ISSN 1980-5411 (On-line version)
Production, 34, e20240001, 2024
DOI: 10.1590/0103-6513.20240001

Research Article

A conceptual framework for standardizing the "Deliver" process in the Mineral Supply Chain Upstream Segment

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Abstract

Paper aims: Developing a conceptual framework for modeling the "Deliver" business process of the Mineral Supply Chain (MiSC) upstream segment, based on a standardized perspective.

Originality: A novel approach is introduced that adapts the Supply Chain Operation Reference (SCOR) and the Exploration and Mining Enterprise Reference (EM) models to standardize the "Deliver" of the MiSC's upstream segment. It fills the gap in existing MiSC models, which lack a standardized framework and boundaries for their segments.

Research method: It followed design science research (DSR), specifically a Requirement- and development-focused research approach. A top-down modeling technique was developed to develop the "Deliver" modeling framework at three levels of abstraction, reusing, and adapting standardized models SCOR and EM.

Main findings: The SCOR can be adapted for "Deliver" in the upstream segment of MiSC. The study establishes the modeling basis for integration with downstream business processes. It also emphasizes the need to support the integration of MiSC with a commercialization framework.

Implications for theory and practice: The "Deliver" model developed offers a practical tool for MiSC practitioners to integrate upstream and downstream segments. This study encourages further research in the MiSC, especially in the upstream segment, to improve transparency and understanding for stakeholders.

Keywords

Mineral supply chain. Business Process Modeling. Design Science Research. SCOR model. EM model.

How to cite this article: Castillo-Villagra, R. I., & Thoben, K. D. (2024). A conceptual framework for standardizing the "Deliver" process in the Mineral Supply Chain Upstream Segment. *Production*, *34*, e20240001. https://doi.org/10.1590/0103-6513.20240001

Received: Jan. 01, 2024; Accepted: Sep. 5, 2024.

1. Introduction

The European Union's goal of achieving carbon neutrality by 2050 –Net-Zero 2050– lies in a significant shift from hydrocarbon-based to renewable energy sources (International Energy Agency, 2021a). This transition will lead to an increased demand for critical mineral raw materials, such as copper, lithium, and cobalt (European Union, 2023; International Energy Agency, 2021b), underscoring the importance of the mineral supply chain –MiSC– in achieving this objective.

From a supply chain –SC– management perspective, the MiSC involves all business processes –BPs– related to the flow of raw materials, information, and financial transactions, from the discovery of mineral assets to their final consumption or disposal (Castillo-Villagra et al., 2023; Osborne et al., 2013; Osborne & Dempsey, 2023). MiSC is structurally divided into upstream and downstream segments (Arroyo Ortiz & Viana Júnior, 2014; El Baz et al., 2021; Sauer & Seuring, 2017). The downstream segment involves manufacturing, retailing, use, recycling, and disposal of final products, while the upstream segment encompasses discovering and extracting ore, producing commodities, commodities marketing, and mine closure processes (Bjørndal et al., 2012; Castillo-Villagra & Thoben, 2022, 2024).

In recent decades, there has been an increased interest in comprehending MiSC. On the one hand, it has been driven by MiSC disruptions that have resulted in mineral shortages, impacting green-energy technology and high-tech technology supply chains. On the other hand, due to the demand for products free of human rights violations –due diligence– (Lim-Camacho et al., 2019; Makki & Ali, 2019; Mancheri et al., 2019; Organisation for Economic Co-operation and Development, 2021; Schütte, 2019; Sprecher et al., 2015; Taka, 2014; Zeng et al., 2021). These factors highlight the need to understand the MiSC comprehensively.

Several studies have focused on different minerals, including iron (Nader et al., 2011; Steinberg & Tomi, 2010), neodymium (Sprecher et al., 2015; Sprecher et al., 2017), tantalum (Mancheri et al., 2018; Soto-Viruet et al., 2013), cobalt (Fraser et al., 2020; van den Brink et al., 2020), lithium (Torres & Toro, 2023; Zhou et al., 2022), and copper (Akbari-Kasgari et al., 2022; Vimal et al., 2022). These studies propose various methods, such as optimizing logistics chains through lean methodology (Nader et al., 2011) or applying resilience strategies through simulation models (Vimal et al., 2022). A common theme in these studies relies on the MiSC's graphical modeling to develop the proposed methods. However, a challenge lies in the lack of standardization in MiSC modeling, leading to stakeholder misunderstandings. On the one hand, several modeling tools are used, requiring expertise in their use. On the other hand, the lack of standardization in BPs leads to inconsistencies at the boundaries of MiSC segments. For instance, studies on the same mineral may have modeling starting points in different BPs, such as the work by (Nader et al., 2011), which set the iron discovery processes as the starting point, while the work by (Sachs, 2009) set it in the process of construction the mineral asset.

To standardize the MiSC model, an end-to-end MiSC mapping approach has been adopted, providing a comprehensive view of SC business processes, enhancing management of global supply chains, and supporting effective planning and control of material, information, and financial flows (MacCarthy et al., 2022). It also aids in developing resilient strategies (Mubarik et al., 2021), optimizing global performance (Chae, 2009), and ensuring transparency in supply chain processes, reinforcing "due diligence" efforts (Dietrich & Melcher, 2022; Fraser et al., 2020).

Most studies on MiSC mapping focus on the downstream segment (Sauer & Seuring, 2019; Zúñiga, 2015), with few addressing the upstream. In the latter focus, the Exploration and Mining Enterprise Reference Model –EM Model– is recognized as a standard framework for BPs' MiSC (Carter, 2013; Livingstone-Blevins, 2018; Philo, 2023). However, the EM Model's confinement to the upstream segment poses challenges for integration with the downstream segment, making unified end-to-end modeling difficult.

Some researchers have adapted modeling frameworks to address the SC integration challenge. For instance, sustainability-focused MiSC models, such as the circular economy model for mining processes (Lèbre et al., 2017), industrial ecology concepts (Lèbre & Corder, 2015), and environmental assessment models like the life cycle assessment of recycled minerals for battery production (Abdelbaky et al., 2021; Abdelbaky et al., 2023).

Likewise, other efforts focused on process-oriented models have involved adapting standardized supply chain reference models, such as the Supply Chain Operations Reference –SCOR– Model (Association for Supply Chain Management, 2017) in the upstream segment. In this perspective, seminal works by Zúñiga (2015) and Castillo-Villagra et al., (2023) have demonstrated SCOR's ability to represent MiSC business processes and the feasibility of integrating seamlessly with downstream segments. While (Zúñiga, 2015) defined the "Source" process, detailing from mineral asset discovery to mineral extraction, (Castillo-Villagra et al., 2023) defined the "Make" process, adapting the processes of mineral beneficiation and the transformation of the mineral into a commodity. However, the "Deliver" and "Return" processes were left pending modeling, requiring their development to complete the end-to-end mapping of the upstream segment. Although the SCOR model's "Return" process does not fit the dynamics of the MiSC upstream segment (Agudelo, 2009; Castillo-Villagra et al., 2023; Zúñiga, 2015), the "Deliver" process is crucial for integration with the downstream segment.

