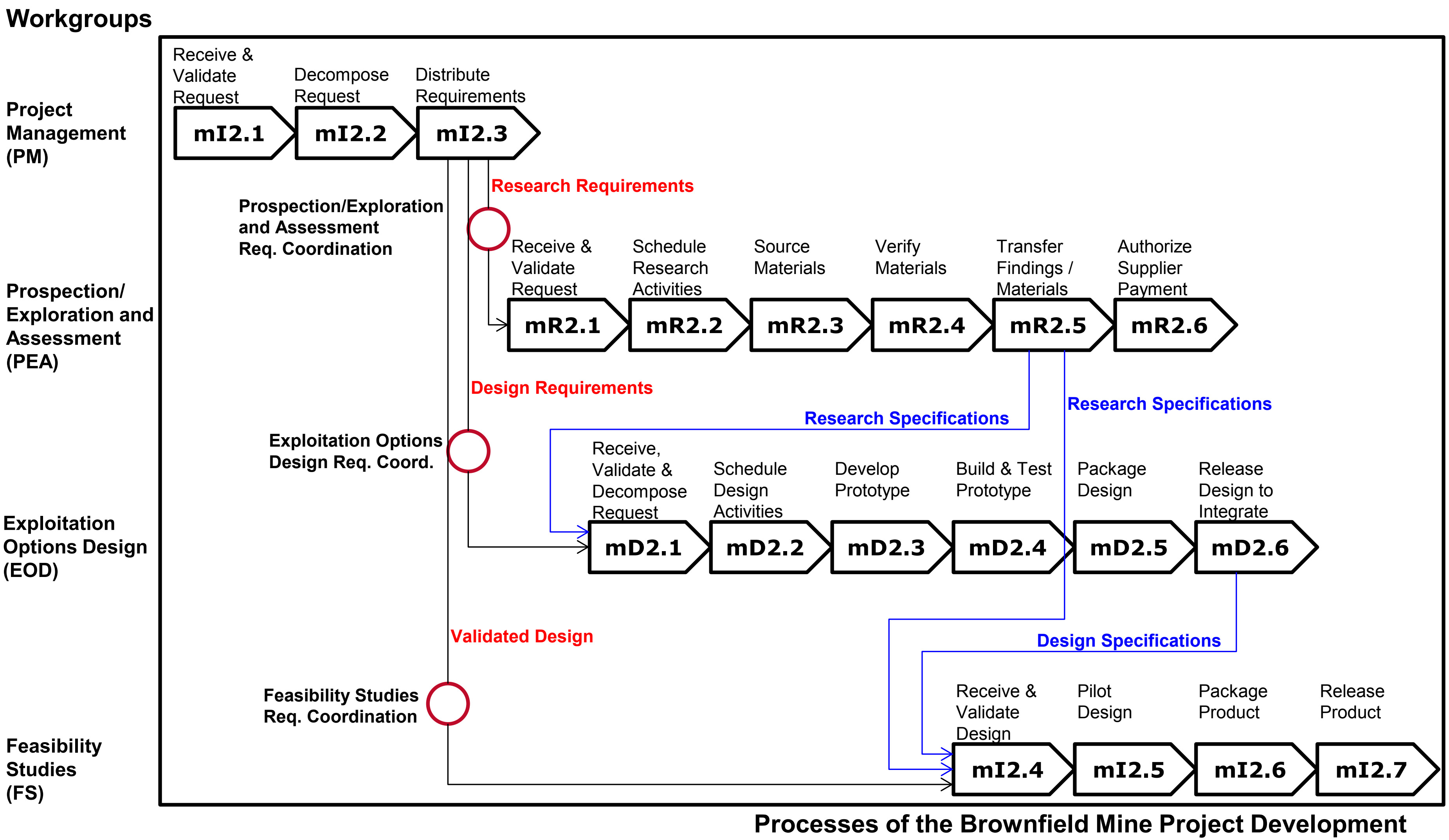

Figure 5-17. Adaptation of the DCOR Level 3 model to the exploration process of a Brownfield mine project (Adapted from Juan et al., 2009)

5.2.3 Adaptation of DCOR model to the engineering design process of a Brownfield mine project

Figure 5-18 depicts the approach for adapting the processes of DCOR model to the engineering design process of the EM model in the context of a Brownfield mine project. This figure presents the sub-processes of the engineering design process of the EM model. In addition, Figure 5-18 shows three execution processes of the DCOR Level 2 model: R2, D2, and I2. In the context of mining, these processes need to be adapted to the semantics of the mining domain. For this adaptation, the commonalities between the mining processes of the EM model and the processes of the DCOR model need to be taken into account. Then, the adapted processes of mDCOR Level 2 can be obtained by considering the commonalities and variations between the mining processes of the EM model and the processes of the DCOR model.

The main processes of the DCOR model are adapted to describe the engineering design process in the context of mining industry. The existing definitions of DCOR processes in the context of product development are inputs to adapt the DCOR model to the engineering design process in the mining domain. In this section, the definitions and descriptions of the engineering design process, which were indicated in section 2.3.1.2, are considered. In addition, these adaptations consider the type of mine projects described in section 2.2 and the new categories of the DCOR model indicated in section 5.2.1.

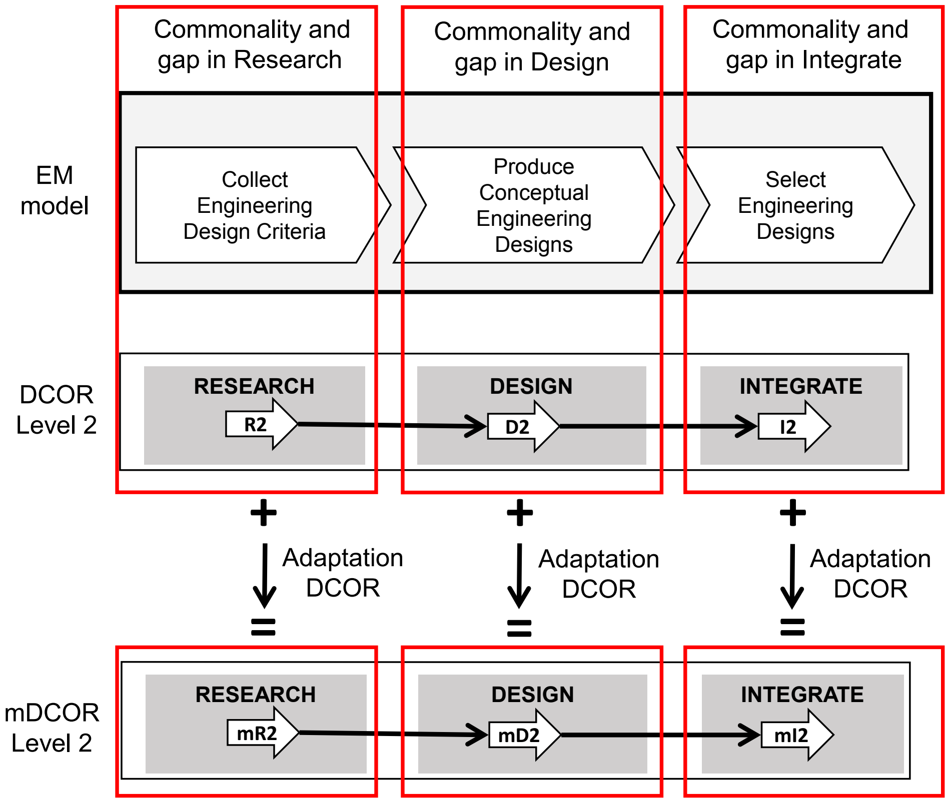

Figure 5-18: Approach for adapting the processes of DCOR to the engineering design process of the EM model

5.2.3.1 Adaptation of DCOR Level 2 model to engineering design process

Figure 5-19 depicts the processes of the DCOR Level 2 model to the engineering design process of a Brownfield mine project. This process is driven by the results of the exploration process. These results determine the requirements for the engineering design process of a new mine project near the current operations. The main processes of the DCOR model need to be adapted to be suitable for modeling the engineering design process. For this, the processes mR2, mD2, mI2, and mA3 are analyzed and adapted in the context of the engineering design process of a Brownfield mine project, as follows.

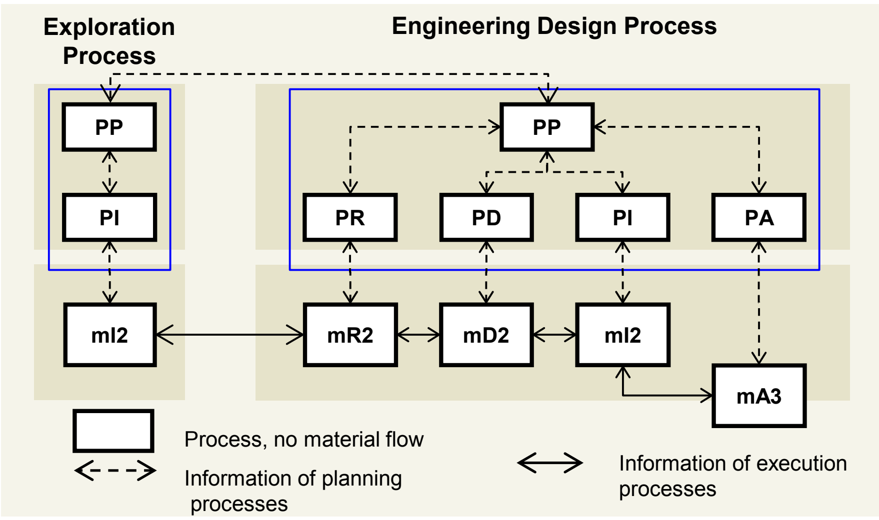

Figure 5-19. Adaptation of DCOR Level 2 model to the engineering design process of a Brownfield mine project

Research Brownfield mine project (mR2). In the context of the engineering design process, mR2 encompasses the processes of collecting engineering design criteria that is carried out in a new mine project near an existing mine. The purpose of these processes is the identification and decomposition of research topics, obtaining and synthesizing information to obtain and confirm all relevant technical parameters, and standards that required producing the requisite designs. The output of the mR2 process is the evaluation and publishing of research findings regarding the engineering design criteria for ensuring medium-term viability and continuity of the mining operation near an existing mine. In addition, the mR2 process includes the identification of sources of supply, sourcing, and validation of materials/products against requirements. The mR2 process is driven by the mI2 process of the exploration process.

Design Brownfield mine project (mD2). In the context of the engineering design process, mD2 encompasses the definition, creation, analysis, testing, and releasing of process, size, and function for a new mine project near an existing mine. The process is focused on producing conceptual engineering designs for

this new mine project. This includes development of manufacturing, testing, servicing, and disposal processes.
Integrate Brownfield mine project (mI2). In the context of the engineering design process, the mI2 process encompasses synthesizing the engineering design definitions and decomposition of the design definitions into sets of component engineering design definitions, releasing project and project definitions to construction process execution, and releasing engineering design documentation to support organizations for new mine projects near an existing mine.
Amend mineral commodity specs (mA3). In the context of the engineering design process, this process includes the activities associated with Specification Change. The process is triggered by the gathering of an issue and commodity specifications. The process culminates with the publication of a Specification Change Order (SCO). The process should encompass the requisite reviews and approvals.

The main processes of the DCOR Level 2 model have been adapted to be suitable for modeling the engineering design process of a Brownfield mine project. The DCOR Level 3 model for this process is analyzed in the next section.

5.2.3.2 Adaptation of DCOR Level 3 model to engineering design process

In section 4.3.2 the approach that is proposed by Juan et al. (2009) was described. This approach defines a procedure of three steps by using the DCOR Level 3 model for defining the Concurrent New Product Development (CNPD) process. This procedure was selected as the most suitable for the adaptation of the DCOR Level 3 model to describe the development process of a mine project development.

The adaptation of the DCOR Level 3 model is developed in the context of the engineering design process (see Figure 5-20). The DCOR process elements are used to describe the main activities carried out by the different workgroups. In addition, cooperation activities for coordination among these workgroups are taken into account.

Figure 5-20 shows the adapted DCOR Level 3 model to describe the engineering design process for a Brownfield mine project. Four workgroups are involved in the development of a Brownfield Mine Project. These workgroups are: Project Management (PM), Project Design (PD), Component Design (CD), and Engineering and Feasibility (EF).

Workgroup PM starts the development process with customer requirements and then works with the workgroups' Project Design (PD), Component Design (CD) and Engineering and Feasibility (EF) to reach a consensus about the requirements. Next, based upon the design requirements, workgroup PD defines, creates, analyzes, tests, and releases the process, size, and function of the prototype of Brownfield Mine Project. In order to do this, workgroup PD requires confirmation from workgroup EF about the project prototype design, and a consensus on the requirements for all the project components from workgroup CD. Afterwards, workgroup CD satisfies all component requirements through the identification of sources of supply, sourcing and validation of materials against project requirements. Finally, workgroup EF creates and verifies the product (project) pilot and releases the final project definition and documentation with the drawings, the general and detailed specifications for the construction process and support organizations.

Table 5-2. Cross-workgroup information flow retrieved from the adaptation of the DCOR Level 3 model to the engineering design process

Input/Output	Description / Definition
Design Requirements	Design requirements are the translation of a set of functional requirements of the Brownfield mine project into design specifications that meet both the enterprise's and the customer's expectations.
Research Requirements	Research requirements related to design needs, including additional information about specific characteristics of the mineral deposit, and the equipment required for the processing plant.
Validated Design	A design of mine project which ensures performance and conformance to defined specifications and requirements.
Research Specifications	Research specifications: mine project description, mineral rocks characteristics, specifications of equipment required, production considerations, production process, etc.
Design Specifications	Design Specification will: a) define the technical scope of the mine project; b) define the expected use and purpose of the project; c) define relationships with existing mine projects; and d) describe the design of the mine project with all the documentation and specifications.

