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Analysis of international EPC projects using SCOR model, MoneteCarlito simulation, and relationship management

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Abstract

The EPC contracting mode (Engineering, Procurement and Construction) has been broadly applied in construction projects, particularly, at the international level. However, the procurement process has been scarcely in literature. The purpose of this thesis is to research the procurement processes of different types of products—ETO (Engineer to order), MTO (Make to order), and MTS (make to stock)—in supply chain for a real international EPC cement project in Ethiopia. The procurement processes of steel bar (MTS), precast steel structure (MTO), and vertical mill (ETO) for the "Raw Meal Grinding and Exhaust Gas Treat," one of the cement plant workshops, have been analyzed as a case study. Three levels' of SCOR models (Supply Chain Operation References) for the three products are established; the inventory costs were selected as the performance measure for the supply chain. The SCOR models helped in finding the locations where the inventory costs were incurred, and helped in identifying the factors that may influence the inventory cost. In addition, based on the SCOR models, a basic simulation model has been set up, MonteCarlito simulation, and was applied to the precast steel structure based on the inventory cost. A sensitivity analysis was conducted to evaluate the impacts of the pre-delivery waiting time, the delivery time, and the construction time on the total inventory cost. The results revealed that the construction time has the highest impact. Moreover, high inventory cost resulted from poor management relationship with the import agent company. Four key elements were identified which leading to such a relationship: trust, collaboration communication, and problem solving. A questionnaire about these four key elements was developed and responses analyzed (38 responses). Ten suggestions were made to improve the relationship management with suppliers.

Chapter One

Introduction

The EPC (Engineer, Procurement and Construction) contract mode is broadly applied to international construction projects. Under the traditional contract model, the owner takes the design and procurement works and selects a contractor to execute the construction work; whereas the main contractor under the EPC contracting mode, particularly at the international level, will be responsible for engineering, procurement and construction activities. Due to such a large amount of work, the main contractor has to interconnect sub-contractors, financial commitment, time-based procedures and enough resources as well (Yeo & Ning, 2002).

Procurement is considered as the most critical work in international EPC projects because of its high cost, complex delivery and multiple products (Azambuja & Formoso, 2003). In all of the international EPC projects that the author experienced, the procurement cost for main production plants with matched mechanical and electrical equipment takes up almost 50% of the total cost. Besides, the procurement process commonly contains global transportation with at least an export port and import port. The complicated custom clearance documents and unsure shipment time make it difficult to ensure the time of entering site. The poor road conditions sometimes also result in the damage of products during the land transportation. Meanwhile, there are so many kinds of products to buy in an international EPC project, especially in the industry projects that contain many production plants and matched electrical and mechanical equipment. Previous literatures classify the products into different categories. Elfving (2003) and Arbulu, Koerckel, and Espana (2005) described the characteristics of four general types of construction products: ETO (engineer to order), MTO (make to order), and MTS (make to stock). Cheng, Law, Bjornsson, Jones, and Sriram, (2010) represented the products from three different types: stocked standard products, configurable products and custom products. Due to such kinds of products, multiple suppliers are involved in the complicated global procurement processes.

In order to overcome the challenges of organizing and managing the procurement process discussed above, some main contractors prefer to apply conventional procurement strategies to let materials and equipment enter into a project site earlier and stock them to avoid suspension and delay, but it increases the cost of reallocation, inventory, nature loss and depreciation. So looking for an effective method, which not only drives the required products to enter project sites on time, but also decreases the inventory cost during the procurement process, is very valuable to project management. For this reason, this thesis focuses on optimizing the inventory cost through applying construction supply chain management theory, which has been comprehensively researched and strongly proved to be an effective method in the past few years.

In general, research on the construction supply chain is relatively new. It only dates from the 1990s when it became a specific area (London & Kenley, 2001). Construction supply chain management (CSCM) is an emerging area of practice. It is inspired by but differs substantially from manufacturing supply chain management (MSCM). MSCM focuses on modeling volume production, whereas CSCM is more concerned with the coordination and operation of the discrete products delivered to specific construction projects (Vaidyanathan & O’Brien, 2003). The plan, organization, sourcing and delivery of products are becoming increasingly complex across the global construction industry. In order to organize the complicated procurement process and drive the construction supply chain to be effective, setting up a construction supply chain model is very necessary. The model describes the whole procurement process of one kind of specific product and concentrates on decreasing inventory cost based on a real international EPC cement plant construction project in Africa.