This study aims to develop a conceptual framework for modeling the "Deliver" business processes within the MSC upstream segment. This will allow the completion of the development of a reference model for this segment by enabling integration with the previously established "Source" and "Make" processes. Moreover, based on the SCOR version 12.0 and the EM version 1.0 models, this framework will facilitate integration with the MiSC downstream segment, allowing the end-to-end MISC supply chain to be mapped. This study will help practitioners and researchers understand and manage interactions between upstream and downstream segments of MiSC, promoting efficient and transparent supply chain management.

The article is structured as follows: Section 2 describes the upstream segment of the MiSC BPs and their relationship to the mining lifecycle. Section 3 outlines the design science research –DSR– methodology. Section

4 details the development of the standardized modeling framework for Deliver's business processes. Section 5 demonstrates the conceptual framework developed in a technical note on copper concentrate marketing. Section 6 discusses the study, establishing the developed framework's modeling capability and limitations. Finally, Section 6 presents the study's conclusions.

2. The upstream segment of the mineral supply chain

The upstream segment of MiSC involves extracting ore, producing raw materials, selling them, and disposing of mining waste while the mine is closed. This segment has specific BPs and a mining lifecycle –MiLC–, contrasting it with the downstream segment (Cameron & Stanley, 2017; Castillo-Villagra & Thoben, 2022, 2024). The MiLC comprises four stages: mineral exploration, mine development, mine operation, and closure, spanning 10 to 100 years or more (Pimentel et al., 2016). As shown in Figure 1, each stage has unique mining BPs describing its operational activities (EMMM Forum, 2013; Society for Mining, Metallurgy and Exploration, 2011).

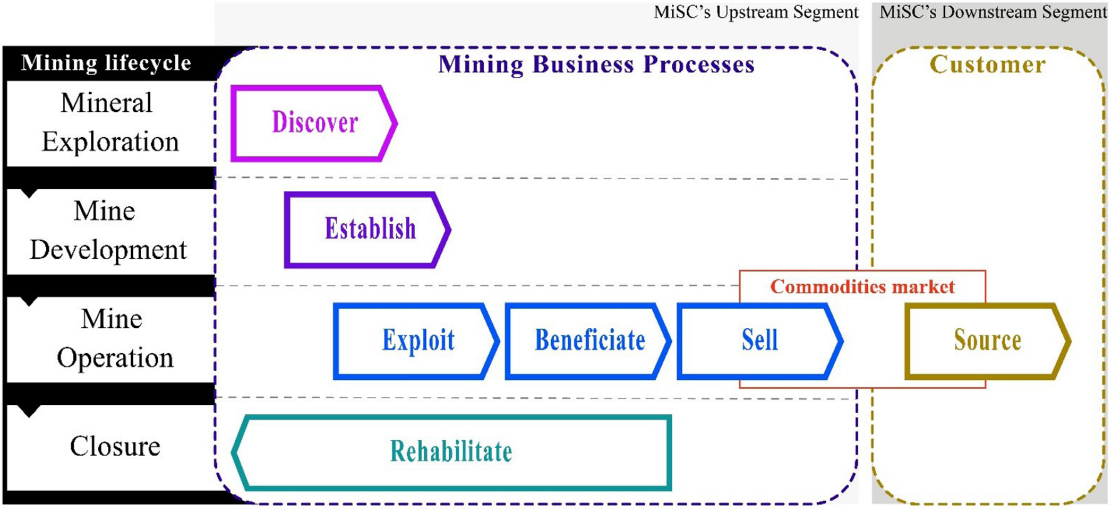

Figure 1. Relationship between the business processes of the MISC´s upstream segments and the mining life cycle (adapted from (Castillo-Villagra & Thoben, 2024)

Mineral Exploration involves the "Discover" process, focusing on exploring and defining mineral assets.

Mine Development encompasses the "Establish" process, including tasks necessary for creating the mining environment and infrastructure.

Mine Operation includes the "Exploit" process for ore extraction, the "Beneficiate" process for transforming ore into a commodity, and the "Sell" process for managing customer interactions and commodity delivery to downstream segments.

Closure: The "Rehabilitate" process involves restoring the mine site to its original or better state.

Mining BPs in the first three stages of the mining life cycle can be aligned with standardized supply chain BPs such as "Source," "Make," and "Deliver" (Castillo-Villagra et al., 2023). "Source" is defined as the articulation and definition of exploration objectives of a mineral resource for economic exploitation, including the exploration strategy and quantification of the mineable resource. This includes the "discovery," "establish," and "exploit" processes (Zúñiga, 2015).

"Make" focuses on processing and transforming the ore into a saleable product or commodity by modifying its physical properties and removing unwanted components to improve its quality, purity, and grade. Here, the "Beneficiate" process is assimilated with "Make."

Finally, "Deliver" manages customer interactions, encompassing marketing and product delivery processes to downstream segments. It connects the final mining operations with the initial processes of the downstream segment and ensures quality and regulatory compliance. Its link to mining business processes is related to the "Sell" process.

2.1. Comparing mineral supply chain up- and downstream segments

Stakeholders, decision-makers, researchers, and supply chain practitioners must understand the differences between the upstream and downstream segments. A better understanding facilitates standardized modeling of BPs in the upstream segment, providing insight into its unique industry characteristics. Table 1 summarizes the differences between the MiSC's up- and downstream segments. For more details, refer to the works of (Cameron & Stanley, 2017; Castillo-Villagra et al., 2023; Castillo-Villagra & Thoben, 2022, 2024; Darling, 2011; Zuñiga et al., 2015).

Table 1. Summary of differences between Up-and Downstream segments of the Mineral Supply Chain.

Topic	MiSC Upstream Segment	MiSC Downstream Segment
Capital Intensity	*High capital-intensive, require large initial investments.*	*Less capital-intensive investments focused on productivity efficiency.*
Industry Segment´s Uncertainty	*High uncertainty is subject to geological, environmental condition, and regulatory conditions.*	*Lower uncertainty focused on market demand and technological changes.*
Environmental Impact	*Significant long-lasting impacts on landscapes and ecosystems.*	*Reduces impact through sustainable practices (e.g. renewable energies applications, circular economy strategies).*
Operation Planning	*Focus on operational efficiency and long-term optimization.*	*Focus on agility and quick response to market demands and changes.*
Industry Integration	*Vertically integrated structures, integration of BPs from mine to commodity markets.*	*Integration at the end of the supply chain, direct relationship with the end consumer.*
Regulations	*Specific, focused on environmental regulation and rehabilitation*	*Regulations focused on industry standards*
Raw material	*Natural Depletion. The raw material is a non-renewable resource, and management is focused on efficiency and resource optimization.*	*Not Depletion. Accessible raw materials are available from global suppliers, and management is focused on supply chain management.*
Artisanal and Small-Scale Mining Industry	*Mostly dependent on labor and operation, often unregulated operations.*	*Mostly formalized and regulated operation.*

The upstream segment requires significant investments in assets and infrastructure to carry out its operations. In contrast, the downstream segment invests in production efficiency and technological innovations to meet market demand.