From the above information, a mining company can first designate the names of workgroups from Project Management to Engineering and Feasibility on the Y-axis (Step 1). Next, by mapping the process elements of DCOR (depicted in Figure 5-20) to workgroups' tasks, process elements I2.1–I2.3, D2.1–D2.6, R2.1–R2.6, and I2.4–I2.7 are assigned to workgroups PM, PD, CD, and EF, respectively. Afterwards, the input/output information vertically flowing among workgroups (as shown in Table 5-2) is retrieved from DCOR and depicted on the diagram to connect relevant process elements (Step 2). As Figure 5-20 shows, there are seven cross-workgroup information flows which indicate a likely place for cooperation-activities. However, four early cooperation-activities, including Project Design Requirements Coordination, Component Design Requirements Coordination, Prototype Requirements Coordination, and Engineering and Feasibility Requirements Coordination are finally specified in the diagram (Step 3), and the desired Development process of a Brownfield mine project is derived. It is mainly charged with receiving, decomposing, and distributing requirements.

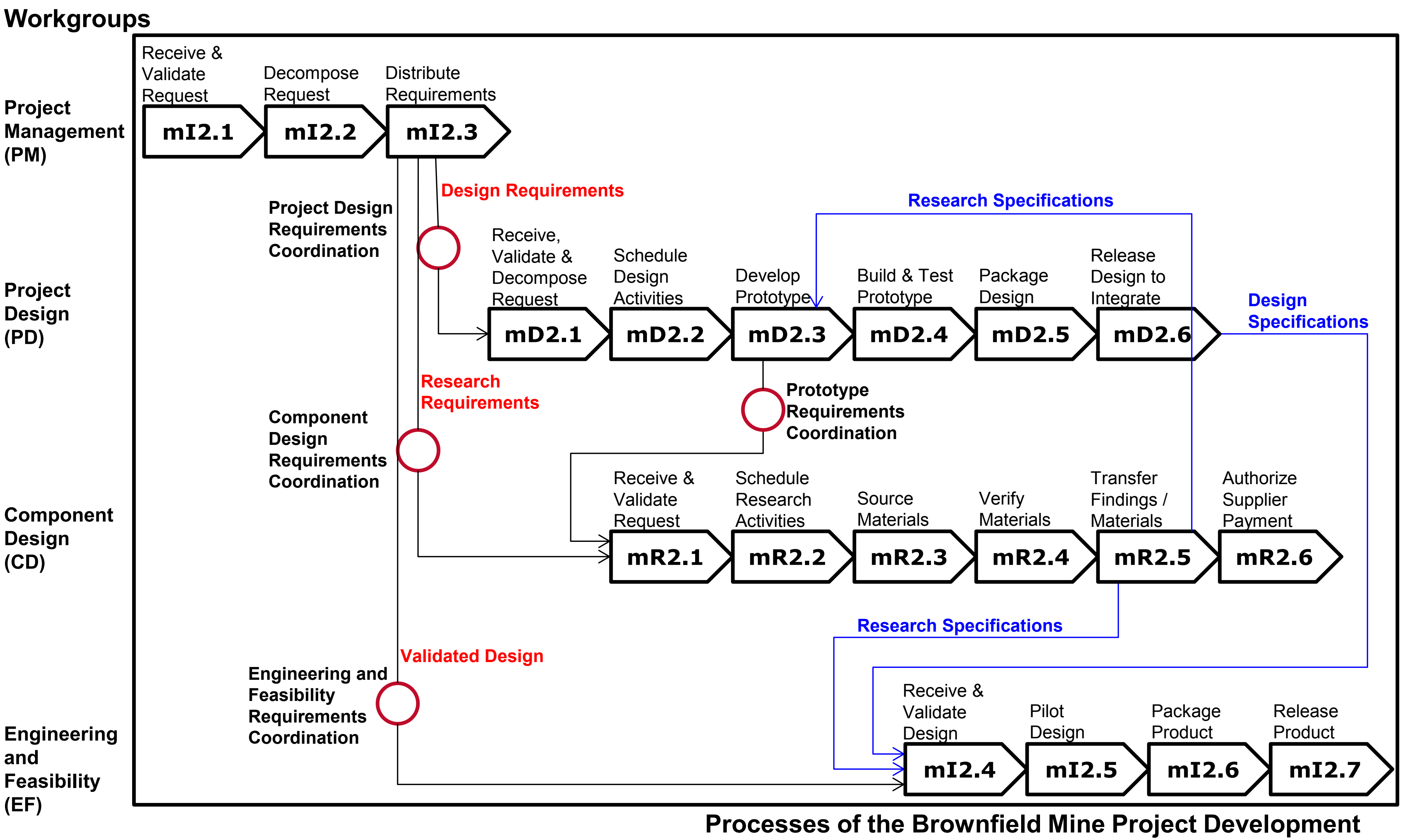

Figure 5-20. Adaptation of DCOR Level 3 model to the engineering design process of a Brownfield mine project (Adapted from Juan et al., 2009)

5.3 The adapted SCOR and DCOR model for modeling the mining processes

In this section, the adapted SCOR and DCOR model is shown in Figure 5-21. This adapted model describes the integration between the SCOR model and the DCOR model for modeling the processes of the early part of the supply chain in the mining industry. The SCOR model has been adapted for modeling the processes of construction and extraction and the DCOR model has been adapted for modeling the processes of exploration and engineering design. In addition, the link between the SCOR model and the DCOR model is developed in this section.

5.3.1 The adapted SCOR and DCOR model

Figure 5-21 shows the adapted SCOR and DCOR model for modeling the early part of the supply chain in mining industry. The sourcing process of mining industry is described using the adapted SCOR and DCOR model. The applications and adaptations of the SCOR model to the construction process and the adaptations of the SCOR model to extraction process are indicated in Table 5-3. This table shows the sections and figures of this thesis where the applications and adaptations of the SCOR model are described. These applications and adaptations involve the Levels 2 and 3 of the SCOR Level 3. In addition, the adaptations of the DCOR model to the mining processes of exploration and engineering design are indicated in Table 5-4. This table indicates the sections and figures where adaptations of the processes of Levels 2 and 3 of the DCOR model have been developed. These adaptations involve translation of the processes of DCOR model to the semantics used in the mining domain.

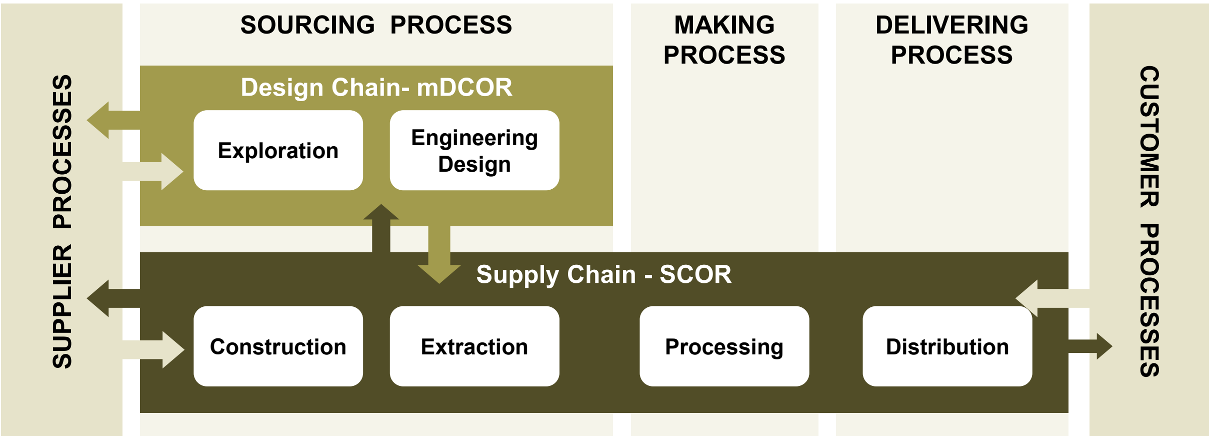

Figure 5-21. The adapted SCOR and DCOR model for modeling the early part of the supply chain in mining

The applications of the SCOR model indicated in Table 5-3 are presented in chapter 4. For example, section 4.2.1.1 describes in Figure 4-7 the existing applications of SCOR Level 2 model to the 'Source' process of the SCOR model in the construction process. In chapter 5, the adaptations of the SCOR model are developed in this thesis in order to close the existing gap in the literature. For instance, section 5.1.2 develops and describes in Figure 5-4 the adaptation of SCOR Level 2 model to the extraction process.

All the adaptations of DCOR model indicated in Table 5-4 are developed and described in chapter 5 of this thesis in order to close the existing gap in the literature. For example section 5.2.2.1 describes in Figure 5-16 the adaptation of DCOR Level 2 model to the exploration process for a Brownfield mine project. Another example, section 5.2.2.2 describes in Figure 5-17 the adaptations of the DCOR Level 3 model to the exploration process for a Brownfield mine project.

Table 5-3. List of sections and figures of applications and adaptations of the SCOR model

Processes	Sections and Figures of applications and adaptations of the SCOR model	
	SCOR Level 2	SCOR Level 3
Construction (Supply of materials)	Section 4.2.1.1 and Figure 4-7	Section 4.2.1.2 and Figure 4-8, 4-11, 4-12, 4-13
Construction (construction site)	Section 5.1.1 and Figure 5-1	Section 5.1.1 and Figure 5-3
Extraction	Section 5.1.2 and Figure 5-4	Section 5.1.3 and Figure 5-6, 5-7, 5-8
Link Construction and Extraction		Section 5.1.4 and Figure 5-9

Table 5-4. List of sections and figures of adaptations of the DCOR model

Processes	Sections and Figures of DCOR adaptations	
	DCOR Level 2	DCOR Level 3
Exploration	-Section 5.2.2.1 and Figure 5-16 -Section 9.1.1 and Figure 9-1 -Section 9.2.1 and Figure 9-3	-Section 5.2.2.2 and Figure 5-17
Engineering design	-Section 5.2.3.1 and Figure 5-19 -Section 9.1.2 and Figure 9-2	-Section 5.2.3.2 and Figure 5-20 -Section 9.2.2 and Figure 9-4

The SCOR model allows modeling the abovementioned processes without relevant changes on the processes of the SCOR model. The DCOR model has been adapted to the semantics used in the mining domain in order to facilitate or guide the applicability of the DCOR model in the mining context. These adaptations to the semantics used in mining are made in the categories of DCOR model and its processes.

The adapted DCOR model to suit the exploration and engineering design processes in the mineral raw materials industry environment is depicted in Figure 5-22. This mDCOR model identifies the adapted processes with a small letter ‘m’, for example mR1 is the 'Research Operational Mine Project'. The adapted DCOR Level 2 model for mining includes the following process categories: Research (mR1, mR2, and mR3); Design (mD1, mD2, and mD3); Integrate (mI1, mI2, and mI3); and Amend (mA3).

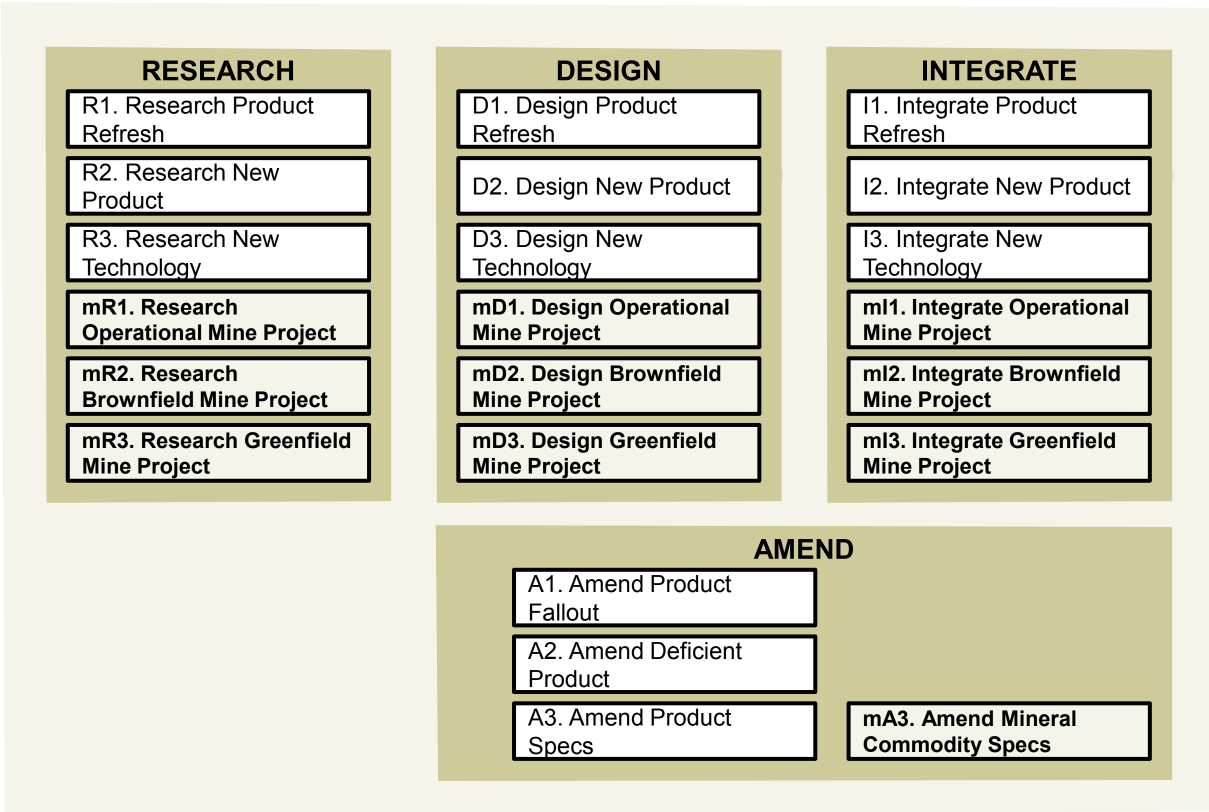

Figure 5-22. The adapted DCOR model for modeling the processes of exploration and engineering design in mining

5.3.2 Adaptation in the link between SCOR and DCOR in the processes of engineering design and construction

In the context of mining, the link between the processes of engineering design and construction need to be adapted in the context of the mining domain. The engineering design process supplies the construction site with the engineering design documentation. The engineering design process contributes with key information regarding design and technical specifications, which are necessary for the acquisition of materials and to build the product at the construction site. The process 'mI1' that is shown in Figure 5-23 is the 'Integrate' process of the mDCOR Level 2 model for Operational mine project, which is linked with the 'M3' process of SCOR Level 2 model. In a similar way the process of the mDCOR Level 2 model, 'mI2' for a Brownfield mine project and 'mI3' for a Greenfield mine project are linked with the 'M3' process of the SCOR Level 2 model. This 'M3' process performs the manufacturing activities to produce products (e.g. build mineral extraction capability, build beneficiation capability) based on the requirements of a customer and the specifications of the engineering design process.