One framework of setting up a construction supply chain model was presented in *Construction Supply Chain Management Handbook* (O'Brien, Formoso, Vrijhoef & London, 2009). The framework includes five steps and emphasizes the first step to establish the purpose of the model. There are a number of comprehensive purposes that have been modeled in previous literature, including reducing lead time, evaluating buffering decision and so on. Among all the purposes discussed before, cost problems always played a critical role, so researchers have paid them more attention. The International Group for Lean Construction (IGLC) has invited international researchers to develop models for supply chain cost, which include purchasing cost, production cost, inventory cost and transportation cost. Azambuja and O'Brien (2007) divided cost into inventory costs, process costs, transportation costs, ordering costs, and cost of resources when they aimed to assess construction supply chain cost by setting up a model.

This thesis focuses on inventory cost because it has been verified as the critical element to the project cost control by previous research, such as inventory management using the just-in-time theory (Baladhandayutham & Venkatesh, 2012), material delivery management using transparency of material availability and short response times in the supply chain (Ala-Risku & Mikko, 2006) and procurement process analysis using an optimized construction supply chain model (Pan, Lee, & Chen, 2011). But most of the literature that concentrated on the inventory cost analysis in construction project only discussed the inventory management to construction material, such as steel bar belonging to MTS, but did not pay more attention to other kinds of products, such as products of MTO or ETO. In practice, the cost for procuring products of MTO and ETO for construction is more than construction materials, especially in some industry projects (CNBM, 2007). Therefore, except for discussing construction materials, this thesis also researches the procurement process and inventory cost of ETO and MTO products.

Unlike other previous literature concentrating on only native construction projects, such as inventory cost analysis in Indonesia (Abduh, Soemardi, & Wirahadikusumah, 2012), this thesis pays attention to the construction supply chain from the international perspective and focuses on the whole inventory cost during the integrated global transportation. In order to fulfill the purpose of setting up an international construction supply chain to optimize inventory cost for procurement processes, some factors involved in the supply chain should be identified first. These factors are described generally as follows:

Products—Previous literature always chooses one of the three products as the main topic in discussing its procurement process. *Construction Supply Chain Management Handbook* also explained how to confirm a type of product in the second step of establishing a construction supply chain model (O'Brien et al., 2009). In order to display the overall procurement process in international EPC projects, this thesis focuses on three kinds of products including MTS, MTO and ETO products, which were discussed by Cheng et al. (2010) for analyzing their inventory costs.

Locations—In international EPC projects, inventory cost is not only the stock fee in the project site; it also involves the predicted and unpredicted cost happening in suppliers' storehouses, warehouses in the export port and warehouses in the import port. Except for these four locations that result in direct inventory cost, the main contractor headquarters is another location where the procurement plan and delivery document are established. The work done in the main contractor headquarters will influence the delivery time and lead to indirect inventory cost. So this thesis identifies five locations where inventory cost happens: suppliers' storehouses, export port warehouses, import port warehouses, project site storehouses and the main contractor headquarters.

Stakeholders—Based on different products, the specific stakeholders may be different. For example, the supplier for MTS should be a production factory, while the supplier for ETO should be a manufacturer with design capability. This thesis generally identifies five stakeholders responding to five locations: the product suppliers, the export and shipment agent at the export port, the import and transportation agent at the import port, the main contractor at the project site and the main contractor in charge of procurement in the headquarters. The specific stakeholders will be explained when discussing the specific product's procurement process.

Operations—It is identified as the actions done by each stakeholder in each location in the procurement process of one product. They are the main elements influencing inventory cost in the international construction supply chain. The specific operations will be classified into four general categories referenced by the Supply Chain Operations Reference (SCOR) model developed by the Supply Chain Council (SCC) for standardization, measurement and improvement: plan, source, make and delivery (Supply Chain Council, 2008). The more critical and detail operations are described in Level 3 of the SCOR model, which identify the correlations among each operation and draws out the factors influencing inventory cost.

The construction supply chain model for the products procurement processes is created associated with the SCOR model and based on a real international EPC cement project experienced by the author in Ethiopia, Africa. Some key factors increasing the inventory cost are learned through practice. In this case, three kinds of products in the raw material grinding workshop are chosen as the analyzing objects. They are steel bar as MTS, precast steel structure as MTO and vertical mill as ETO. The steel bar and the precast steel structure were produced in China, while the vertical mill was produced by a Germany company. They were all delivered to the project site through shipment as the planned schedule.

The specific data exposed described by the cast study draws out three main problems that caused overspending of inventory cost: transaction constraints, unsuitable adjusting of delivery plan and poor relationship between main contractor and suppliers. Based on the established SCOR models of construction supply chain, the first problem can be resolved through analyzing the flexible transaction methods and the information flows. Through drawing out the SCOR models, the events of influencing the inventory cost are very clear to be found. According to the events' specifics, the constraints of transacting the events can be discovered. This thesis analyzes the constraints and issues some advices about how to make transaction more flexible, such as multiple choices to the suppliers and not submitting the cargo documents too early. The SCOR models also provide the information flows, which make the communication and information more visible. It benefits to decrease or remove the transaction constraints.