In addition, the upstream segment faces uncertainties related to exploration feasibility, economic viability of mineral deposits, metal price volatility, and environmental and social regulations, which affect the entire MiLC. Factors such as quality, quantity, location, and natural depletion of minerals significantly influence the segment's competitiveness and the industry´s continuity. In addition, these deposits are often located in remote and inaccessible locations and susceptible to complex environmental and climatic disturbances, making the industry prone to operational disruptions. These uncertainties impact upstream operational planning regarding long-term efficiency and resource optimization, often leading to vertical integration of mining BPs. In contrast, the downstream segment faces uncertainties related to market demand, technological changes, and the management of global supply chains; hence, operational planning in the downstream segment focuses on agility and adaptability to market needs, being more centralized, with direct supply chains from production suppliers to end consumers.

It is also essential to recognize the considerable environmental impact of the upstream segment due to the intensive extraction of natural resources and waste generation, framed into strict waste management regulations and mandatory land restoration. In contrast, the downstream segment has focused on reducing environmental impact through sustainable practices, and its regulations are focused on production and occupational safety standards.

Finally, artisanal and small-scale mining –ASM– in the upstream segment relies heavily on labor and often operates without regulation, which impacts social and environmental regulations. This underscores the need for due diligence strategies and more control in commodity production. In contrast, artisanal and small-scale manufacturers in the downstream segment are often more formalized and regulated and compete under the same market rules.

3. Methodology

Our study develops a conceptual framework to model the "Deliver" BP within the MiSC upstream segment, aligning with standardized modeling practices. Conceptual frameworks are essential for understanding phenomena by organizing information and identifying patterns (Rapoport, 1985). They can serve as blueprints for domain-specific modeling or a reference model, which evolves to meet the unique needs of specific fields (Fettke & Loos, 2003).

Two main approaches address the development of reference models: i) building new models from scratch, which is time-consuming and requires extensive validation, and ii) reusing existing models, which saves on development costs, reduces modeling time, and enhances quality (Fettke & Loos, 2007). The latter approach is common as it establishes a common language and improves stakeholder communication (Georgise et al., 2017; Thomas, 2006).

In this study, we reuse an existing model, adapting it to a new application context. This approach aligns with the exaptation knowledge contribution framework in the Design Science Research –DSR– context (Gregor & Hevner, 2013). Exaptation research adapts specialized artifacts for new domains, framed as an incubation solution (Bagni et al., 2024; Holmström et al., 2009). Therefore, this study requires a methodology emphasizing the non-trivial nature of constructing artifacts based on prescriptive knowledge –rigor– and their importance in new applications –relevance–.

We adopted the DSR methodology –DSRM–, which focuses on creating or modifying artifacts to address and solve existing challenges (Dresch et al., 2019; Holmström et al., 2009; van Aken, 2005), ensuring rigor and relevance. We follow the framework proposed by Johannesson & Perjons (2014) focusing on a requirements and development approach that includes i) artifact design requirements, ii) artifact development, and iii) evaluation or demonstration.

To design requirements, we selected prescriptive models as standardized frameworks based on the standard SC model, such as the SCOR model, providing baseline requirements. In addition, we used the EM model's business process framework for contextualization and extension in a new domain context, the MISC upstream segment. To support the feasibility of integration of both reference models, we applied a process matching technique (Beheshti et al., 2016) analyzing terminology, granularity, and behavior/structure. Based on this, we established design requirements for the Deliver BP development.

For artifact development, we built the "Deliver" BP, applying the top-down expansion technique (Ostrowski & Helfert, 2014), starting at the highest level –Abstraction Level 1– and detailing each process down to the lowest level –Abstraction Level 3–.

Finally, we demonstrate the ability to explain the trading process of the MiSC upstream segment based on information from an Inter-American Development Bank –IDB– Technical Note focused on the Latin American copper concentrate case.

4. Design requirements

This section details key challenges and considerations for integrating the EM and SCOR models using the matches technique, providing context and understanding for effective alignment.

4.1. The Exploration and Mining Business Reference Model (EM)

Developed in 2010 by the Exploration, Mining, Metals, and Minerals Forum from the Open Group consortium, the EM serves as an industrial framework for organizations involved in exploration, mining, metallurgy, and their suppliers. Its primary goal is to establish a standardized set of business processes specific to its industrial segment. The EM model outlines the standard industrial business processes, providing strategic, tactical, and operational insights for the MiSC upstream segment.

The EM categorizes business processes into three abstraction levels, as shown in Figure 2. At the highest level are the "Enterprise Processes," which describe the sequential activities within the MiSC's upstream segments, including "Discovery," "Establish," "Exploit," "Beneficiate," "Sell," and "Rehabilitate." These processes are logically sequential, but strict adherence is not mandatory. The middle level encompasses "Value Chain Processes," which add value to the mineral product. These processes typically follow a sequential order but can be skipped or executed concurrently if subsequent stages have the necessary outputs available. Lastly, the lowest level, "Business Processes," describes the operational activities within each Value Chain process, detailing the industrial dynamics of the MiSC's upstream segment.

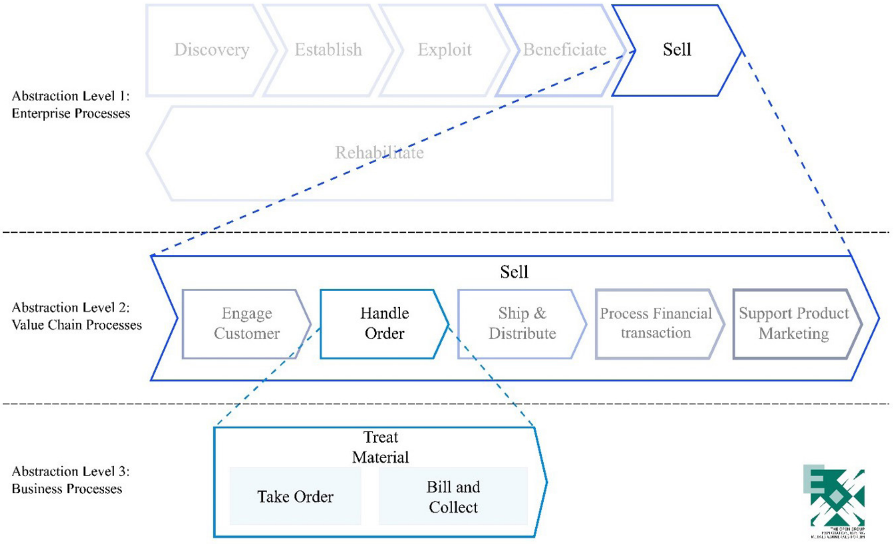

Figure 2. The EM breakdown adapted from (EMMM Forum, 2013). Abstraction Level 1 represents Enterprise Processes. Abstraction Level 2 shows the breakdown of the "Sell" Value Chain process. Abstraction Level 3 depicts the breakdown of the "Handle Material" Business process.