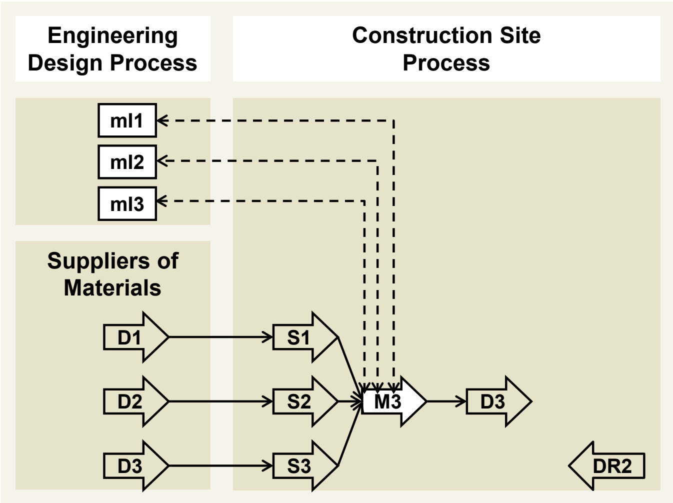

Figure 5-23. Link between mDCOR Level 2 model and SCOR Level 2 model

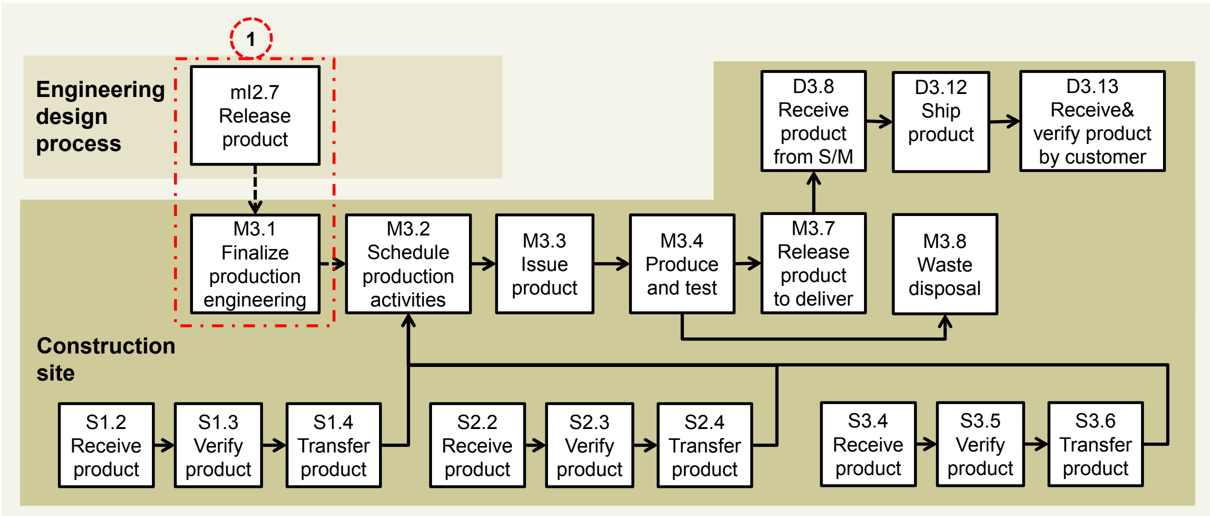

Figure 5-24. Link between mDCOR Level 3 model and SCOR Level 3 model

Figure 5-24 depicts in the circle a number 1, the link between the process element 'M3.1' of the SCOR Level 3 model of the construction site and the process element 'mI2.7' of the mDCOR Level 3 model of the engineering design process. In a mine project, design specifications come from the 'engineering design process'. The process element 'mI2.7' is defined as the process of obtaining approval and releasing the Brownfield mine project. In the case of an Operational mine project, this process element is 'mI1.6', and for a Greenfield mine project is 'mI3.8'. The engineering design process releases the mine project, which is the specification of the construction site to the process element M3.1. This 'M3.1' process element of SCOR model is named as 'Finalize Production Engineering,' and it is defined as "Engineering activities required after acceptance of order, but before product can be produced. They may include generation and delivery of final drawings, specifications, formulas, part programs, etc. In general, the last step in the completion of any preliminary engineering work done as part of the quotation process" (SCC, 2010).

5.4 Summary

This chapter initiates the adaptations of SCOR and DCOR models to the sourcing process of the early part of the supply chain in mining industry. The focus throughout this chapter is on the modeling of the processes of exploration, engineering design, construction, and extraction in which some gaps were identified. An adaptation of the integrated SCOR and DCOR framework for solving the problem has been developed in this chapter.

Existing applications of the SCOR Levels 2 and 3 were identified to describe the supply of materials to the construction site. Some adaptations of the processes of Levels 2 and 3 of the SCOR model were developed for the construction site. This allows bridging the existing gap between SCOR model and the construction process. Moreover, for the extraction process, some adaptations of the processes of Levels 2 and 3 of the SCOR model have been developed for modeling this mining process. In addition, the link between the processes of construction and extraction has been developed by using the adaptations of the SCOR model.

The applications of the DCOR model in other industrial domains have allowed adaptation of the DCOR model to the processes of exploration and engineering design in the context of mining industry. An important adaptation of the DCOR model was developed in the categories of the DCOR according to the semantics used in the mining domain. After this adaptation, the processes of Levels 2 and 3 of the DCOR model have been adapted for modeling the processes of exploration and engineering design.

Finally, the adapted SCOR and DCOR model is presented by the integration of the adapted SCOR model and the adapted DCOR model for modeling the early part of the supply chain in the mining industry. Additionally, the gap in the link between the SCOR and DCOR models has been closed by combining the adaptations developed in SCOR modeling of the construction process and DCOR modeling of the engineering design process.

6 Evaluation of the adapted SCOR and DCOR model in a case study

The previous chapter presented an adapted SCOR and DCOR model for the early part of the supply chain in the mining industry. The research evaluation is conducted by using two case studies from distinctive mining processes (extraction and exploration) based on 'real world' information about copper companies in Chile. The purpose of choosing two cases is to highlight the general applicability of the adapted SCOR and DCOR model.

In section 6.1, the extraction process of a copper mine company is used as an example to demonstrate how the SCOR model describes this process. In section 6.2, a case example is used to show how the adapted DCOR model is used in the exploration process of a Brownfield mine project. Finally, based on these findings, section 6.3 presents a critical discussion of the results and implications related to the adapted SCOR and DCOR model in the sourcing process of the mining industry.

6.1 Evaluation of the adapted SCOR model to extraction process[9]

The extraction process is studied in a copper mine company located in the north of Chile. This mining company possesses three open-pit mines (A, B, and C) located in the same district. Raw materials (mineral rock) are produced in these mines. In 2009, the extraction of materials reached 200 million tons (MT) from mine A, 4.7 (MT) from mine B, and 21.7 (MT) from mine C. The company has a total of four primary crushers in the processing plant which receive the mineral rock extracted. Figure 6-1 shows the Mines A and B with total material extracted in the year 2009 (mineral and sterile), the stocks pile of mineral rock, the flow of mineral rock (millions of tons), and one crusher which receives the mineral rock.

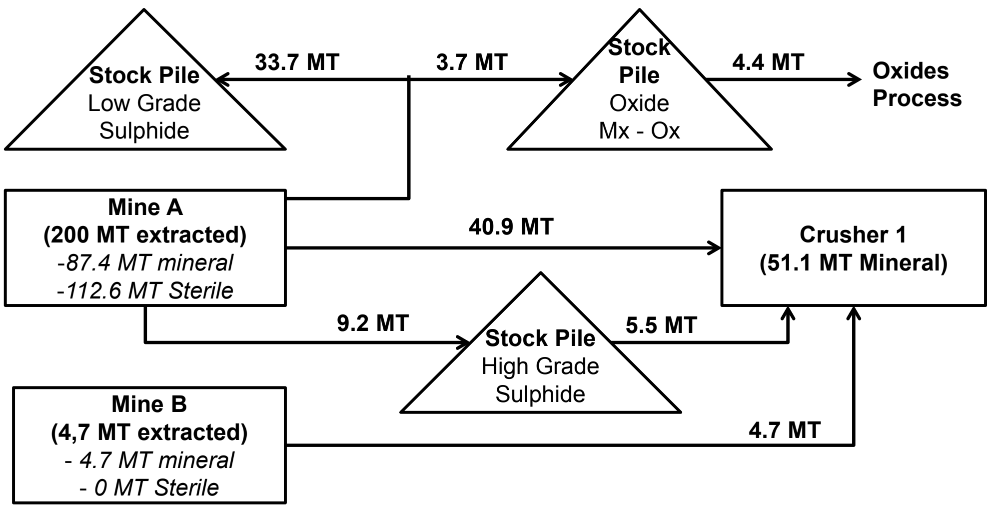

Figure 6-1. The Mines A and B of a copper mine company from Chile

[9] The content of this section has been partly published in (Zuñiga, Wuest & Thoben, 2013).

6.1.1 Material flow and resources in the extraction process

As an example, Figure 6-2 shows the extraction of material from mine A, where only 87.4 (MT) is mineral, and the remaining 112.6 (MT) is sterile. This translates into the mineral rock only representing 44% of the total tons to be transported to the following destinations: 40.9 (MT) are sent to the primary crusher; 9.2 (MT) are sent to the high grade sulphide stock pile, 5.5 (MT) being later sent to the primary crusher; 33.7 (MT) are sent to the low grade sulphide stock pile; and the remaining 3.7 (MT) are sent to the oxide stock (Mx-Ox). The remaining 56% of the material, i.e. 112.6 (MT) of the sterile material is carried to predefined destinations.

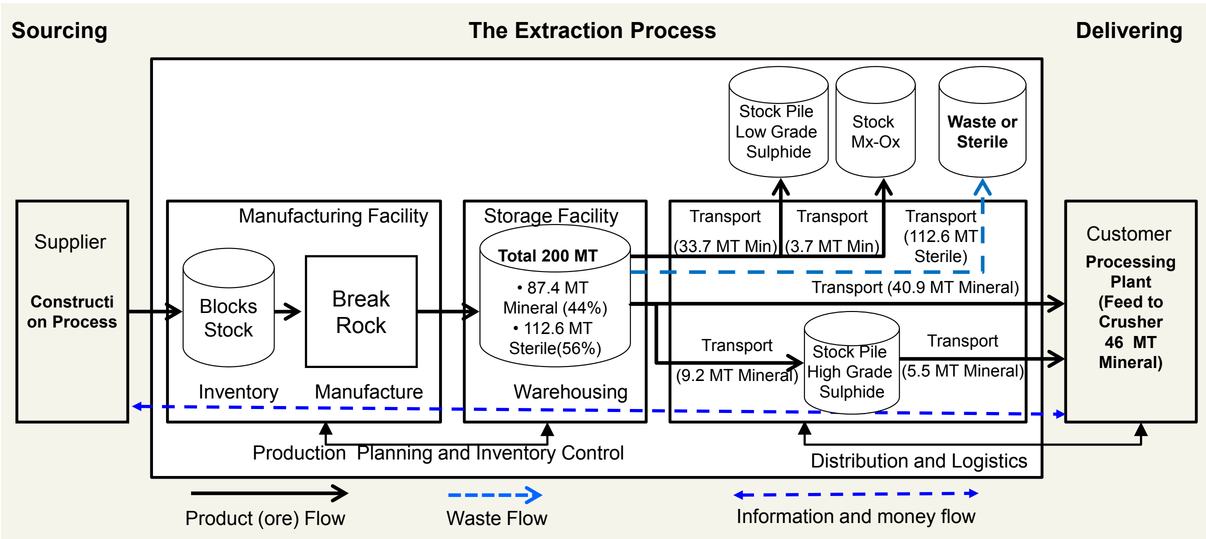

Figure 6-2. The extraction in one year of the mine A in a copper mine from Chile (Zuñiga, Wuest, & Thoben, 2013)

Additionally, the mining company holds the following critical resources for each process (see Figure 6-3): 17 drillers for the drilling process, in the loading process there are 16 power shovels and 4 front-end loaders which are used in the loading of mineral and sterile rock, and there are 107 trucks of 240-373-tons for the transportation of mineral and sterile rock to different destinations (dump, stock, or crusher).