Under the background of the real case and the established SCOR models, a precast steel structure supply chain simulation model is established in Excel for analyzing the delivery plan problem. The supply chain simulation model includes two locations where inventory cost happens, five variables about the supply chain process, four parameters used to calculate the results and two critical decision rules about the inventory time. A simulation model framework and a supply chain diagram containing the above information are described. The simulation runs 400 times in the MonteCarlito tool and obtains four performance measures results about average inventory time and cost. Through calculating and analyzing the confidence intervals of the results, this thesis discusses the validation of the simulation and the significance to the real project.

The relationship management problems are discussed based on a questionnaire and interview process. The questionnaire covers eight key elements for improving the relationship management:

supplier’s selection, objectives, trust, collaboration, communication, problem solving, risk allocation and supplier’s improvement. After 38 interviewees completed the questionnaire, a face-to-face interview was conducted. After compiling the data and concluding the interview, 23 suggestions had been issued to main contractor for building, controlling and managing the relationship with suppliers according to the interview results from 38 interviewees.

This thesis first set up the SCOR models based on general information of the real case, and then describes the three problems exposed by the specific raw-mill-workshop information through the case study. After that, the three problems are analyzed by the established SCOR models, the MonteCarlito simulation and the relationship management interview in sequence.

Chapter Two

Literature Review: EPC Projects

2.1 Procurement process in international EPC projects

International EPC projects are managed by a main contractor, who is in charge of the Engineering, the Procurement, and the Construction aspects of the projects. The procurement processes constitute a major and critical part of the project; they include planning, sourcing, purchasing, contracting, and on site management (Yeo & Ning, 2002). Processes include international logistic, which contains in-land and off-shore transportation, and custom clearance which are done by suppliers and delivery agents, who are employed by the main contractor.

The procurement phase in international EPC projects consists of an overall process that starts with the main contractor planning procurement and ends with the delivery agents delivering products to the construction site. It overlaps with the design phase and greatly defines the final configuration of a construction supply chain (O’Brien et al., 2009). In this phase, most of the suppliers of each kind of product are selected. Price, quality, reputation, schedule performance and previous experiences are often evaluated as the criteria to select those companies. Once signing the contracts or agreements, a number of conditions and constraints will be specially recognized and identified on the construction supply chain (O’Brien, 1998). The locations of suppliers are already known, the delivery plans are established, and the resources of suppliers are declared (although these factors conditions may be changed during the operation). At this moment, a competent project manager should have the ability to predict the potential change and understand how to figure out the possible problems which might occur on the construction supply chain. He should plan and protect their projects from the negative impacts that variability and uncertainty may cause (O'Brien & Fischer, 2000).

Some of problems affecting construction supply chain during the procurement period are related to suppliers, such as the delay of fabrication, low productivity or late delivery; some causes come from import or export agents, who have low power to transact the custom clearance and transportation arrangement; some causes are due to the main contractor, who ignores the interactions among different products' delivery plan and so on.

From the perspective of resources, there are main elements that may influence the entire procurement supply chain: inventory, transportation, facilities and information (Chopra & Meindl, 2001). Research shows that the last three elements including transportation, facilities and information have a very close relationship with inventory. Transportation changes the inventory between each two locations in the supply chain; facilities are placed for producing and storing inventory; and information is collected and distributed for inventory operation and inspection (Tserng, Yi, & Li, 2006). So decreasing inventory cost is the very important objective for determining the value of these three elements (Chopra & Meindl, 2001).

In order to manage the inventory cost in the entire procurement supply chain, the most apparent and effective method is to describe the procurement process through setting up a supply chain model and try to find the inventory locations and possible factors influencing inventory cost by analyzing each step in the process (O'Brien et al., 2009). It has been found that an effective material procurement management system can increase the construction productive by 6-8% and decrease the required space for inventory; however, the construction industry only invested 0.15% of the total material costs for improving materials supply chain management (Marsh, 1985). With the successful application and development of supply chain management in the manufacturing field, the construction supply chain management has been gradually adopted in the construction industry. At the same time, government and construction companies became more and more interested in this field because more potential profits and benefits are found during the practical study (Formoso & Revelo, 1999). The Brazilian government encouraged small building firms to use quality management methods to improve construction material supply chain management (Formoso & Revelo, 1999); the Taiwan government led the key construction companies for the Taiwan High-speed Railway project to build a supply chain system to exchange information among the stakeholders (Tserng et al., 2006); and the Indonesian government encouraged the researchers to focus on construction supply chain analysis during the procurement phase including relationship analysis between contractor and suppliers, performance indicators for construction supply chain performance and how to reduce the integrated costs in the entire supply chain (Abduh et al., 2012). These governments only concentrated on local project, but ignored to applying construction supply chain management to international construction projects.