4.2. The Supply Chain Operation Reference Model (SCOR Model)

Developed in 1996 by AMR Research and the consulting firm PRTM, the SCOR model has since gained recognition from the Supply Chain Council and endorsement from the Association for Supply Chain Management. SCOR's main goal is to provide organizations with a methodology and benchmarking tool to enhance their supply chain processes.

A key strength of SCOR is its ability to represent both complex and simple supply chains through standardized definitions, making it the 'de facto' standard for supply chain modeling in academia and industry (Böhle et al., 2014; Huan et al., 2004; Ntabe et al., 2015). The model has evolved over time, with the latest version, 12.0, introduced in 2017.

SCOR is structured around three abstraction levels, as shown in Figure 3. The highest level, "Major Process," includes fundamental processes like Plan (P), Source (S), Make (M), Deliver (D), and Return (R). The middle level,

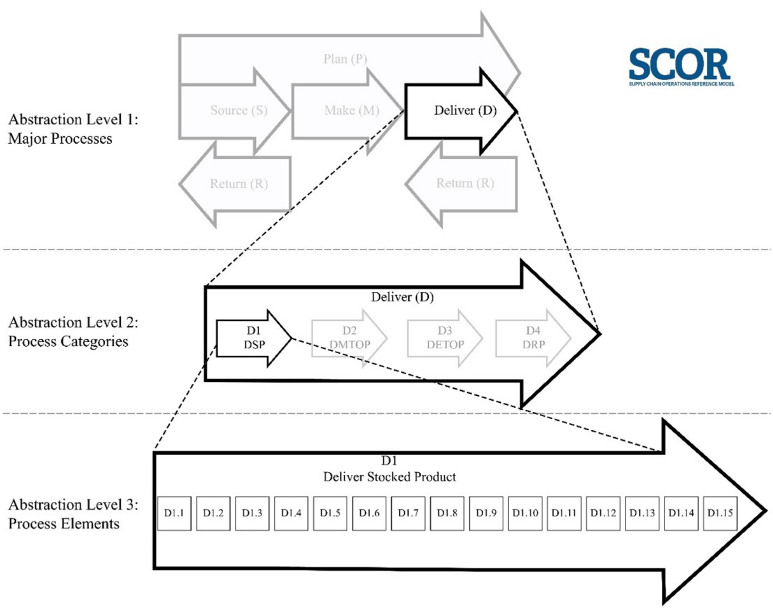

Figure 3. The SCOR breakdown adapted from (Association for Supply Chain Management, 2017)). Abstraction Level 1 represents the major processes. Abstraction Level 2 shows a major process breakdown of the "Deliver" process. Abstraction Level 3 represents the "DSP" (Deliver Stocked Product) process elements.

"Categories Process," outlines specific setups, such as Make-to-Stock (MTS) or Make-to-Order (MTO). The lowest level, "Process Element," details operational components like inputs/outputs, skills, performances, best practices, and capabilities. Additional company-specific processes fall outside SCOR's scope.

4.3. The matching process technique between SCOR and EM models

The process matching technique effectively aligns industrial process models like SCOR and EM by addressing syntactic differences in process names, inputs, and outputs, focusing instead on process concepts. This technique provides an approximate mapping based on Terminology, Granularity, and Behavior/Structure.

Terminology: It finds commonalities between processes at all three abstraction levels despite different names. For example, at abstraction level 1, the "Sell" process in EM, which handles customer orders to sell products and generate revenue, aligns with SCOR's "Deliver" process, which manages customer order processing. At abstraction level 2, the EM model includes processes such as "Handle Order," "Ship & Distribute," and "Process Financial Transaction," focusing on order reception, shipping planning, delivery scheduling, and transaction closure. These align with SCOR's "Deliver Stocked Product," which fulfills customer orders based on aggregated orders, forecasted demand and inventory reorder parameters. Similarly, at abstraction level 3, EM's "Take Order" process, handling customer requests and scheduling, aligns with SCOR's "Receive, Enter, and Validate Order," which examines and secures orders. However, EM processes like "Engage Customer" and "Support Product Marketing" do not align with SCOR since SCOR does not cover sales and marketing (demand generation).

Granularity: It compares the activity composition levels of process elements to find matches. SCOR and EM differ in mid- and lowest-level processes. SCOR's mid-level "Process Categories" configure capabilities of "Major Processes" with at least three categories (e.g., "Plan," "Source," "Deliver"). In contrast, EM's Value Chain processes mainly consist of a single element. At the lowest level, EM describes "Business processes" activities by listing unit operations, while SCOR's "Process Elements" detail each processing element in the "category processes." Consequently, SCOR's higher-level simplicity contrasts with its specificity at lower levels, requiring EM to break down its level 3 processes into more detailed elements.

Behavior/Structure: It analyzes activity sequences and abstraction levels. EM and SCOR have three abstraction levels, but EM processes are not strictly sequential, whereas SCOR's framework follows a defined sequence of activities. This rigidity in SCOR does not accommodate the flexible industrial dynamics depicted in EM; hence, it requires an external toolbox for modeling.

For the design requirements of the "Deliver" BP, it's, first, essential to comprehend the equivalence of the "Sell" process, ensuring it aligns with SCOR's standard framework for maintaining consistency in process building across different supply chain segments. Second, understanding the mining industry for seamless integration of the EM model into SCOR. This requires a deeper understanding of mining industry BPs and the differences between upstream and downstream industrial dynamics, which is covered by the authors' experience and supported by specialized literature in the extractive mineral industry. This ensures that the unique aspects of mining BPs are accurately reflected in the "Deliver" BP model. Finally, an external business process modeling tool is needed to represent industrial dynamics, as SCOR alone is not capable of doing so. So, the BPMN 2.0 (Object Management Group, 2010) is a well-known toolbox for business process modeling that can be integrated with the SCOR model (Cheng et al., 2010; Lhassan et al., 2018; Torres, 2011; Verdouw et al., 2011; Zúñiga, 2015).

5. Modeling the "Deliver" process of the MiSC´s Upstream Segment

This section outlines the design and development of the "Deliver" BP. The EM's "Sell" enterprise process is adapted and modeled based on SCOR levels. First, the "Sell" process is modeled at the highest SCOR level. Then, the EM's Value Chain processes for "Sell" are modeled using SCOR. Finally, the detailed industrial activity processes of the EM's "Sell" Value Chain are modeled with SCOR and supported by the BPMN 2.0.