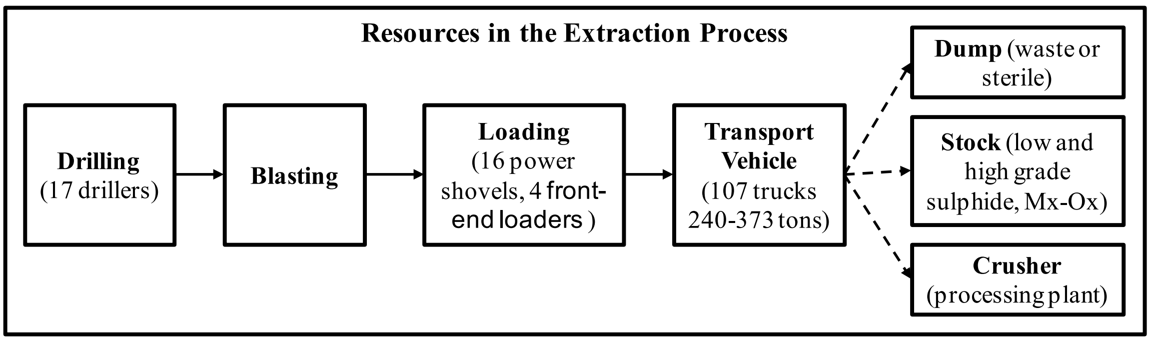

Figure 6-3. The resources in the extraction process of a copper mine company

Based on extraction levels of mineral rock and on the management of available resources, the mining company produced a total of 535.8 thousand tons of copper in 2009. However, the total copper production decreased in 2010 to a total of 504 thousand tons, i.e. a 6% production reduction. This variation in production levels is not only caused by natural causes (e.g. electric storms), but also by other risks and uncertainties typical of this type of activity. It is worth mentioning that in 2010, the company was hit by a 5-day subcontractors' strike, and a 33-day workers' strike by the end of the same year. Furthermore, an operational accident at the seaport caused a logistic problem. In companies of this nature, these types of contingencies affect the production plan.

Given the above, this type of company faces important challenges in the planning of the extractions process, mainly in terms of estimation and control of those variables that may affect the extraction plan. For instance, when comparing planned vs. real figures of a given month in 2013, the following variations in the extraction process are observed: There was a 7.8% reduction in material extraction from the mines as compared to what was originally planned, and an 8% decrease in the average transport performance of trucks in tons per operational hour. Nevertheless, a 4.9% increase was observed in the feeding of mineral rock to the crushing plant as compared to the total fine copper. This variation can be partially explained by the amount of mineral rock sent to the primary crusher, the ore grade of the mineral that goes into the primary crusher, the recovery rate of this mineral in the processing plant, and the availability and performance of resources, among other variables. It should be noted that the most relevant indicators used in the extraction process are related to the degree of completion of the plan, the availability and performance of critical assets, the copper ore grade in the crusher feeding, and the recovery rate in the plant. These are some of the significant indicators in this type of company, which are used to calculate the company's extraction costs.

6.1.2 The SCOR Level 3 model in the extraction process

The SCOR model is successful in describing, at a generic level, the main activities in the company's extraction process. Figure 6-4 depicts the SCOR Level 3 model to describe the extraction process of the copper mine company from Chile. The "stock of rocks" shown in this figure is 200 MT in total in the year 2009. This total of rocks was extracted by the company from mine 'A' indicated in Figure 6-1. The flow of mineral rock, i.e. the 40.9 (MT) is sent to the processing plant through the process sequence: M1.6, D1.8, D1.11, D1.12, and S1.2. In the case of the transportation of 9.2 (MT) of mineral rock to the high grade sulphide stock pile, the material flow sequence involves the same processes as above: M1.6, D1.8, D1.11, D1.12, and S1.2. In this case, process S1.2 represents the reception of mineral rock in the high grade sulphide stock pile. Then, the mineral rock is sent from the stock pile to the processing plant. In the last case, the material flow can be described using the generic processes S.1.4, D1.8, D1.11, D1.12, and S1.2, where the S1.2 process represents the reception of the material in the processing plant. This demonstrates that the generic processes are similar and standard for all the other cases, such as sterile flow. Moreover, it is important to mention that process D1.3 is one of the critical processes that integrates the biggest amount of information, since it is coordinated with a bigger number of processes. This process integrates information about the sourcing plan (P2.4), production plan (P3.4), delivery plan (P4.4), extraction activity schedule, material stock levels, production plant requirements, and amount and date of mineral rock delivery to the production plant, and contributes to the assigning of resources for the loading and transportation of the mineral and sterile rock, and so on.

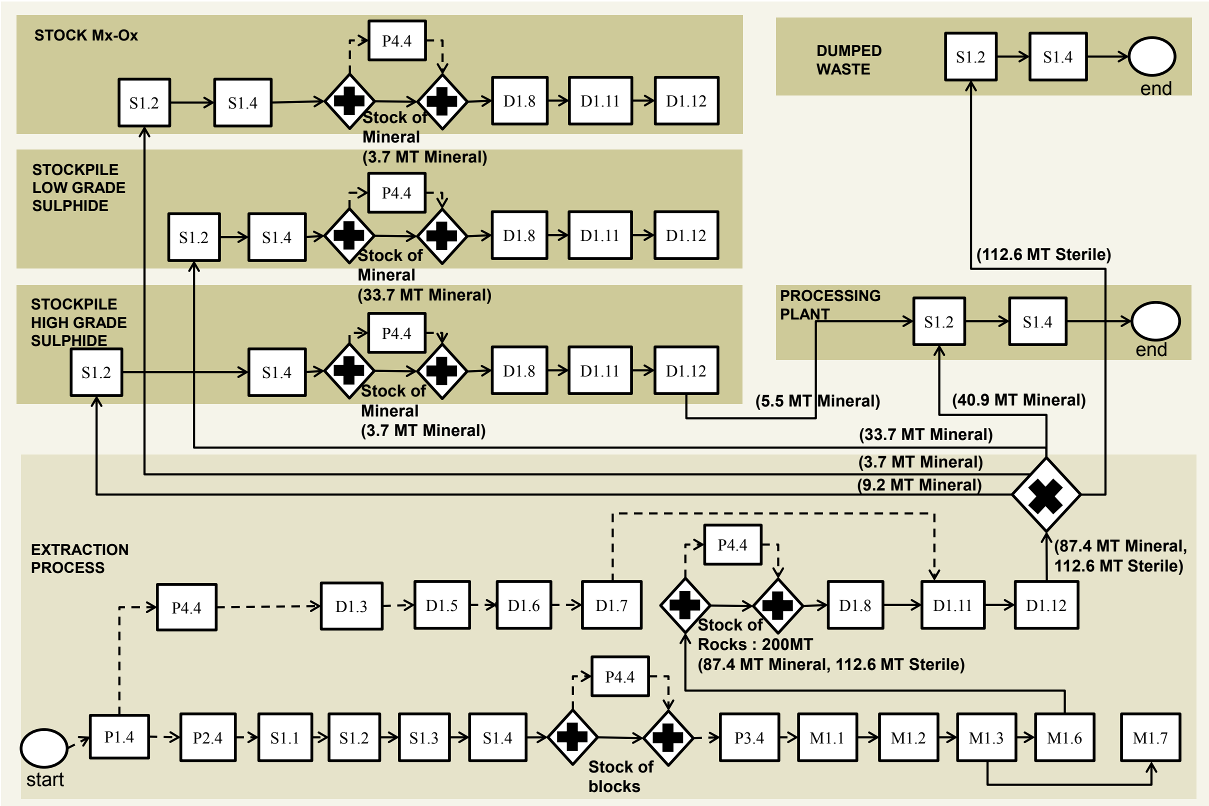

Figure 6-4. The extraction process using SCOR Level 3 model in a copper mine company

6.2 Evaluation of the adapted DCOR model to exploration process

An empirical case of a Chilean copper mining company is used to illustrate and evaluate the proposed adapted DCOR model for the exploration process in a Brownfield mining project. The exploration process is selected for evaluation because it is the most unique process compared to processes in other industries. This section describes the major activities represented by the adapted DCOR Level 3 model. These core activities are performed by the various workgroups that were defined by the mining company to develop the project. In addition, there is adequate coordination activity among the various workgroups, which are represented by nodes in Figure 6-5.

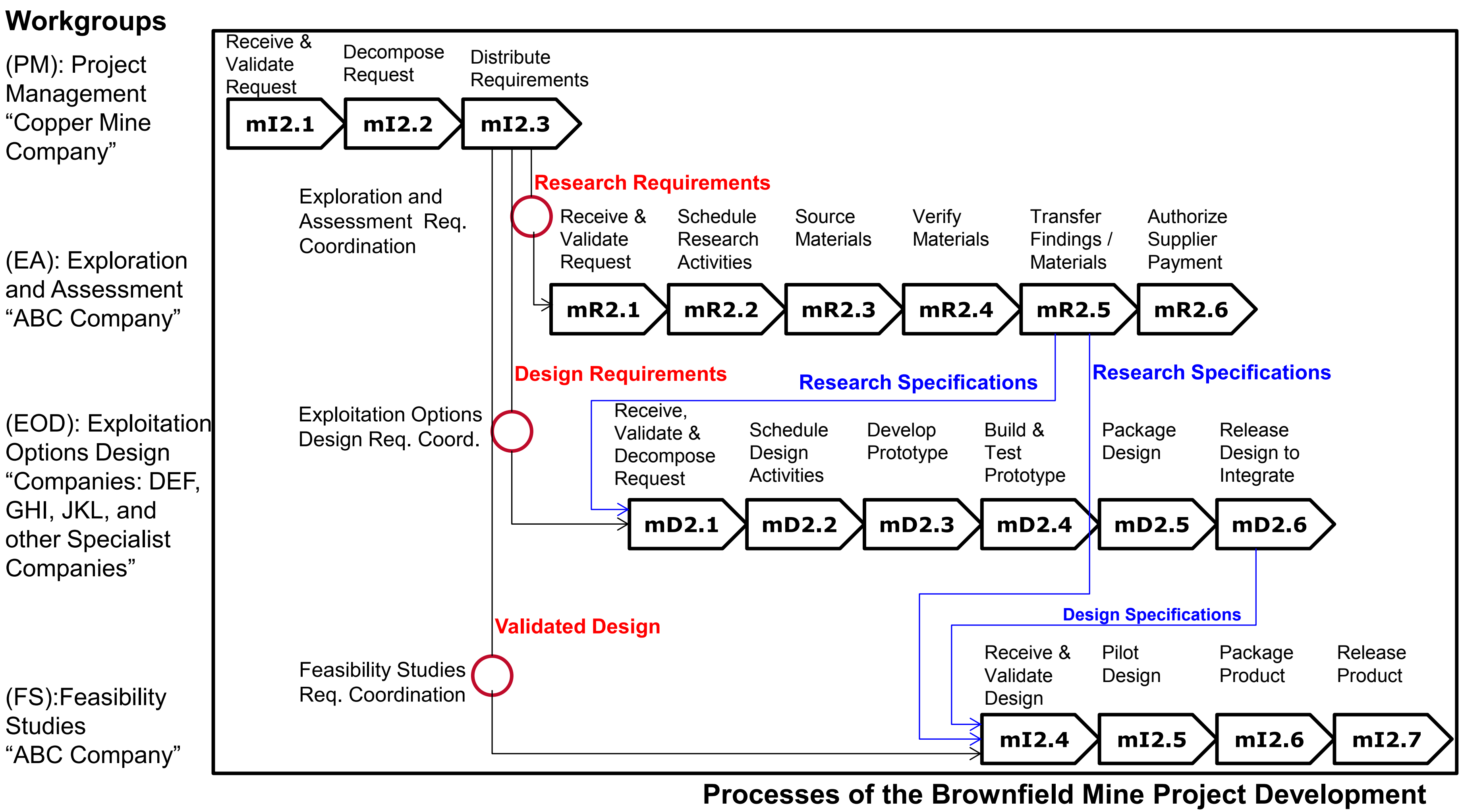

Figure 6-5. The adapted DCOR-Level 3 model for a Brownfield mine project in the context of exploration process of the company

The Chilean copper mining company acquired mining assets where there are three main sources of mineral resources, each one with a determined level of knowledge and resource classification. In order to maintain the privacy of the copper mine company, these three sources of mineral resources have the following designated names: mineral resource A, mineral resource B, and mineral resource C.

6.2.1 Definition of the workgroups

The model proposed in Section 5.2.2.2 discusses the development of a Brownfield mine project for a mining company. Figure 6-5 shows the different workgroups on the Y axis that is defined by this mining company to conduct the exploration process. On the X axis is the sequence of process elements of the DCOR Level 3 model used to describe the main activities of this project. These are the main activities carried out by each workgroup during the exploration process.