Under the background of developing research on construction supply chain, modeling the construction supply chain in the procurement process especially for the material supply chain, drove researchers' interests: Pan et al. (2011) provided a systematic approach for exploring the behavior of the construction supply chain process and developed a performance evaluation method to improve the supply chain management of construction projects. Cheng et al. (2010) presented a network construction supply chain model based on different kinds of products, and set up a framework to monitor the performance of construction supply chain. These two aforementioned papers established the construction supply chain model in the same way that described the management processes firstly and applied the same SCOR model framework. But these two studies focused only on the common construction projects. They did not talk about the supply chain management in the EPC project, which is the most common type of contract in international construction projects.

2.2 The SCOR Models

The Supply Chain Operations Reference model (SCOR Model), proposed by the Supply Chain Council, is the first standard reference model of the supply chain process, and its diagnostic tools cover all industries (Supply Chain Council, 2008). The SCOR model can be developed to build partnerships on the supply chain and upgrade supply chain activity in construction industries (Schultz, 2003), so it is very suitable to be applied in the construction supply chain to present the activities operation. The SCOR modeling framework is based on five basic management processes in supply chains—Plan (P), Source (S), Make (M), Deliver (D), and Return (R)—to meet planned and actual demand (Cheng et al., 2010).

Plan (P) is the most important step in these five components (Lockamy & McCormack, 2004), and it includes the critical processes for balancing resources. The established plans should best meet the supply chains' requirements on sourcing, production, delivery, and return (Cheng et al., 2010). In the procurement process of international EPC projects, each participator in the supply chain sets up the plans for tendering, producing, and transporting. The plans are frequently established before each stakeholder executes work and are sometimes adjusted during specific operation. The contents of plans include time, cost and quality control to each milestone, resources arrangement for production, emergency proposal for unpredicted issues, and risk management for accidents. To effectively manage the supply chain, the main contractor prefers to ask partners to submit their plans at the first step.

Source (S) includes processes that manage the procurement, delivery, receipt, and transfer of raw material items, subassemblies, products and services (Cheng et al., 2010). In the procurement process of international EPC projects, sources cover the processes of coordinating and balancing resources by each partner according to respective plan, commercial operations using bills and receipts and other preparation works for essential works in the next step. During the source phase, the communication and cooperation among participators are very important, because for example some bills for payment or custom clearance will be delivered from one to another.

Make (M) includes processes that transform products to a finished state (Cheng et al., 2010). In the procurement process of international EPC projects, make means that factories produce goods, such as construction materials or production plants, which are the object in the procurement contract. The most important thing in this phase is quality. For this reason, control and inspection are always executed during the make process by suppliers and the main contractor.

Deliver (D) includes processes that provide finished goods and services, including order management, transportation management, and distribution management (Cheng et al., 2010). In the procurement process of international EPC projects, the deliver phase means mainly the logistical step including shipment, in-land transportation, custom clearance and the related commercial payment operation. Due to crossing different countries and complicated import and export documents, delivery is always viewed as the critical part to control project schedule and payment.

Return (R) includes post-delivery customer support and processes that are associated with returning or receiving returned products (Cheng et al., 2010). In the procurement process of international EPC projects, because of high delivery cost and complex custom clearance process, redundant goods are always sold in the projects' local market, such as redundant steel bar or electric cable. Moreover, the broken goods provided by suppliers will be abandoned without returning. At the same time, the main contractor will request suppliers to provide same goods in the fastest way and for free. So the return in the procurement process seldom happens in international EPC projects.

2.3 Framework of Supply Chain Model

Demand and supply of these five components are planned and controlled in different levels. There are four levels in SCOR models to define the operation steps, measure the performance identify the correlations and verify the information (Huan, Sheoran, & Wang, 2004). They are top level, configuration level, process level and implementation level. In Level 1 (top level), the modeling provides a broad definition of the scope and content for the SCOR model and describes the five fundamental processes; Level 2 (configuration level) modeling divides the five basic management processes into process categories, which allow companies to describe the configuration of their supply chains. The stakeholders in the supply chain should choose the section type based on the upper level. For example, under the plan section, the main contractor must select plan supply chain, plan source and plan delivery. Level 3 modeling provides companies with the information for detailed planning and setting goals. Every process type in Level 2 is divided into detailed process units including inner process and external process. Level 4 modeling focuses on the detail implementation that is not defined in SCOR because SCOR only defines common standard supply chain reference structure. In Level 4 modeling, users need to design the implementation details of each Level 3 process to meet their own needs. Through the four levels of development, the SCOR models can be extended to capture and represent complex interactions among supply chain partners. Except for the four levels, a performance metric designed for evaluating the construction supply chain always includes reliability, responsiveness, flexibility, cost and assets (Pan et al., 2011).