5.1 Highest level processes – Abstraction Level 1

The EM defines "Sell" as a customer-focused process that deals with product disposal, revenue generation, and marketing. "Sell" involves five value chain processes: i) "Engage Customer," which entails customer interaction and information gathering; ii) "Handle Order," which involves obtaining accurate product information and analyzing customer preferences; iii) "Ship & Distribute," which carries out the shipment and distribution of products to customers; iv) "Process Financial Transaction," which recognizes revenue and tracks debt resulting from order fulfillment; and v) "Support product marketing," which requires strategic customer and order information to ensure effective marketing of products in line with organizational goals.

Figure 4 depicts that the EM "Sell" enterprise process is similar to the SCOR "Deliver" major process. The value chain processes "Handle Order," "Ship and Distribute," and "Financial Transaction" fit into the operation of fulfilling customer orders; therefore, they can be modeled from the perspective of SCOR's "Deliver" operational process. In contrast, the value chain processes "Engage Customer" and "Product Support" fall outside the SCOR scope, as they focus on demand generation and customer engagement, which requires a sales and marketing-centric modeling approach. Although these processes do not fit into SCOR, they provide valuable information from the mineral trading process –e.g., legal and financial commitment, insurance, lead time, commodity prices, and penalties, among others–, which are mainly carried out in commodities markets as the London Metal Exchange –LME[1]–.

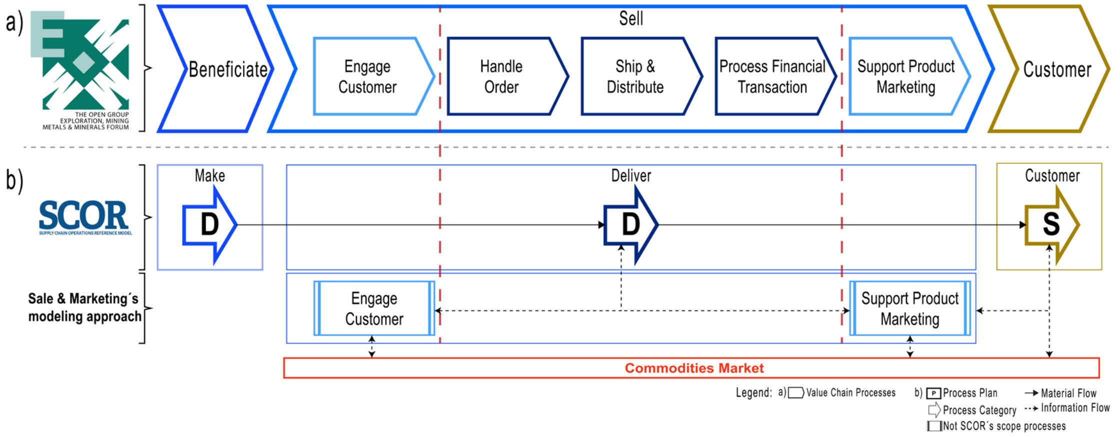

Figure 4. Modeling the "Deliver" highest-level process of the MiSC's upstream segment – Abstraction level 1. (a) The "Sell" enterprise process of the EM Model. (b) The "Deliver" major process of the SCOR Model.

5.2 Middle-level processes – Abstraction Level 2

Bulk commodities, e.g., mineral concentrated, mineral pellets, and non-bulk commodities, e.g., cathode and ingot, are the products of the MiSC´s upstream segment. These products are standardized and produced based on forecasted demand rather than specific customer orders, which implies a production environment based on Make-to-Stock. In this sense, "Sell"'s value chain processes fit into SCOR process categories based on Deliver Stocked Product (D1). The "Sell"'s value chain processes into SCOR are depicted in Figure 5.

Based on SCOR, the D1 process requires a Source-Stocked Product (S1). S1 orders, receives, and transfers bulk and non-bulk commodities to the loading area when they are required for customer dispatch. Although this process is not established in Sell's value chain process, it is considered for modeling within the SCOR perspective.

"Engage Costumer" includes the sub-processes: i) Follow Up Leads, which is responsible for collecting sales leads and engaging with potential customers, and ii) Manage Customer Relationship, which focuses on maintaining customer satisfaction, order tracking, and interactions. From a SCOR perspective, "Engage Customer" offers data into future customer, and satisfaction levels. These are vital for planning future commodity deliveries and adjusting upstream mine production plans, particularly given the prevalence of forward and futures contracts in commodity trading, e.g. LME. Furthermore, customer satisfaction data influences the configuration of beneficiation processes and validates geological models in mining projects, as the customer validates the final quality of the commodity.

"Handle Order" involves the sub-processes: i) Take Order, which collects and captures the customer's order information, guaranteeing a dispatch of what the customer wants appropriately, and ii) Bill and Collect, which focuses on the

[1]LME - The London Metal Exchange is a commodities exchange that deals in metals futures and options. It is the largest exchange for options and futures contracts for base metals, which include aluminum, zinc, lead, copper, and nickel.

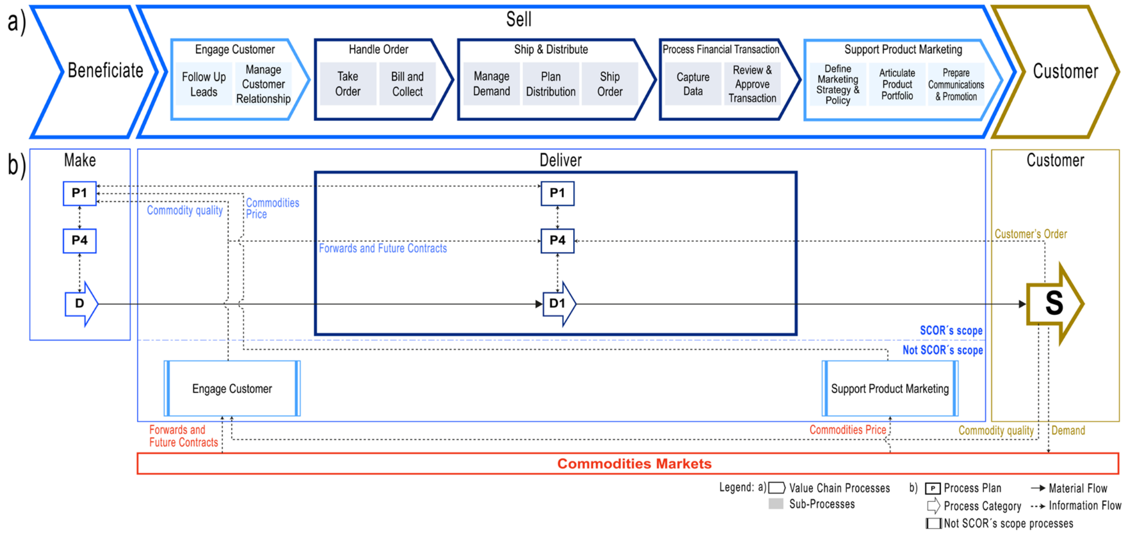

Figure 5. Modeling the "Deliver" middle-level processes of the MiSC's upstream segment – Abstraction level 2. (a) The "Sell"'s value chain processes of the EM Model. (b) The "Deliver" process categories of the SCOR Model.

creation of an invoice against order and the collection processes to collect the money from the outstanding invoices. Both sub-processes are SCOR's Deliver Stocked Product (D1), mainly focused on customer-supplier communication.