The company defines and allocates the following four workgroups: Project Management (PM), Exploration and Assessment (EA), Exploitation Options Design (EOD), and Feasibility Studies (FS). In order to maintain the privacy of the copper mine company and other companies, the real names of the companies of the workgroups have been changed. The copper mine company participates in the workgroup PM. The workgroup EA includes the ABC company. The participating companies in the workgroup EOD are contracted by the mining company, and are integrated for DEF company, GHI company, JKL company, and Specialist Engineering companies. Finally, the workgroup FS is integrated by the ABC company.

6.2.2 The main activities of the workgroups

The main activities performed by each workgroup are determined by the mining company. Given this, workgroup PM initiates the development process with the owners of the mining company (e.g. customer's requirements). The tasks for PM are represented by the process elements I2.1-I2.3 shown in Figure 6-5. The following are the main activities of the workgroups:

Workgroups PM-EA

The process elements of DCOR (depicted in Figure 6-5) to workgroups' tasks, process elements R2.1–R2.6 are assigned to workgroup EA. PM works with Exploration and Assessment (EA) to reach a consensus on customer requirements (research requirements). After that, and based upon the requirements, EA identifies and decomposes the research topics to locate the presence of economic mineral deposits.

During year 2002, the copper mining company decided to increase knowledge and classification of its geological resources. With this purpose, a drilling program was developed for 18,700 meters and finalized in January 2003. These activities and the procedures applied were permanently controlled and audited by an external company (ABC). The main works carried out in each of the resource areas are summarized in the following paragraphs:

a) Mineral resource A

This is the main orebody currently known. The drillholes carried out in this orebody during 2002 had two objectives: improve the classification of the geological resources in accordance with international standards and delimit the extension of the deposit. The estimate of reserves of the *Mineral resource A* evaluation techniques have been applied with a precision level according to the reserves category. Proven reserves resulted from the application of the mine design to the model while probable reserves were obtained by applying mining recovery and dilution factors obtained from the proven reserves calculation.

b) Mineral resource B

The mine and plant assets acquired by the copper mine company operated between years 1972 and 2000, extracting 32,000,000 tonnes of ore with a grade of 2% CuT (total copper) and 1.80% CuS (soluble copper), that were treated by vat leaching and heap leaching with processing of the solutions in a precipitation plant using scrap iron. These operations generated the same amount of leaching tailings that were dumped in a location adjacent to the plant. The drilling activities carried out by the copper company in 2002 included 4 drillholes (twin holes) to check the grades obtained in previous campaigns. ABC company has elaborated an extraction program for the leaching tailings, using the block model and focused on grade sequencing.

c) Mineral resource C

Given the metallurgical inefficiencies of the previous precipitation process and the consequent high operating costs, only high grade ore could be processed, in the range of 1.5% to 2% CuT. This meant that lower grade ore could not be mined, this material is still in the old open pit mines and has been identified with the name of remnants.

Part of the drillholes carried out by the copper mine company in year 2002 was oriented to quantify one sector of these resources, which being remnants of open pit operations, should have a low mining cost. Mineable remnant reserves were calculated from the block model using specialized open pit mining software.

Workgroups PM-EOD

The process elements of DCOR (depicted in Figure 6-5) to workgroups' tasks, process elements D2.1–D2.6 are assigned to workgroup EOD. Once the EA workgroup obtains certain results that meet customer requirements, PM works with the EOD workgroup to reach a consensus on customer requirements and to begin main activities. For this, EOD must take into account the results on the research specifications obtained by EA. Based on the research specifications provided by EA, EOD workgroup presents the most convenient options for mineral resource exploitation by a mine project.

The activities of this workgroup are the followings:

- The Mineral Resource A Mining Project has been carried out by ABC company. The mining method designed for this orebody is Post Pillar Cut and Fill, considering the geomechanical recommendations from DEF company.
- Regarding to the design of the processing plant, the objective of the process plant is to obtain copper cathodes (99.98% purity) via the hydrometallurgical process of heap leaching, solvent extraction (SX), and electrowinning (EW). SX-EW plant nominal capacity is 19,000 tonnes of copper per year, cathodes type LME grade A, with a EW bay comprising of 88 electrolitic cells, using significant part of the equipment and installations of the Lo Aguirre plant. The stages of the process are: Crushing, agglomeration, and conditioning leach pads formation, leaching, solvent extraction (SX), electrowinning (EW), discarding of raffinate solution (control of leaching impurities), project metallurgical tests.
- Related to the Engineering of Process Plant, the engineering studies carried out at this stage were oriented to confirm the technical feasibility of the project and to establish an adequate estimate of the required initial investment. The level of definition of the project, either from the general perspective of the works required or its dimensioning, is more than adequate to backup the feasibility study. Total costs of procurement, construction, and assembly of the plant amounts to US$ 15,161,950.
- Regarding the Production Plan, an integrated production program was elaborated considering the three available resources: Ore from Mineral resource A (proven and probable reserves), Mineral resource C (ventana), and old Mineral resource B (ripios). It must be highlighted that this program considers, for the first three years of operation, only proven reserves from Mineral resource A and a complement of ripios. The production plan program is used for the economic evaluation.

Workgroups PM-FS

The process elements of DCOR (depicted in Figure 6-5) to workgroups' tasks, process elements I2.4–I2.7 are assigned to workgroup FS. After the EOD workgroup has reached certain results, PM works with the FS workgroup to reach a consensus on the customer's requirements and to initiate its main activities. This is done based on the results delivered by the workgroups EA (Research specifications) and EOD (Design specifications). The FS workgroup embraces the synthesis of design definitions and decomposition of design definitions in developing the business plan. The main tasks for this workgroup are the followings:

- Related to the Operating Costs, the average operating cost for the life of the mine is estimated at 54.7 cUS$/lb. Cost of operation and sales is estimated at 57.4 cUS$/lb. These costs are 51.7 cUS$/lb and 53.9 cUS$/lb respectively for the first six years of the project.
- Regarding the Project Investment, pre-operational investment estimated for the project is MUS$ 34,701. The investments are relevant for the economic evaluation.
- The Economic Evaluation determines if the project is viable. Among the basic assumptions, the project evaluated considers a 10 year operational life with an annual production of 19,000 tonnes of electrowon copper cathodes. The project construction and start up period has been estimated between 12 and 14 months starting from the moment of the project 'construction decision'. Other assumptions are related to: copper price, selling terms, taxes, depreciation & amortization, and working capital. The net present value of the project cash flow, before financing, amounts to MUS$11,503 and MUS$ 7,135 for discount rates of 10% and 12% respectively.
- Finally, this workgroup generates the conclusions of the risks analysis. As part of the Feasibility Study certain potential project risks have been identified with their eventual impacts, studying the necessary actions to control them. The aspects identified were:
    1. To achieve the metallurgical recovery parameters within the cycle defined in the design.
    2. To achieve the estimated costs for the ripios handling operation considering the uncertainties of the ripios block model.
    3. To achieve the recovery of the reserves of the underground mining of the Mineral resource A and the accuracy in the application of the selected mining method.
    4. The existence of geological structures slightly different than those defined in the geological model.
    5. Competence of the organization.

6.2.3 Coordination activities among workgroups

The input/output information vertically flowing among workgroups is shown in Figure 6-5 and connects relevant process elements. As Figure 6-5 shows, there are six cross-workgroup information flows which indicate a place likely for cooperation-activities. However, three early cooperation-activities, including Exploration and Assessment Requirements Coordination, Exploitation Options Design Requirements Coordination, and Feasibility Study Requirements Coordination, are finally specified on the diagram, and the desired Development process of a Brownfield Mine Project for the copper mining company is verified.

Section 9.3 describes in detail each of the adapted process elements of the DCOR model. These adapted process elements of the DCOR model represent the activities that are performed by the different workgroups of the exploration process of the Brownfield mine project. These process elements of the DCOR model have been adapted to the semantics used in the mining domain.

6.3 Discussion of results and limitations

The findings of this thesis, modeling ***the extraction process*** of the mining industry according to the established SCOR model annotation of the manufacturing industry, are evaluated based on the extraction process of a copper mining company in Chile. This mining company possesses three open-pit mines (A, B, and C) located in the same district. In 2009, raw materials (mineral rock) were produced in these mines at a quantity of 200 million tons (MT) from mine A, 4.7 (MT) from mine B, and 21.7 (MT) from mine C. The company receives the extracted mineral rock with a total of four primary crushers in the processing plant. For example, Figure 6-2 shows the extraction of material from mine A, where only 87.4 (MT) is mineral and the rest of the material, 112.6 (MT), is sterile. This means that the mineral rock only represents 44% of the total tons transported to the following destinations: 40.9 (MT) are sent to the primary crusher; 9.2 (MT) are sent to the high grade sulphide stock pile, where 5.5 (MT) are later sent to the primary crusher; 33.7 (MT) are sent to the low grade sulphide stock pile; and the remaining 3.7 (MT) are sent to the oxide stock (Mx-Ox). The remaining 56% of the material, i.e. 112.6 (MT) of the sterile material, is carried to predefined destinations (waste dump). Additionally, the mining company is in possession of the following highly critical resources for each process: 17 drillers for the ‘Break Rock’ process, 16 power shovels, 4 front-end loaders used for the loading of mineral and sterile rock, and 107 trucks of 240-373 tons for the transport of mineral rock and sterile.

Based on extraction levels of mineral rock and on the management of available resources, the mining company produced a total of 535.8 thousand tons of copper in 2009. However, the total copper production decreased in 2010 to a total of 504 thousand tons, i.e. a 6% production reduction. This variation in production levels depends not only on natural causes (e.g. electric storms), but also on other risks and uncertainties typical for this type of activity. It is worth mentioning that by the end of 2010, the company was hit by a 5-day subcontractors’ strike and a 33-day workers’ strike in the same year. Furthermore, an operational accident at the seaport caused a logistic problem. Within companies of this nature, these types of contingencies affect the production plan.

Given the above circumstances, this type of company faces important challenges in the planning of the extraction process, mainly in terms of estimation and control of those variables that may affect the extraction plan. For instance, when comparing planned vs. real figures of a given month in 2013, the following variations in the extraction process are observed: There is a 7.8% reduction in material extraction from the mines as compared to what was originally planned, and an 8% decrease in the average transport performance of trucks in tons per operational hour. Nevertheless, a 4.9% increase is observed in the feeding of mineral rock to the crushing plant as compared to the total fine copper. This variation can be partially explained by the amount of mineral rock sent to the primary crusher, the ore grade of the mineral that goes into the primary crusher, the recovery rate of this mineral in the processing plant, and the availability and performance of resources, among other variables.

It should also be noted that the most relevant indicators used in the extraction process relate to the degree of completion of the plan, the availability and performance of critical assets, the copper ore grade in the crusher feeding, and the recovery rate in the plant. These are some of the significant indicators in this type of company that are used to calculate the company's extraction costs. Moreover, it should be mentioned that the SCOR model provides a set of KPI standards that may be used in the extraction process to measure the performance of both internal and external (client) aspects. In regard to the internal aspects, the SCOR model considers the KPIs of 'costs' and 'assets.' Regarding external aspects, SCOR puts forward KPIs to measure 'reliability,' 'responsiveness', and 'agility.' The mining company makes use of only those KPIs that are used to measure the internal aspects related to cost and asset management. There is a gap in the mining company's measurement of the external aspects of the extraction process, and all aspects related to the performance of the extraction process towards the client. This gap may be covered by the use of those KPIs of the SCOR model most appropriate for measuring extraction process performance.

The SCOR model has proven successful in describing, at a generic level, the main activities in the company's extraction process. Take, for instance, the SCOR Level 3 model in Figure 6-4. This figure describes the extraction process of the company indicated in Figure 6-2. The 'stock of rocks' shown in Figure 6-4 corresponds to the 200 (MT) of material extracted by the company from mine A. Figure 6-4 shows only the flow of mineral rock, i.e. the 40.9 (MT) sent to the processing plan through the M1.6, D1.8, D1.11, D1.12, and S1.2 process sequence. In the case of the transportation of 9.2 (MT) of mineral rock to the high grade sulphide stock pile, the material flow sequence involves the same processes as above: M1.6, D1.8, D1.11, D1.12, and S1.2. In this case, process S1.2 represents the reception of mineral rock into the high grade sulphide stock pile. The mineral rock is then sent from this stock pile to the processing plant. The material flow can be described using the same generic processes, M1.6, D1.8, D1.11, D1.12, and S1.2, where the S1.2 process represents the reception of the material in the processing plant. This demonstrates that the generic processes are similar and standardised for all the other cases, such as sterile flow. Moreover, it is important to mention that process D1.3 is one of the critical processes that integrates the biggest amount of information, as it coordinates with a larger number of processes. This process integrates information about the sourcing plan (P2.4), production plan (P3.4), delivery plan (P4.4), extraction activity schedule, material stock levels, production plant requirements, as well as amount and date of mineral rock delivery to the production plant. It also contributes to the resource assignment for the loading and transportation of the mineral and sterile rock. However, if a more detailed report of the company's extraction activities is required, the SCOR Level 3 model must be decomposed to Level 4, and subsequently to Level 5. The SCOR model does not include standard Level 4 and 5 processes. Instead, this model suggests that each company develop these levels of detail, considering the specific requirements and practices of each process in the company.

In addition, the DCOR model has proven successful in describing, at a generic level, the main activities in the company's ***exploration process*** in a Brownfield mine project. For instance, the process elements of DCOR Level 3 model in Figure 6-5 describe the activities performed by the workgroups of the copper mine company.

In order to maximise the full potential of the operation in the chilean copper mine, it was critical that the mine manager of the company ensured that the mine had sufficient reserves to both operate at a steady level and have the flexibility to respond to any changing needs. In this case the central goal was to expand to take advantage of improved commodity prices. For this, a key part was to have a good understanding of the potential resource in the area of the existing district.