A more generalized framework to set up construction supply chain model has been discussed in the book *Construction Supply Chain Management Handbook* (O'Brien et al, 2009). The framework for developing the construction supply chain model consists of five basic steps which support the modeling process. They are (a) define SC model purpose; (b) establish SC performance measures; (c) determine product type; (d) define SC configuration; and (e) characterize SC elements. This framework will provide the necessary support to develop a comprehensive SC model that includes the model goal and metrics, as well as adequate boundaries, elements, and attributes (O'Brien et al., 2009). Figure 1 shows the framework to set up the construction supply chain model in five steps.

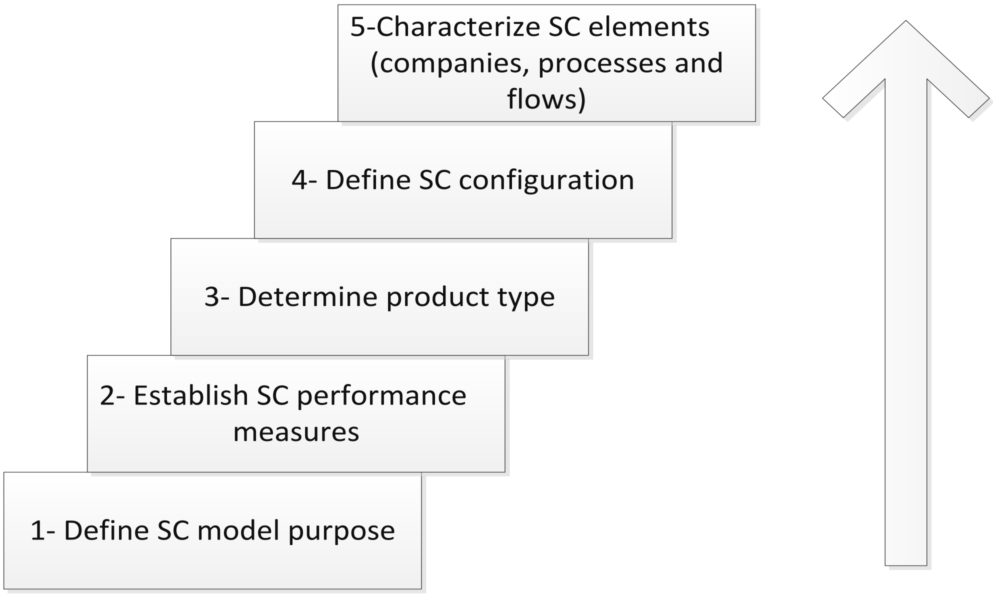

Figure 1. Framework to set up construction supply chain model. Adapted from *Construction Supply Chain Management Handbook* by William J. O'Brien, Carlos T. Formoso, Ruben Vrijhoef and Kerry A. London, 2009, p.2-17

Construction supply chain model can serve various purposes, which vary from decreasing integrated delivery cost to those that estimate how project management methods affect supply chain through performance. The purpose of this thesis is to decrease the cost in the procurement phase. In order to achieve this purpose, this thesis selects inventory cost as the performance measure and will check the inventory cost from four different locations.

2.4 Products

Generally, there are three kinds of products: ETO (engineer to order), MTO (make to order), and MTS (make to stock). ETO products are specially made for the customer following detailed specifications (e.g., power distribution equipment, preassembled rebar components), commonly characterized by long lead times and complex engineering processes for product specifications. MTO products are usually products manufactured once customer orders have been placed (e.g., cast-in-place concrete, prefabricated panels). Usually, MTO manufacturers don't hold stock and lead times can be either long or short, depending on the manufacturing complexity. MTS products are commodities (e.g. consumables such as bricks and steel bar) characterized by short lead times. MTS manufacturers usually hold stock; however, managing the physical distribution of such products may be complex.

Most previous literature prefers to choose a kind of product when establishing the determining the product type in the third step of construction supply chain model framework. Pan et al. (2011) chose the MTO product (precast concrete) to research the supply and demand behaviors by using a SCOR model under a case study of the bridge superstructure construction process; steel bar is always chosen as the MTS product for analyzing the construction supply chain (Abduh et al., 2012; Ala-Risku & Mikko, 2005; Baladhandayutham & Venkatesh, 2012; Tserng et al., 2006). Very little research focuses on multiple products and their interactions on construction supply chain. Cheng et al. (2010) described three different kinds of products—stocked standard products, configurable products and custom products—and established their SCOR models. But in the case study of this paper, the stocked product and configurable product are the raw materials for the custom product. This thesis identifies three types of products working for three different and connecting critical works: civil construction, steel structure erection and main plant erection.