"Ship & Distribute" involves the sub-processes: i) Manage Demand, which handles the alignment of material supply with customer demand, enabling seamless order placement and delivery; ii) Plan Distribution, ensuring efficient fulfillment and distribution of customer orders in line with their requirements; iii) Ship Order, responsible for the shipping and dispatch of orders, establishing the necessary logistics mechanisms. Within the SCOR, these sub-processes align with SCOR's Deliver Stocked Product (D1), primarily focusing on logistics planning for shipments.

"Process Financial Transaction" involves the sub-processes i) Capture Data, responsible for gathering essential financial information from the customer, and ii) Review & Approve Transaction, which finalizes the financial transaction process, requiring approval from both the customer and the supplier's organizational governance structures. These processes together encompass the financial transaction or payment process from the customer to the supplier, constituting the concluding phase of SCOR's Deliver Stocked Product (D1).

"Supporting Product and Marketing" includes the sub-processes: i) Define Marketing Strategy and Policy, which establishes mechanisms for implementing marketing strategies and policies; ii) Articulate the product portfolio, ensuring continuous product portfolio optimization throughout its life cycle; iii) Prepare Communications and Promotion, organizing promotional materials for product marketing. "Supporting Product and Marketing" contributes key data to the SCOR, particularly regarding commodity pricing, which is heavily influenced by demand (Wuest & Thoben, 2012). This information drives strategic decisions in mining projects, such as by-product production, low-grade ore processing, and early mining operation closure planning (Stage iv "closure," cf. Sect. 2). It also guides operational decisions, including major maintenance and plant shutdowns (Castillo-Villagra & Thoben, 2022).

5.3 Lowest level processes – Abstraction Level 3

Figure 6 depicts a sourcing plan carried out (S1.1) based on a commodity sales commitment (P1.4 – P4.1). From "Beneficiate," Bulk (D2) and non-bulk (D1) commodities are supplied, which are received (S1.2) and checked (S1.3). Once the receipt is confirmed, the product remains in stock (S1.4) until D1.3 requires the commodities transfer.

Effective communication is established for "Customer" requirements and shipping processes (D1.1) to plan mineral product shipments (P4.4) cross-referenced with future shipping plans provided by "Engage Customer" forward and futures contracts. Orders are then consolidated for delivery fulfillment. When a customer places an order, it is accepted by D1.2, and the current inventory is reviewed in D1.3 to determine the need for material transfer to fulfill the order. Delivery date is planned and confirmed based on commercial commitments, all orders are set, and material loading processes are selected (D1.4). The services and mechanisms required for loading are found, and the means of transportation are defined (D1.5). Routes are identified to meet delivery deadlines (D1.6), and transportation companies are selected (D1.7) that will handle the transportation process from the loading zone,

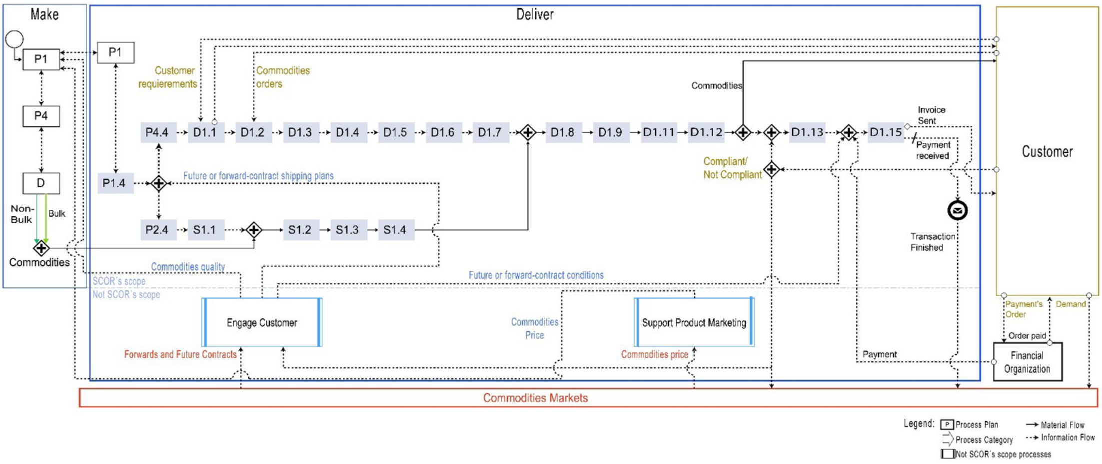

Figure 6. Modeling the "Deliver" lowest-level processes of the MiSC´s upstream segment—abstraction level 3. "Make" on the left is modeled at abstraction level 2. "Deliver" in the middle is modeled at abstraction level 3. "Customer" and "Financial Organization" on the right are considered black boxes.

mainly in Bulk and Non-bulk commodity ports, to the "customer" destination. Commodities (D1.8) are then received from S1.4, and, if necessary, loading and transfer from other finished material warehouses (D1.9) are established. The loading process begins (D.11), including the loading transports' operational tasks and the documentation's administrative preparation. Once loading is completed, the order is shipped to the customer (D1.12).

Once the commodities are received by the "Customer," the information on receipt is sent to the delivery process as compliant or non-compliant (D1.13). The final financial procedures (D1.15) are then carried out with external financial companies. These companies determine the payment based on the commodities price and any penalties provided previously in the trading commitment. Penalties may be contemplated for the final quality of the goods made by the customer ("Customer Engage"), which impacts the final sales price. Lastly, the finalization of the financial transaction is communicated to the customer, the supplier, and the metal exchange.

6. Demonstration

The demonstration of the "Deliver" BP in the MiSC upstream segment was based on the IDB technical note "El proceso de comercialización de concentrados de cobre: una mirada a América Latina y el cumplimiento" –*English: "The commercialization process of copper concentrates: a look at Latin America and tax compliance"*– (Reyes-Tagle & Guajardo, 2023). This lack of literature is due, on the one hand, to the fact that raw materials are traded on the LME and the New York Mercantile Exchange, coming from various sources, and buyers do not have direct contact with sellers, and, on the other hand, buying in unregulated markets generates non-tracing of trading minerals (Östensson, 2018; Schütte, 2019; Taka, 2014).