To ensure goal achievement, the roles and responsibilities of the different workgroups in the exploration process has to be clearly understood. In this case study workgroups have shared views about what needs to be done. Some workgroups are more clear about identifying future resource requirements to support the life-of-mine production schedule. Other workgroups have more expertise in assessment of Brownfields exploration opportunities. In this case, the workgroups had to include an assessment of the global undiscovered endowment in the area near the existing mine. This study helps to ensure that efficient operations are maintained. These workgroups need to agree about the optimum level of Brownfields funding related to new investments and the operations costs.

In this case study, the leader of the project of the company had a very important role to play in helping set the consistency of purpose and effort in exploration in general. He had to define the requirements of the company and communicate these requirements to each workgroup. This case was a commitment to a program which aimed to maximise the full value of the operation for the existing mine assets (three sources of mineral resources).

The evaluation of the adapted DCOR Level 3 model to the exploration process demonstrate that this process can be standardized using an adaptation of the DCOR model to the language used in the mining domain. This is one of the most valuable processes for added value creation in mining. The competitiveness and survival of this industry depends on the efficiency and performance of this process. However, exploration is one of the most specialized processes in the mining industry and in the future, requirements for the exploration process are going to increase dramatically to face new challenges in the mining industry. Thus, this process needs to improve its efficiency, performance, and its integration in the early part of the supply chain. Any contribution to the standardization of the exploration process contributes to addressing new challenges. Therefore, any improvement in this process will affect the performance and efficiency of downstream processes, especially in the processes of engineering design, construction, extraction, processing, and distribution.

6.4 Summary

This chapter presents the evaluation of the adapted SCOR and DCOR model for the early part of the supply chain in the mining industry. The research evaluation is conducted by using two case studies from distinctive mining processes (extraction and exploration) based on 'real world' information about copper companies in Chile. The reason for choosing two cases is to highlight the general applicability of the adapted SCOR and DCOR model.

The extraction process was studied in a copper mine company located in the north of Chile. This process is used as an example to evaluate the SCOR model in the description of this process. Raw materials (mineral rock) are extracted in three open-pit mines (A, B, and C) located in the same district. In 2009, the extraction of materials reached 200 million tons (MT) in mine A. The company has a total of four primary crushers in the processing plant which receive the mineral rock extracted. This case study considered the total material extracted in the year 2009 (mineral and sterile) from Mine A, the stock pile of mineral rock, the flow of mineral rock (millions of tons), and one crusher in the processing plant which receives the mineral rock to be processed in the year 2009.

The second case study is an empirical case of a Chilean copper mining company which is used to illustrate and evaluate the adapted DCOR model for the exploration process in a Brownfield mining project. The Chilean copper mining company acquired the mining assets, where there are three main sources of mineral resources, each one with a determined level of knowledge and resource classification: Mineral resource A, Mineral resource B, and Mineral resource C. During year 2002, the company decided to increase the knowledge and classification of its geological resources. With this purpose a drilling program was developed for 18,700 meters that was finalized in January 2003. The major activities represented by the adapted DCOR Level 3 model are performed by the various workgroups that were defined by the mining company to develop the project. In addition, there is an adequate coordination activity among the various workgroups.

The evaluation of the adapted SCOR and DCOR model in the processes of extraction and exploration confirmed that it is possible to describe the mining processes using the standard SCOR and DCOR model, which was adapted using mining language of the EM model to guide the implementation of the developed model.

7 Conclusions and outlook

This chapter, structured into three sections summarizing the research work, discusses the main contributions of the thesis and describes some future research directions.

7.1 Summary

The research problem of this thesis is set in the early supply chain processes of the mining industry; it focuses on the modeling of these processes with the goal of bringing them into highly integrated supply chains or networks. The modeling is based on the adaptation of the integrated supply chain framework DCOR and SCOR to the mining industry. Today, existing solutions of supply chain models focus mostly on the manufacturing industry, instead of the whole supply chain, since they do not incorporate the processes of the mining industry. It was found that these mining processes can have a significant and varying effect on the performance of the downstream processes and thus on the entire supply chain.

In order to understand the reasons of this lack of integration, the analysis of the unique characteristics of the mining industry and its processes helps to identify the challenges faced by this industry. Then, different characteristics of the processes within mining and manufacturing are presented and compared. This analysis reveals various differences, which can explain the missing integration and annotation of standardized supply chain models in manufacturing. Consequently, the sourcing process presents the largest gap and the greatest challenges facing the mining. This process differs from the “source” process of the SCOR model. From the above-mentioned information, the modeling efforts focus on the processes of exploration, engineering design, construction, and extraction. In order to understand the requirements of industry-specific models, the dedicated EM model (mining) and the generic SCOR as well as DCOR models (manufacturing) are presented and compared before elaborating on of the identified gap. Through the literature review the gap between the SCOR model and the processes of construction and extraction, and the gap between the DCOR model and the processes of exploration and engineering design, were determined. After going into details within the individual processes and the required adaptations needed for an integration of the aforementioned processes in the SCOR and DCOR models, the derived model is presented in different granularities (SCOR and DCOR Levels 1, 2, and 3). After that, an integrated model for the sourcing process in mining could be obtained and analyzed.

The research evaluation was conducted by using two case studies from distinctive mining processes (extraction and exploration) based on “real world” information about copper companies in Chile. The purpose of choosing two cases was to highlight the general applicability of the adapted SCOR and DCOR model. The evaluation confirmed that it is possible to describe the mining processes by using standard SCOR and DCOR models, which must be adapted by using the mining language to guide the implementation of the developed model.

7.2 Research contributions

Integration of the mining industry in the supply chain is one of the keys to effective supply chain management. This thesis investigates and demonstrates how to adapt the standard SCOR and DCOR models to describe the mining processes, which can facilitate integration and collaboration among supply chain members. This thesis also describes the modeling of the processes of exploration, engineering design, construction, and extraction in the early part of the supply chain in the mining industry. The following are the major contributions made in this thesis:

First supply chain framework for the early part of the supply chain in the mining industry

This research work is the first attempt to create a basis for further research in the early part of the supply chain of the mining industry which depends on a mineral deposit. This paper demonstrates how SCOR and DCOR models may be adapted to describe the processes in the mining domain. It implies that these models allow modeling a crucial part of the early part of the supply chain in the mining industry, without any need to integrate other generic processes into the existing SCOR and DCOR models. The mining processes are relevant because they represent the processes that support the supply of the raw materials required by the manufacturing industry. Any variations in performance and efficiency for these processes may influence the downstream processes. In addition, it can be concluded that there is a potential integration of the processes of the early part of the supply chain in the mining industry with other processes in the supply chain by using SCOR and DCOR models.

Differences between the sourcing process in mining and manufacturing

Another important outcome of this research is a description of the main differences between sourcing in the mining industry and the manufacturing industry. Owing to the unique characteristics of the mining industry, this thesis demonstrates that the process “source” of the SCOR model is different from the sourcing process in mining. Consequently, it can be said that the SCOR model does not cover every step from the supplier’s supplier to the customer’s customer as promised. To overcome this gap, the DCOR model was adapted to the mining context in this research. Finally, this thesis can demonstrate that the adaptation of the integrated SCOR and DCOR models allows a description of this sourcing process. This is a significant contribution of this research, since this sourcing process is one of the most important current and future challenges for the mining industry.

The new supply chain framework for mining can be integrated with the current supply chains of auxiliary materials for mining

For the “real world” of mining, this research work contributes with a new supply chain framework which is more focused on the main raw material for mining processes, in comparison with the current approach that focuses on the supply of the auxiliary materials for the mining processes. The current approach in mining considers the mining processes working in isolation and managed only by specialists. The best example is the exploration process that supports other processes, but this process is not well integrated with other mining processes under the perspective of a supply chain. Mining processes nowadays act as isolated units that must meet a plan and should meet the costs and predefined KPIs. Given this, it can be concluded that a new supply chain framework has the potential to be integrated with the supply chains of auxiliary materials for mining by using the same integrated SCOR and DCOR frameworks. Therefore, the new supply chain framework of this research contributes to the process integration, both internally and externally.

A new contribution to the standardization of the exploration process in the mining industry

This thesis contributes to the standardization of the exploration process by using an adaptation of the DCOR model to the language used in the mining domain. This is one of the most valuable processes for added value creation in mining. The competitiveness and survival of this industry depends on the efficiency and performance of this process. However, exploration is one of the most specialized processes in the mining industry and is only managed by geologists. Some geologists claim that this process is purely creative in such a way that the design chain approaches are not applicable in the context of mineral exploration. They state that luck plays a large factor in the discovery of deposits. However, a newer generation of geologists thinks that the design chain models improve the efficiency and performance of this process by using standard design chain models and certain KPIs.

In the future, requirements for the exploration process are going to increase dramatically to face new challenges in the mining industry; therefore, this process needs to improve its efficiency, performance, and integration in the early part of the supply chain. This research is a significant contribution to the exploration process because it proposes a new standard design chain model that contributes to answering new challenges. Any improvement in this process will affect the performance and efficiency of downstream processes, especially the processes relating to engineering design, construction, extraction, and processing.

7.3 Outlook and future work

KPIs and Best Practices

This research is the basis for future research on key performance indicators (KPIs) and best practices specific to and more suitable for the mining industry. This is possible because SCOR and DCOR models provide a set of KPIs and best practices validated throughout the supply chain. The KPIs and best practices focus on the manufacturing industry, and they do not consider the specific characteristics of mining. The existing KPIs in mining focus primarily on two of the five categories listed in the SCOR model, costs, and assets. Customer-oriented KPIs such as reliability, responsiveness, and agility are not considered. For improving the situation it is necessary to identify what KPIs and best practices of SCOR and DCOR models should be adapted to measure the performance of the processes of this industry. Furthermore, the existing KPIs and best practices of SCOR and DCOR models have to be expanded to be more applicable to the geological environment, depending on the existence of finite natural resources.

It can be safely said that in the near future, the amount of information and standard KPIs derived out of mining operations will increase due to these types of models. This offers opportunities and challenges for mining companies and manufacturing companies. Consequently, in future research, the selection of the most suitable KPIs and best practices can contribute to improving the integration, transparency, and performance of the mining processes, and therefore, improve the performance of the subsequent processes in the supply chain.

Identifying and evaluating supply risks of critical mineral raw materials in the early part of the supply chain

The proposed adapted model for the early part of the supply chain reveals supply chain structures, dependencies, and handoffs that may contain risk. SCOR and DCOR mappings are the supply chain and design chain mapping that can be used. A key aspect of supply chain risk management is identification that involves creating a list of potential events which could harm any aspect of the supply chain's performance. Risk identification allows an organization to take steps to create plans to manage risks even before they occur. This is typically more cost-effective than waiting to react to adverse events when they occur (SCC, 2010). These risks in the early part of the supply chain affect the supply of raw materials to manufacturing. This thesis highlights that the scarcity of natural resources is one of the most relevant risks in the early part of the supply chain.

Virtually all analysts agree that there is an increasing scarcity of renewable and nonrenewable natural resources such as energy, water, and minerals. For a manufacturing company in a global supply chain, this scarcity may pose a serious problem. In addition, the raw material supply seems to run the risk of becoming a bottleneck of the global economy since the rise of new economies like China and India. These concerns led to the launch of the European Commission "Raw

Materials Initiative" (RMI) in 2008. The European Commission (2010) indicates that securing reliable access to mineral raw materials has become a critical challenge to many resource-dependent countries all over the world. In the future, a reliable supply of mineral raw materials will be the main success factor for a large section of the manufacturing industry (Seifert & Wüst, 2009).

A new research work focusing on the risks in the early part of the supply chain is required to identify and evaluate possible supply risks, with a special focus on the needs of critical mineral raw materials for European manufacturing industries. The evaluation of the proposed model can be conducted by using three scenarios. These scenarios represent different locations of mining companies (for instance, Chile, China, and Australia). The purpose of choosing these three different scenarios is to highlight the general applicability of the model developed not only for the same mineral raw material but also for mining companies from different countries.

Analysis and validation of the adaptation of the GreenSCOR model to the mining industry

Mining companies publish reports about sustainability by using recognized environmental sustainability standards. These reports, however, do not allow comprehensive visualization and measurement of environmental performance from the supply chain perspective. Therefore, relevant processes of mining companies are not visible to decision-makers in the supply chain. In this context, it is necessary to study how to integrate the supply chain processes of these companies by using the SCOR model with the "environmental management" related to these processes. This integrated view is achieved by using the "GreenSCOR" model (see Figure 7-1).