2.5 Inventory Cost

As discussed above, inventory management is very critical to influence the construction supply chain during the procurement period. Controlling the inventory cost is also the first important purpose of inventory management. Polat, Arditi and Mungen (2007) presented that the time and size of shipment could influence the inventory cost and simulated the supply chain of ordering products for comparing two decision making strategies, just-in-case and just-in-time. Tserng et al. (2006) interpreted that the transaction constraints would result in inventory cost overspending. Arbulu, Ballard, and Harper (2003) explained that the marketplace would influence the inventory cost due to its distance to the site. Besides, they thought a dynamic inventory management system would be helpful to inventory control because the system would provide upgraded supply and demand information. Kern and Formoso (2006) divided the project operation plan into three levels: long term plan, medium-term and short term plan. They thought different level plans would influence the inventory management differently. The long term plan would reduce the inventory cost, the medium term will change the inventory space and the short term plan will keep the inventory information transparent.

2.6. Supply Chain Simulation

Hatmoko and Scott (2010) measured the impact of various supply chain management practices, such as flow of materials, on project performance through investigating tow medium-size building projects and developing simulation models. These models were developed using Pertmaster Risk Expert™ software and performed simulation. The simulation results showed that delays in material flow caused the biggest impact on the project. Pan, Lin, and Pan (2010) set up a supply chain model based on a based on SCOR model and a case study of a bridge construction project. The model was simulated by using Java in the Expression function of Simprocess. The simulation results showed that the proposed hybrid modeling methodology helps construction supply chain participants identify their roles and communicate easily, helps project managers identify bottlenecks in a supply chain, and significantly improves supply chain performance. Vidalakis, Tookey, and Sommerville (2011) presented a logistical analysis of construction supply chains by assessing the impact of varying demand on the performance of building materials and developing a conceptual logistics model. The conceptual model was constructed by the means of an activity cycle diagram (ACD) and implemented simulation using Simul8 (Visual8 Corporation), a commercial off-the-shelf discrete-event simulation package. The simulation results showed that demand variability, as one of the major issues, can hinder the application of logistics management in construction and dealt with the resultant increased complexity by implementing a stochastic simulation modeling approach.

Ebrahimy, AbouRizk,, Siri, and Mohamed (2011) developed a simulation model for the upstream supply chain of a real-time tunneling construction project and aimed to capture complex variables impacting the productivity. The simulation model was developed by the Simphony Supply Chain Simulator (SSCS) and the variables were studied by sensitivity analysis. The results suggested several approaches to addressing supply chain including effective quality control, increasing storage space, and anticipating leading-time.

AbouRizk and Halpin (1992) studied the statistic distribution application to construction duration. The results showed that beta distribution is suitable for representing the construction activity durations and could be used in the simulation. McCabe (2003) discussed the schedule risk in the construction management using the MonteCarlito simulation and verified that the beta distribution can be approximated with a triangular distribution, which requires three parameters for its definition: the lower limit, the most likely value and the higher limit. The triangular distribution is widely used in project management as an input into the critical path method (CPM) to model events which take place within an interval defined by a minimum and maximum value. Polat, et al. (2007) explained why just-in-case strategy has less inventory cost than just-in-time strategy through setting up a simulation model. In the model, the triangular distribution was used to represent the activity duration in the construction projects.

2.7 Relationship Management

In practice, international EPC projects often suffer from schedule delays and inventory cost overspending. Just as discussed above, more research pays attention to the causes of the poor performance, but few studies focus on the influence of the supply chain management on the relationship between the main contractor and suppliers (supplying products or supplying service). Meng (2012) explained the huge effects to project operation by supply chain relationship from 10 indicators: mutual objectives, gain and pain sharing, trust, no-blame culture, joint working, communication, problem solving, risk allocation, performance measurement, and continuous improvement. Zhao, Flynn, and Roth (2007) showed the need to research how Chinese international project contractors manage the relationship with suppliers. Under their research, the relationship management could be studied in multiple topics including supplier selection, evaluation, and management; supply chain collaboration and relationship management; and impact of culture on supply chain management.

Trust can be identified as the foundation of relationship management and influence so many key factors of SCM, such as communication, long-term orientation, commitment, and satisfaction (Khalhan, McDermott & Swan, 2007). Subsequently, these factors can be used to improve relationships and evaluate relationships' quality in business relationships. For example, communication and long-term orientation have been applied to assess relationship's quality. The influence from trust to relationship management takes effectiveness in the construction field as well (Jiang, Henneberg, & Naudé, 2012), especially among supply chain members, because trust relationship is based on long-term collaboration and cooperation between supply chain partners (Akintoye & Main, 2007), and trust, as the key element impacting relationship quality in construction industry, is an important tool in supplier relationship management (Jiang et al., 2012).