The IDB technical note examines the complexity of trade in copper concentrates –CoCo—a key intermediate product in the production of refined copper. The study focuses on Latin America, highlighting Chile and Peru as export leaders. It covers valuation and impurity penalties to treatment and refining charges, highlighting the MiSC upstream Segment BP required for commercialization.

In our opinion, the text is unique in its attention to integrating fiscal aspects, transparency, and traceability, which are crucial for customs regulation and control. The detailed description of contracts and types of transactions, both direct and brokered, provides a solid basis for understanding the challenges and developing efficient models. However, although the study does not establish with certainty the BP of mineral trade, it clarifies the challenges and the logical and procedural commercial process with its different players and processes involved. Whereby we were able to establish the trade business process and model it with the "Deliver" process developed in this study, as described below and depicted in Figure 7.

CoCo Production for Commercialization: These processes begin with the extraction of the ore in the mines, followed by its transportation and disposal in beneficiation plants, as detailed in (Zúñiga, 2015). Next, the ore is then crushed and milled, followed by metallurgical processes for the production of CoCo, as detailed

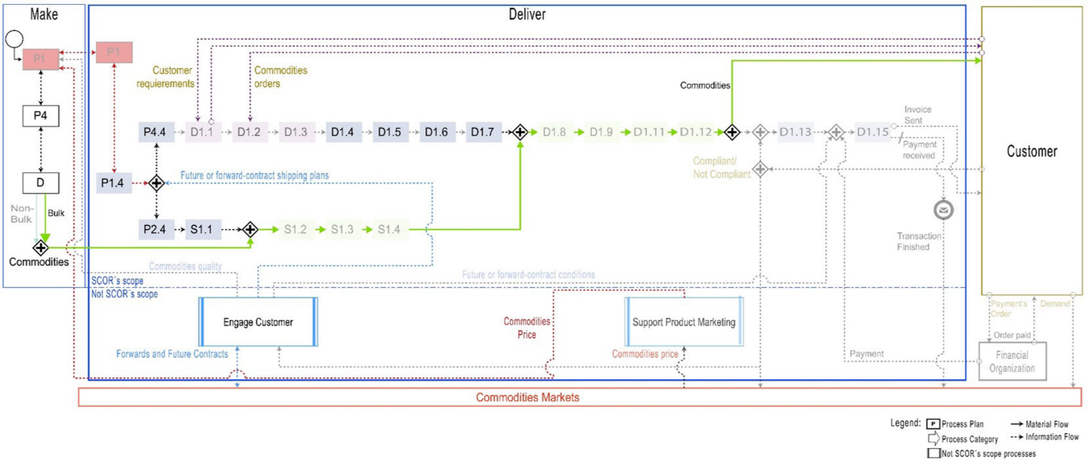

Figure 7. Lowest level modeling of the "Deliver" BP based on the IDB technical note "El proceso de comercialización de concentrados de cobre: una mirada a América Latina y el cumplimiento" (Reyes-Tagle & Guajardo, 2023) – Abstraction Level 3.

in (Castillo-Villagra et al., 2023). Finished CoCo is sent from the beneficiation plant (D2, green light line) for quality control (S1.3) and stockpiling (S1.4), pending purchase requests, or to meet commitments already made.

CoCo valorization: Once produced and stored, the CoCo is subjected to a detailed analysis to determine the concentration of copper, other valuable metals, e.g. gold or silver, and impurities present, e.g., arsenic or antimony (S1.3). This analysis is crucial for the valuation of the product, as the payable metal content and impurity penalties directly influence its price. Payable metal prices and penalties are established by the tradable prices of the commodities in the metals markets, such as the LME (red dotted line into P1). This valuation establishes the selling prices in the segment's production and sales plans.

CoCo Commercial Transaction: CoCo transactions are formalized through long-term contracts, with continuous supply agreements (blue light dotted line into P4.4) or spot one-time sales (D1.1). The spot contract method establishes delivery terms, prices, penalties, and other commercial details (D1.2 - D1.3). In addition, treatment (TC) and refining charges (RC) that affect the final commercial value are considered, which are usually established by incoterms[2], which define the discount for the missing stages of concentrate valorization to obtain refined copper. Transactions can be direct, where the producer sells directly to the final consumer (purple dotted line into and to customer), or intermediate, where traders buy the concentrate and then sell it to refiners or final consumers.

CoCo Logistics and Transportation: It is a crucial stage in commercializing copper concentrate. This product is transported from the dispatch areas (S1.4) to the export shipping facilities (D1.8), establishing the logistical processes for product shipment (D1.4 - D1.7), export documentation, and legal taxes (D1.11). Exports are directed to smelting and refining facilities, often located in different countries, with Asia being the primary consumer.

An overall evaluation of the "Deliver" BP confirms its ability to represent the industrial dynamics and the "Sell" process of MiSC in the upstream segment as a standardized conceptual framework. The commercialization process described in the IDB technical note largely mirrors the "Deliver" process developed, representing at the highest levels of detail (abstraction level 3) the various industrial dynamics present in the MiSC sell process.

For example, it considers the information delivery processes for ore valuation, the planning of different types of contracts, such as long-term and spot contracts, and the penalties in the contract application process. It also includes planning and transportation, as well as the source of the ore to be marketed, linking these processes with those established in the model developed in this study.

However, some situations described in the IDB technical note could not be established in the "Deliver" process. This is mainly due to the action and participation of a trader in the commercial contracting processes, a situation not stipulated in the "Deliver" BP conceptual framework developed in this study. Therefore, it should be modified as set out in Figure 8.

[2]Incoterms: A glossary of terms used in international commerce and trade that details each party's obligations (exporter-seller and importer-buyer) when delivering the goods (International Chamber of Commerce, 2024).

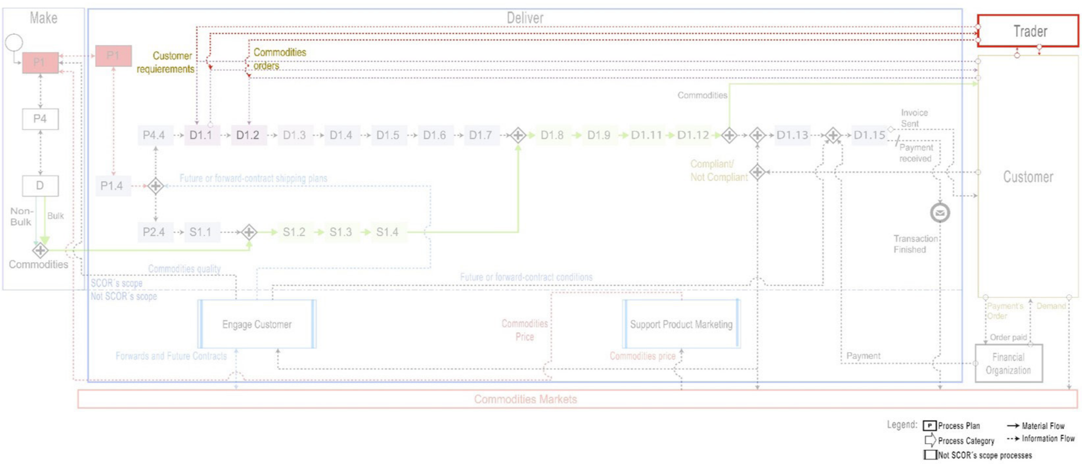

Figure 8. Adaptation of the modeling to the lowest level of the "Deliver" process based on the technical note "El proceso de comercialización de concentrados de cobre: una mirada a América Latina y el cumplimiento" (Reyes-Tagle & Guajardo, 2023) - Abstraction level 3. On the Right, Model Adaptation considers the trader an intermediary for customer sale - Abstraction level 1.