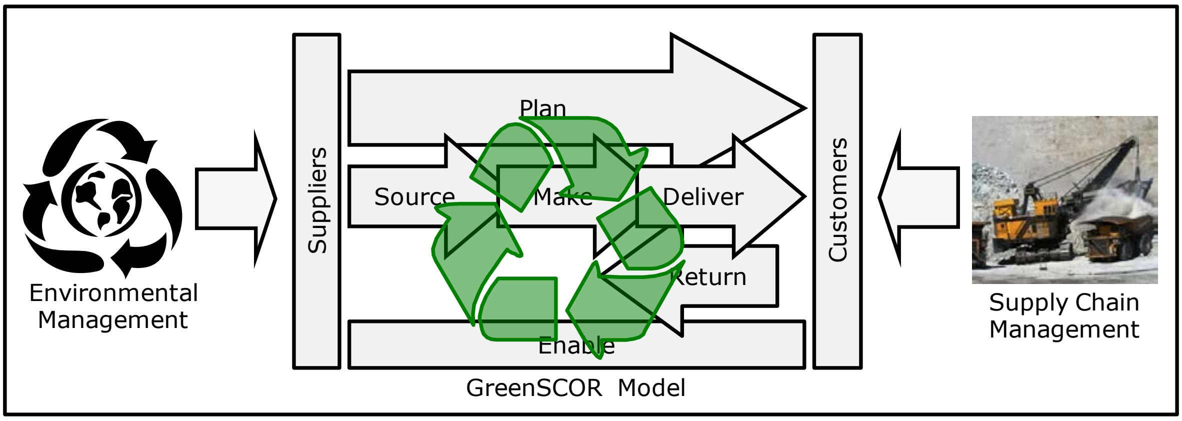

Figure 7-1: The extension of the GreenSCOR model in mining (Adapted from SCC 2010)

The GreenSCOR model contains standard processes to describe the supply chain, and includes KPIs for both the supply chain and environmental management. However, this model includes neither the standard processes of the mining industry nor those KPIs that are most suitable for the sustainability of minerals natural resources. It is precisely this gap that should be addressed in future research, extending the GreenSCOR model to include the standard processes and KPIs regarding the supply chain and sustainability, taking into account environmental management in the mining industry. Among the important objectives of future research are the following:

- Analyzing the adapted SCOR model, which, after being proposed in this research, integrate the environmental management in mining companies to the GreenSCOR model.
- Validate the extension of the GreenSCOR model by identifying and evaluating the KPIs for sustainable development in the processes of extraction, processing, and distribution in the mining industry.

Analyze and validate how the adapted SCOR and DCOR models can be applied in the petroleum industry

The supply chain of the petroleum industry is complex, in comparison with other industries (Szucs & Hassen 2012; Hussain et al. 2006). The production is concentrated in certain areas, but the product itself is in demand all over the world. The oil supply chain essentially can be divided into two closely linked major segments: the upstream and downstream supply chains. The upstream supply chain involves the acquisition of crude oil and related operations such as exploration and production. Afterward, logistics management has to be involved in order to deliver the crude oil from the exploitation point to the refinery. The downstream supply chain starts at the refinery, where the crude oil is converted into consumable products that are the specialty of refineries and petrochemical companies, and then, its derivatives are delivered to customers.

The processes of the petroleum industry have some similarities with the mining processes of exploration, engineering design, construction, extraction, processing, and distribution. In this case, exploration represents searching for deposits. The engineering design represents searching for ways to create access to the deposits. The construction process is the building of infrastructure and the equipment installation to extract petroleum. The extraction process represents the extraction of petroleum. The processing represents the refinement or purification of petroleum, while the distribution represents the distribution of products to customers.

Hussain et al. (2006) identified numerous challenges faced by the petroleum industry, including an integrated process management. Improved supply chain efficiency in the petroleum industry will help to address these challenges. Given that the challenges and opportunities lie within the entire oil supply chain, it follows that improving the supply chain processes does have the potential to confer competitive advantage for this industry. Therefore, new research is required to analyze and validate how the adapted SCOR and DCOR models can be applied to the petroleum industry. In addition, the research aims to verify the similarities between mining supply chain processes and petroleum industry processes.

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9 Appendixes

9.1 *Adaptation of DCOR Level 2 model to Operational mine project*

The operational mine project includes different types of projects. Some of them can be applied in development or optimization of the mine and other projects can be applied in processing plant improvements. Also, some projects focus on reducing costs or productivity improvements.

Figure 9-1 depicts the processes of DCOR Level 2 model for Mine Project Refresh. The Mine Project Refresh involves the processes research (mR1), design (mD1), integrate (mI1), and amend (mA1). These processes must be adapted to be suitable for the processes of exploration and engineering design. The description of the processes in the EM model (EMMMV, 2010) and the DCOR model (SCC, 2006) are used for these adaptations. The Execution processes and the Amend process are explained and analyzed in the context of the processes of exploration and engineering design. The analysis of these adjustments is described below.

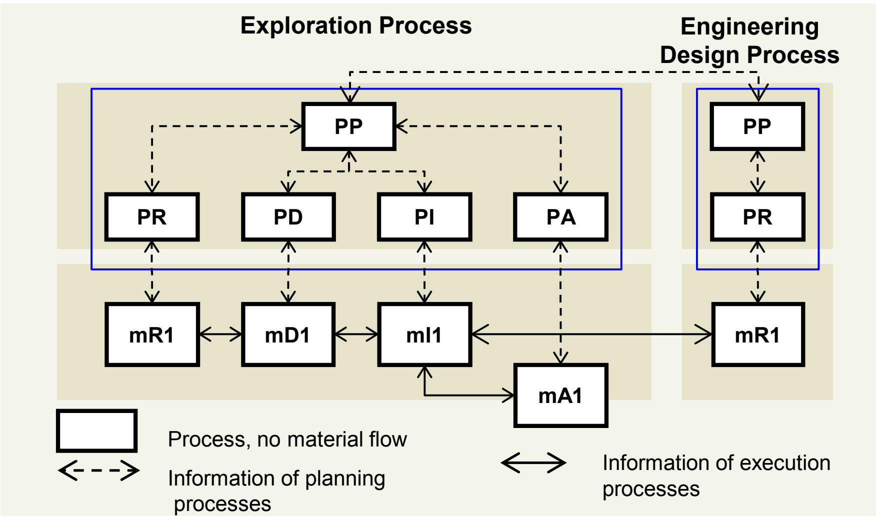

Figure 9-1. Adaptation of DCOR Level 2 model to exploration process of a Operational mine project

9.1.1 Adaptation of DCOR Level 2 model to exploration process

This is the first process in the early part of the supply chain and includes the processes of DCOR Level 2 model mR1, mD1, mI1, and mA1. These processes are analyzed and adapted in the context of the exploration process as follows.

Research Mine Project Refresh (mR1). In the context of the exploration process, mR1 represents the processes of prospection, exploration, and assessing mineral resources that are carried out on the mine site in current operations. The purpose of these processes is the identification and decomposition of research topics to search for continuity of ore-body and updated geo-models and grade-models with an accepted level of confidence. From this, information is obtained and synthesized to establish their nature, extent, and grade, and improve the resolution of the size, volumetric shape, spatial location, spatial grade distribution, and mineralogical characteristics of the ore-body and its environs. The output of mR1 process is the evaluation and publishing of research findings regarding the potential extraction target and the day-to-day enhancement of the level of confidence in the geological model. In addition, mR1 includes the identification of sources of supply, sourcing, and validation of materials/products against requirements.

Design Mine Project Refresh (mD1). In the context of the exploration process, mD1 encompasses the refreshing of definition, creation, analysis, testing and releasing of process, size, and function for the most convenient production options of an existing mine. This process involves the design and feasibility of a technical mine and beneficiation plan at an appropriate level of confidence. The process is focused on improving levels of confidence on mine site in the current operations. The output of mD1 is the operational technical mine plan (i.e. volume and product profiles over time).

Integrate Mine Project Refresh (mI1). In the context of the exploration process, mI1 encompasses release of refreshed business case and the mine definitions to enable decision making in the early part of the supply chain execution and releasing refreshed design documentation to engineering design process, operations, and support organizations. Also, this process includes acquiring rights when necessary. The develop business plan is focused on the analysis and creation of the financial viability plan associated with the exploitation of a particular site in order to be able to make a go/no-go decision in current operations. The outputs of the mI1 process are: documented business case to enable a decision making in current operations, and production forecast and budget for operational cost. In addition, the process of acquire involves securing all the necessary rights applicable to exploiting an existing mine. In this case the outputs are the secured rights for operations, and sufficient information to make an operational decision.

Amend Mineral Commodity Fall Out (mA1). In the context of the exploration process, this is a process of gathering, analyzing, and addressing a mineral commodity's manufacturability. The process is triggered by feedback that manufacturing quality and process standards/metrics cannot be met. This includes regulatory compliance issues.

9.1.2 Adaptation of DCOR Level 2 model to engineering design process

In most of the cases, this process is driven by the exploration process. For example, in the development of a new mine phase, the engineering design process is driven by the results of the exploration process. In the rest of the cases, engineering design process is driven by the plan design (PD). The example of installation of a new conveyor belt and a new primary crusher is a project for improving the processing plant. Thus, the interaction between exploration process and engineering design process depends of the type of project.

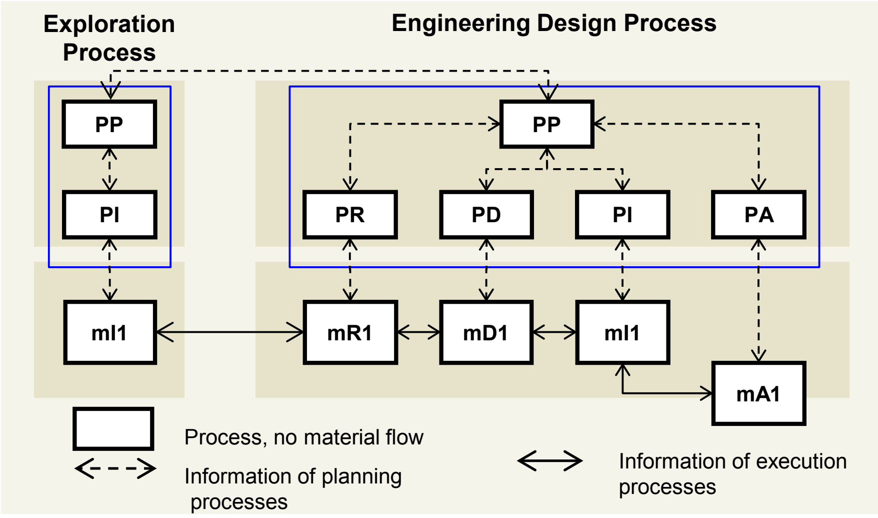

Figure 9-2. Adaptation of DCOR Level 2 model to engineering design process of a Operational mine project

The main processes of the DCOR model need to be adapted to be suitable for modeling the engineering design process. For this, the processes mR1, mD1, mI1, and amend mA1 are analyzed and adapted in this context as follows.

Research Mine Project Refresh (mR1). In the context of the engineering design process, mR1 represents the processes of collecting engineering design criteria that are carried out on mine site in current operations. The purpose of these processes is the identification and decomposition of research topics and obtaining and synthesizing information to obtain and confirm all relevant technical parameters and standards that are required to produce the requisite designs. The output of mR1 process is the evaluation and publishing or archiving of research findings regarding the engineering design criteria to create further access to the ore body. In addition, mR1 includes the identification of sources of supply, sourcing, and validation of materials/products against requirements.

Design Mine Project Refresh (mD1). In the context of the engineering design process, mD1 encompasses the refreshing of definition, creation, analysis, testing, and release of process, size, and function for an existing mine. The process is focused on producing conceptual engineering designs for the current operations. This includes reviewing and adjusting sourcing, manufacturing, testing, servicing, and disposal processes. This also covers the same activities performed for minor changes, upgrades, and repairs for facilities.

Integrate Mine Project Refresh (mI1). In the context of the engineering design process, mI1 encompasses releasing refreshed engineering design documentation to Construction process execution and releasing refreshed mineral commodity definitions to the early part of the supply chain.
Amend Mineral Commodity Fall Out (mA1). In the context of engineering design process, this is a process of gathering, analyzing, and addressing a mineral commodity's manufacturability. The process is triggered by feedback that manufacturing quality and process standards/metrics cannot be met. This includes regulatory compliance issues.

The integration of the engineering design process and the construction process is analyzed in section 5.3.2.

9.2 Adaptation of DCOR Level 2 model to Greenfield mine project

Figure 9-3 depicts the processes of DCOR Level 2 model for a Greenfield Mine Project. The Greenfield mine project includes the processes research (mR3), design (mD3), integrate (mI3), and amend (mA3). The Execution processes and the Amend process are explained and analyzed in the context of the exploration process and the engineering design process. The adaptations of the processes of DCOR model are analyzed as follows.

9.2.1 Adaptation of DCOR Level 2 model to exploration process

This process includes the processes of DCOR level 2 model mR3, mD3, mI3, and mA3. These processes are analyzed and adapted in the context of the exploration process as follows.

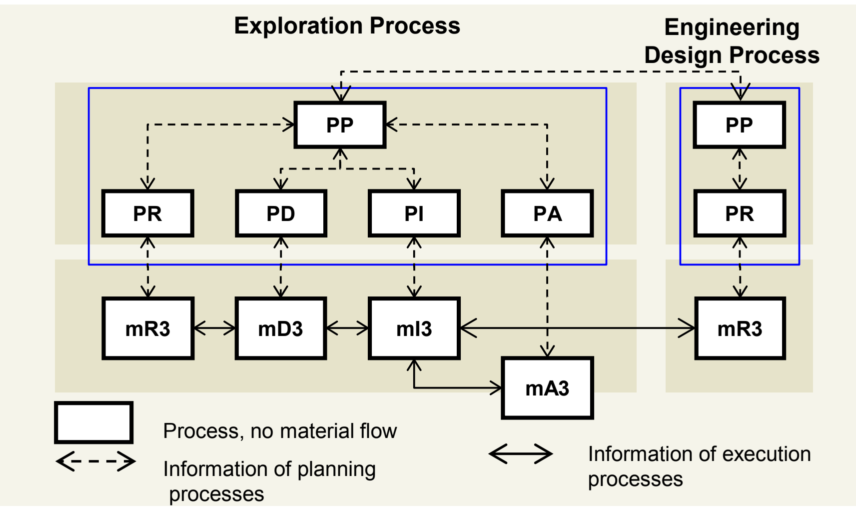

Figure 9-3. Adaptation of the DCOR Level 2 model to exploration process of a Greenfield mine project

Research Greenfield Mine Project (mR3). In the context of the exploration process, mR3 encompasses the processes of prospection, exploration, and assessing mineral resources that are carried out in a new mine project in a new location. The purpose of these processes is the identification and decomposition of research topics to locate the presence of new economic deposits in new location, and consider their attributes of structure, density, grade, and tonnages. From this, information to establish their nature, extent, and grade is obtained and synthesized. The output of mR3 process is the evaluation and publishing of research findings regarding the geological and mineralogical data with spatial attributes, and a geological model used as a basis for design and mine planning. In addition, mR3 process includes the identification of sources of supply, sourcing, and validation of materials/products against requirements. Also, this process is driven by the research plan (PR).