Collaboration is not only a partner attitude, but also the detail joint working behaviors based on trust. All the parties will make their efforts to work together for a project's successful operation. From the perspective of collaboration attitude, trust and no-blame culture assure collaboration climate arise and to be kept during project operation. Goodwill trust will result in initiative works which are out of scope of contract done by some parties. Blame always comes out when some problems and difficulties happen. At this time, the parties often do not look for a solution firstly, instead would like to blame the other parties in order to minimize or escape their responsibilities. They often neglect their poor performance, but focus on other parties' faults (Baiden, Price, & Dainty, 2006). This kind of blame culture is very dangerous to project operation. No-blame culture is not a way refusing to pursue the responsibilities for a fault, but concentrate on finding a suitable and effective solution firstly with a cooperative attitude.

Communication is another key factor contributing to relationship management. Under traditional contracts, each party is used to being secretive with their information. The lacking of sharing information is thought as one of the main reason for the failure partnering relationship (Ng, Rose, & Mak, 2002), so open communication is to exchange information, and two-way effective communication can enhance trust, maximize understanding, reduce dispute and remove conflict, which is also the essences of adopting EPC contract model (Chen, 2007).

Problem solving mechanism is very useful for parties to face sudden and unpredictable issues, but it is more important to each party to set up a problem foreseen mechanism and a learning mechanism for avoiding the same problem from happening again. Some experienced engineers and project manager from each party in a project should constitute a team in the beginning of project operation. The team may focus on following the project operation and try to find some possible problems that may happen. Once some problems happen beyond prediction, the team is also responsible to summarize and study the reasons leading to problems. Some problem structure analysis methods has been researched by some authors for problems' prediction and study, such as Cross Organizational Learning Approach (COLA) (Franco, Cushman, & Rosenhead, 2004), which is to identify and review critical incidents and project successes, in order to generate a limited set of key actions to feedback both to project partners and to future joint projects. Problem solving capacity is a very critical factor to show one party's strength, and it is also a very useful criterion to select suppliers (Humphreys, Shiu, & Chan, 2001).

Chapter Three

Case Study: Cement Factory

3.1 General Description

The case study is for a cement plant project with a capacity of producing 6000 tons cement per day. The project possesses all characteristics of an international EPC construction project. First, the project was located in Ethiopia and owned by DMCC company (an Ethiopian company), and the contractor was CNBM (a Chinese government-owned enterprise). Second, the main contractor was responsible for all aspects of EPC, Engineering this project, Procuring all the equipment and materials, and constructing of the cement plant. Third, the stakeholders except for the owner and main contractors came from different countries. The suppliers for the main production equipment came from European countries and China; the suppliers for the main construction materials were from Ethiopia and China; the subcontractors for civil construction were from China and Ethiopia; the subcontractor for steel erection was from China. The owner also hired a consultancy firm from India to manage the project. The agent company for export from China and shipment was from China; and the agent company for import to Ethiopia and in-land transportation was from Ethiopia. The company codes and main work for each stakeholder are showed in **Table 1**.

The cement plant production line consists of 16 workshops (**Figure 2**), and each workshop has its specific functions. The workshops are analyzed independently, but they are physically connected to make cement.

Table 1

Company Codes and Main Work for each Stakeholder

Stakeholders	Country	Work description	Company Code
Owner	Ethiopia	Sourcing funding for project, paying for main contractor, and providing site, electric and water for construction.	DMCC
Main contractor	China	Managing, planning, inspecting the work of Engineering, procurement and Construction	CNBM
Consultancy	India	Managing the project	HOLT
Suppliers of important main equipment, such as vertical mill	Germany	Engineering, producing, delivering and guiding erection	LEOG*
Suppliers of other mechanical and electrical equipment	China	Engineering and producing	CNCE
Supplier of steel structure	China	Manufacturing precast steel structure, making and erecting the steel structure on the site	PFSH*
Supplier of steel bar	China	Providing and delivering	CSBC*
Supplier of cement	China	Providing and delivering	CCMC
Supplier of brick	Ethiopia	Providing brick	EBFC
Supplier of gravel	Ethiopia	Providing gravel	EGFC
Subcontractor of main civil construction	China	Constructing civil works and erecting equipment	15CC
Subcontractor of pile foundation	Ethiopia	Doing the civil work of pile foundation	DPFC
Export agent	China	Custom clearance and shipping arrangement	EASH*
Import agent	Ethiopia	Custom clearance and in-land transporting arrangement	IADJ*

Note: the suppliers with * are selected for the study.