On the other hand, the "Deliver" process developed includes the payment process by the financial instances, closing the validation cycle of the commodity price for sale. Unfortunately, this process is not considered or explained in the IDB technical note, so it cannot be thoroughly evaluated.

7. Discussion

This study developed a model of the "Deliver" business process within MiSC's upstream segments using a standardized supply chain modeling framework. The development process considered the industry dynamics and complexity of MiSC's upstream segment, framed by the EM model.

The developed "Deliver" BP has the ability to establish itself as a model for MiSC trade processes despite the challenges, scope, and dynamism involved. Although the process demonstration was performed using copper concentrate, remarkable similarities can be found with the commercialization of other minerals. For example, the commercialization of lithium hydroxide for battery producers (Torres & Toro, 2023) or aluminum, where companies vertically integrate recycling processes and final products such as aluminum foil (Young et al., 2008). Once it is captured a complex BP within a reference model allows for unambiguous descriptions, consistent communication, and application to gain a competitive advantage (Böhle et al., 2014). Therefore, developing the "Deliver" provides valuable insights into the trade process in the MiSC upstream segment.

In addition, this model serves as a blueprint that can be modified depending on the industrial dynamics of each type of mineral. This allows for anticipating and achieving performance improvements and benchmarking with the transfer of best practices (Böhle et al., 2014; Fettke & Loos, 2003; Verdouw et al., 2011). Therefore, this model also serves as a resource for stakeholders to make informed decisions and seamlessly integrate their supply chain with the upstream segment of the mineral supply chain.

In this study, the SCOR model has proven to be a tool capable of mostly representing the "Deliver" business process of the upstream segment of the minerals supply chain (Osborne et al., 2013; Osborne & Dempsey, 2023). Although SCOR does not include intermediaries directly in the model, these adaptations are relatively simple to implement. This perspective is closely related to the operations and processes linked to mineral trade. Therefore, the reuse of the SCOR model in this study confirms its recognition as a de facto model for standardized supply chain modeling. It also reinforces its adaptability to different industrial realities and dynamics (Georgise et al., 2017; Huan et al., 2004; Ntabe et al., 2015; Plochet Mendez, 2020). SCOR is also positioned as a standard-setting tool for developing traceability systems such as blockchain (Osborne & Dempsey, 2023), which responds to current calls for transparency and visibility in the MiSC (Pradip et al., 2019; Qiang et al., 2021; Zhu et al., 2017). This increases customer confidence through knowledge of commodity provenance and improves due diligence in the MiSC.

The development of the "Deliver" BP allows integration with the "Source" (Zúñiga, 2015) and "Make" (Castillo-Villagra et al., 2023) models, enabling the development of a reference model to the MiSC upstream segment from the point of view of the SC's BP established. However, in order to achieve a reference model for the MiSC upstream segment, it is necessary to develop the "Rehabilitate" process of the EM model. This process presents challenges, such as restoring mined lands after operations, a concept not covered by SCOR. Therefore, SCOR must be rethought and adapted to represent "Rehabilitate" effectively.

One of the limitations of the "Deliver" BP conceptual framework developed is SCOR's lack of capability to represent the "Sell" value chain processes directly tied to the marketing and sales of the EM. In order to bridge this gap, the Customer Chain Operations Reference model –CCOR– (Association for Supply Chain Management, 2004) presents a reliable solution. CCOR aligns perfectly with the value chain process not modeled with SCOR, namely "Engage Customer" and "Supporting Product and Marketing," as CCOR's scope encompasses business activities associated with all conversion phases, including marketing and sales. Furthermore, CCOR, part of the APICS framework family, shares a similar logic and modeling language with SCOR, ensuring a seamless integration. However, it is worth noting that CCOR has just one version compared to twelve versions of SCOR, showing reduced interest from supply chain practitioners. Similarly, only a bunch of scientific studies demonstrate its applicability (Chen & Pai, 2014; Legnani, 2011; So, 2010; Solodovnikov, 2019). Therefore, further research into the utilization and adaptability of CCOR, particularly in its integration with SCOR, is essential, both within the MiSC context and other industrial domains.

From a methodological viewpoint, this research focused on the requirements and development of "Deliver" BP, developing a demonstration and surface validation of the model, as proposed by (Johannesson & Perjons, 2014). Therefore, future studies should strengthen this model through empirical testing, evaluate its ability to represent a real scenario of the MiSC trade process and assess the actual mineral flows from the upstream segment to the first-tier customers in the downstream segment. Further studies should also be developed on the collection and modeling of MiSC upstream business processes, such as "Source," "Make," and "Deliver," assessing their ability to integrate with the downstream segment of the minerals supply chain.

8. Conclusion

In this study, we have presented the capability of the SCOR model as a standardized framework to partially represent the "Deliver" business process within the upstream segment of the MiSC. In addition, our proposed SCOR-based tool lays a solid foundation for seamless integration between the upstream and downstream segments of the mineral chain.

DSRM's approach has enabled systematic development, leveraging a design strategy based on the reuse and adaptation of reference models. This strategy proved to be effective, especially in adapting the SCOR and EM models. However, it highlighted the need for an external business process modeling toolbox, BPMN 2.0, to represent industrial dynamics at the lowest abstraction level. This methodological approach ensured the model was rigorously developed and relevant to its new application field, providing a robust framework for the "Deliver" business process within the MiSC upstream segment.

This work addresses existing challenges in modeling the MiSC upstream segment. It introduces standardized tools with the potential to support a better understanding and management of this industry segment. The results have significant practical implications for supply chain management practitioners and researchers, as the proposed standardized conceptual model offers a blueprint for making mineral supply chains more transparent, efficient, and resilient. This study is not intended to provide complete solutions but seeks to motivate future research and deeper practices in the upstream segment of the minerals supply chain.

Acknowledgements

The authors thank the International Graduate School for Dynamics in Logistics (IGS) of the University of Bremen. Mr. Castillo-Villagra's work was supported by Agencia Nacional de Investigación y Desarrollo –ANID, Chile, under grant no. 72200439.

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