Design Greenfield Mine Project (mD3). In the context of the exploration process, mD3 encompasses the definition, creation, analysis, testing, and release of process, size, and function for the most convenient production options of a new mine project in a new location. This process involves the design and feasibility of a technical mine and beneficiation plan for an appropriate level of confidence. The process is focused on improving levels of confidence on Greenfields projects. The output of the mD3 process is the technical mine plan (i.e. volume and product profiles over time). This process is driven by the mR3 process.

Integrate Greenfield Mine Project (mI3). In the context of the exploration process, mI3 encompasses synthesizing the design definitions and decomposition of the design definitions into developing a business plan, and releasing the business case and the new mine definitions to enable decision making regarding a new mine project in a new location. Also, mI3 process includes acquiring all necessary rights. The develop business plan is focused on the analysis (including options) and creation of the financial viability plan associated with the establishment of a new mine project in a new site in order to make a go/no-go decision. The outputs of mI3 process are: documented business case to enable decision making, and a bankable feasibility study for investment related decisions. In addition, the process of acquire involves securing all the necessary rights applicable to mine a particular site, including: mineral rights, environmental impact assessment (EIA), approved environmental plan, surface rights, access rights, approved social and labour plan, and water rights. In this case the outputs are the secured rights, and sufficient information to take investment decision.

Amend Mineral Commodity Specs (mA3). In the context of the exploration process, this process includes the activities associated with Specification Change. The process is triggered by the gathering of issue and commodity specifications. The process culminates with the publication of a Specification Change Order (SCO). The process should encompass the requisite reviews and approvals.

9.2.2 Adaptation of DCOR Level 2 model to engineering design process

This process is driven by the results of the exploration process for a new mine project in a new location. The main processes of DCOR model need to be adapted to be suitable for modeling the engineering design process. For this, the processes mR3, mD3, mI3, and mA3 are analyzed and adapted in the context of engineering design process as follows.

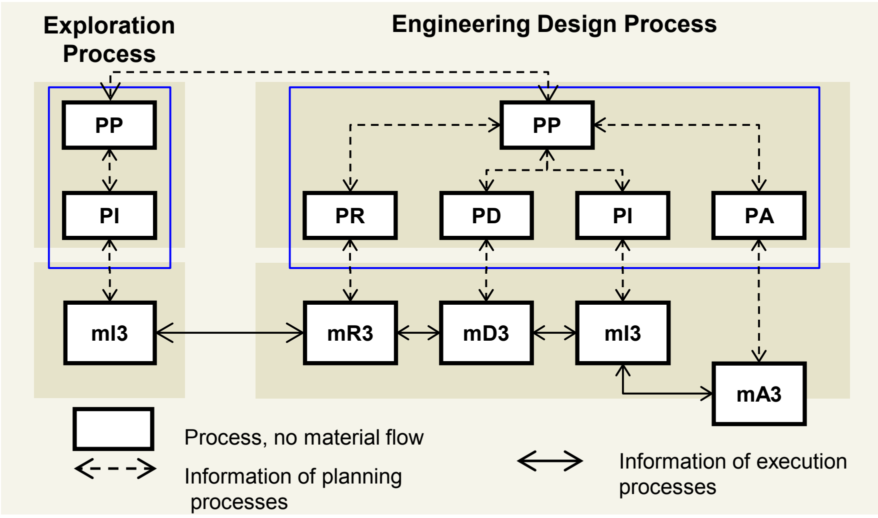

Figure 9-4. Adaptation of DCOR Level 2 model to engineering design process of a Greenfield mine project

Research Greenfield Mine Project (mR3). In the context of the engineering design process, mR3 encompasses the processes of collect engineering design criteria that are carried out in a new mine project in a new location. The purpose of these processes is the identification and decomposition of research topics, and obtaining and synthesizing information to obtain and confirm all relevant technical parameters and standards that are required to produce the requisite designs. The output of mR3 process is the evaluation and publishing of research findings regarding to the engineering design criteria to develop a long-term vision and plan for a new mine in a new location. In addition, mR3 process includes the identification of sources of supply, sourcing, and validation of materials/products against requirements. The mR3 process is driven by the mI3 process of exploration process.

Design Greenfield Mine Project (mD3). In the context of the engineering design process, mD3 encompasses the definition, creation, analysis, testing, and release of process, size, and function for a new mine project in a new location. The process is focused on producing conceptual engineering designs for this new mine project in new location. This includes development of manufacturing, testing, servicing, and disposal processes.

Integrate Greenfield Mine Project (mI3). In the context of the engineering design process, mI3 encompasses synthesizing the engineering design definitions and decomposition of the engineering design definitions into sets of component engineering design definitions, releasing project and project definitions to Construction process execution, and releasing engineering design documentation to Support organizations for new mine project in a new location.

Amend Mineral Commodity Specs (mA3). In the context of the engineering design process, this process includes the activities associated with Specification Change. The process is triggered by gathering issue and commodity specifications. The process culminates with publication of a Specification Change Order (SCO). The process should encompass the requisite reviews and approvals.

The integration of the engineering design process and the construction process is analyzed in section 5.3.2.

9.3 Adaptation of the process elements of DCOR model in exploration process

This section describes in detail each of the adapted process elements of the DCOR model. These adapted process elements of the DCOR model represent the main activities that are performed by the different workgroups of the exploration process of the Brownfield mine project. These process elements of the DCOR model have been adapted to the semantics used in the mining domain. The following are the adapted process elements of the DCOR model, which are presented according to the order and sequence of participation of the workgroups indicated in Figure 6-5.

Workgroup: Project Management (PM)

Starting from the top of Figure 6-5 downwards, we have the following:

mI2.1: Receive & Validate Request. The request is generated in the top level of the company, for example, new investment projects management, which assigns a Head of Project Management, who may have an advisory team to coordinate the project requirements. Therefore, this request is received, recorded, and assigned a number.

mI2.2: Decompose Request. The project is decomposed and documentation of the specifications of the components that are part of developing a new mining project is analyzed. This request must be addressed first by the workgroup of prospection, exploration, and assessment of mineral resources. Moreover, it includes the scheduling of activities and allocation of respective resources for each of the activities to be carried out.

mI2.3: Distribute Requirements. This step begins by transferring the requirements for each component (decomposed) to perform the research process by the workgroup PEA, which is involved in the activities undertaken in prospection, exploration, and assessment of mineral resources.

Workgroup: Prospection / Exploration and Assessment (PEA)

This workgroup performs the following sequence of activities:

mR2.1: Receive & Validate Request. The workgroup PEA receives and records the research request and analyzes the requirements or specifications listed in the request and validates or clarified with PM if in doubt. Subsequently the workgroup PEA decomposes the request in relation to the activities that should be performed.

mR2.2: Schedule Research Activities. The workgroup PEA must schedule and manage the execution of individual deliveries with respect to materials, technologies, services, information, etc. These requirements of PEA arise from the investigation request that is received from the workgroup PM, and their own needs to conduct its research activities. Moreover, it is included the identification and validation of potential suppliers of materials, technology, services, and information that are required to develop planned activities.

mR2.3: Source Materials. In this process materials, technologies, services, and information necessary for the activities are ordered or purchased (if applicable). In addition a subsequent receipt thereof is included. For example: a request for information to agencies that have geographical and geological data about the region to be explored, purchase of satellite photographs of the site to explore, the procurement of prospection and exploration services, procurement of transportation, shopping food and supplies, etc. In addition, included in this process is the request of specific tasks to the internal staff group, who must perform critical activities for prospection, exploration, and assessment of mineral resources. Subsequently PEA receives the results of the tasks assigned to its internal staff.

mR2.4: Verify Materials. In this process conformity with the product or service received in relation to the requirements and quality criteria is determined. Here, all documentation relating to the investigation, the characteristics of mineral deposit, the tests results on different samples analyzed, the shape of the ore body, and the size of the mineral deposit are obtained. It may also include results of laboratory tests of samples and results available about geological and mineralogical information with the attributes of spatiality. This documentation therefore integrates the information generated by suppliers as self-generated by the PEA workgroup.

mR2.5: Transfer Findings / Materials. In this process the requests are received as per the availability of research results and documentation of specifications corresponding to the request. For example, the geological and mineralogical model with spatial attributes of a particular mineral deposit or exploration site. In addition, in this process the transfer of the samples and documentation corresponding to the request is included.

mR2.6: Authorize Supplier Payment. This corresponds to an administrative-financial process to authorize payment to suppliers of goods or services. It includes the collection of bills, invoice matching, and issuing checks.

Workgroup: Exploitation Options Design (EOD)

The activities carried out by this workgroup are described below:

mD2.1: Receive, Validate & Decompose Request. The EOD workgroup receives, validates, and decomposes the design requested by the head of PM workgroup. This activity should clarify any doubts with respect to the requested versus the available information that PEA workgroup send to EOD workgroup. Based on the above, the design is divided into the respective components or parts to be studied (mine, processes, access, services, dumps, etc.).

mD2.2: Schedule Design Activities. The execution of the individual prototypes of designs needs to be scheduled and managed. In this case, it could be the mine design at the level of a prototype, the process design, etc. In this case, the requirements are determined based on the information provided by the PEA workgroup. This includes the characteristics of the mineral deposit, the type of mineral to be processed, and the environmental requirements that need to be considered. Therefore, these are the most significant signals that guide the design.

mD2.3: Develop Prototype. The activities are performed to establish the processes required by the mineral processing, the respective environmental requirements based on current regulations, the infrastructure required to operate a mine, and the test instructions to create and test a prototype of the processing plant. In addition, this includes gathering materials and technology required for the prototype of mineral processing plant, to assess whether the processes allow to processing and recovering the mineral satisfactorily.

mD2.4: Build & Test Prototype. Series of activities in the materials to create a prototype of the processing plant in a laboratory level. It includes the processes related to the validation of performance of different processes of the processing plant to ensure conformity to specifications and requirements defined, in relation to the capacity to process and recover the mineral satisfactorily. This prototype of processing plant could also be tested in computer simulation models to analyze process performance in different scenarios.

mD2.5: Package Design. Corresponds to the activities undertaken to document the design specifications that include the results of the tests conducted to the prototype of the processing plant, and the certification necessary in the case of permits and environmental studies required to operate this type of processing plant. This process must prepare the complete design package with plans, studies, specifications, necessary permits, etc.

mD2.6: Release Design to Integrate. Obtained in this process is the relevant approval with respect to the design, and approval to provide full information about the design (drawings, specifications, analysis, proposals, etc.) to the integration process (FS workgroup).

Workgroup: Feasibility Studies (FS)

This workgroup performs the following activities:

mI2.4: Receive & Validate Design. The FS workgroup identifies, collects, and validates the design received from the EOD workgroup according to the requirements and specifications for the mine and processing plant, and according to customer requirements. For this validation, an economic evaluation is made regarding the design of the selected processing plant, and the financial viability of the project is studied. If the results require more precise information, that is to say with less uncertainty, the PEA workgroup must perform other drilling and sampling in order to update the information and thereby reduce the level of uncertainty in the information requested. Subsequently the EOD workgroup can update the design using new data from PEA. This process can be repeated in the stages of profile, prefeasibility, and feasibility studies, where evaluation at each step determines whether to continue or postpone the project. The project will only continue if the project promises to yield good results, and if at each step the quality of information is improved to make a decision regarding technical and economic feasibility.

mI2.5: Pilot Design. The FS workgroup creates and validates a processing plant at pilot scale. It is performed in order to validate the process performance of the mineral processing plant, in order to ensure conformity to specifications and profitability requirements are defined. Examples: it is verified how a processing plant at a pilot scale (specially designed to process the mineral of the deposit to exploit) behaves in order to determine its performance and recovery of mineral. For this validation, values are adjusted relative to the design proposed in the above process and economic evaluation and financial feasibility of the project is updated.

If the results still require more precise information, that is to say with less uncertainty, the PEA workgroup performs other drilling and sampling in order to update the information and thereby reduce the level of uncertainty in the information requested. Subsequently the EOD workgroup can update the design using new data from the PEA and FS workgroups. This process usually could be repeated in the feasibility stage. Finally, the FS workgroup generates a business case by which it may decide to develop or not develop the project.

mI2.6: Package Product. Corresponds to the activities undertaken to document the experimental results of tests performed in the pilot processing plant, the final design of the processing plant with its respective specifications, the required and necessary certification such as permits and environmental impact studies, and other studies required before delivering the final documentation for final decision-making.

mI2.7: Release Product. In this process, the approval is obtained regarding the design of the processing plant and the respective business plan, to be presented to the decision maker for approval of capital required developing or not developing the Brownfield mine project.