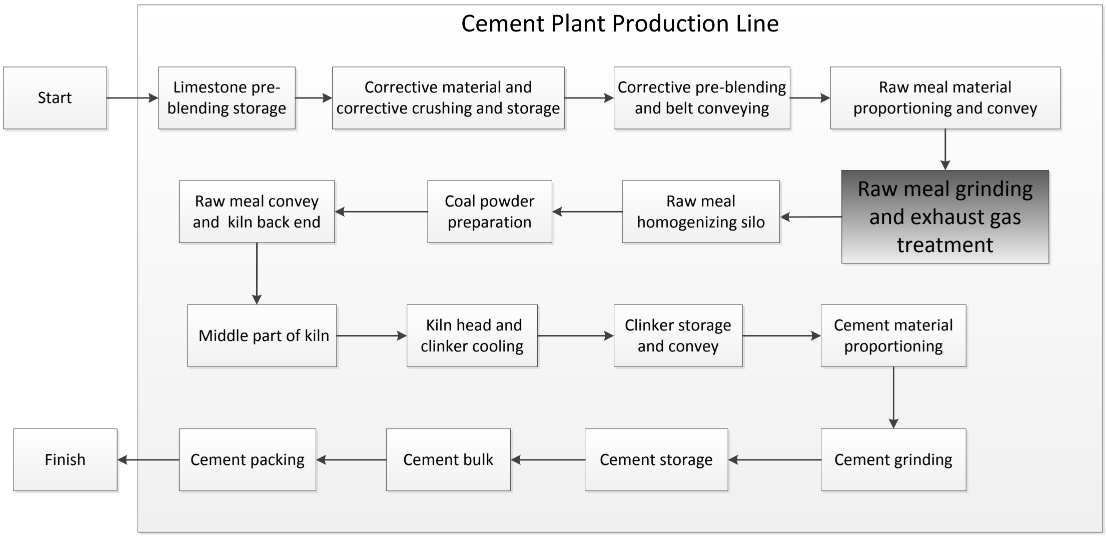

Figure 2. Cement plant workshops, arrows indicate material flow (CNBM.2007)

The Raw Meal Grinding and Exhaust Gas Treat workshop (RMGEGT) is selected for the study (highlighted in **Figure 2**), because it includes all the above mentioned EPC characteristics. The workshop includes seven sub-works. Three are critical in the Construction period: main civil construction, steel structure making and erection, and machinery and electrical equipment erection. The Gantt chart (**Figure 3**) shows that the three sub-works are on the critical path and should be completed sequentially. In other words, the sub-work of steel structure making and erection cannot start until completion of the sub-work of main civil construction; and sub-work of machinery and electrical equipment erection cannot start until completion of the sub-work of steel structure making and erection. **Table 2** clearly shows the stakeholders which performed the seven sub-works.

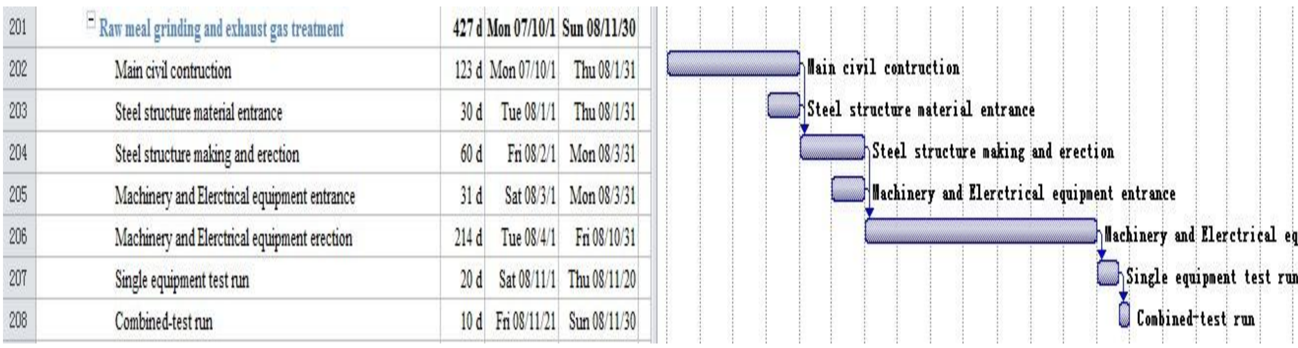

Figure 3. List and Gantt chart of sub-works in RMGEGT (CNBM, 2007)

Table 2.

Description of Work Schedule and Companies that Did each Sub-work

Sub-work	Planned work time(days)	Planned start date	Planned finish date	Suppliers or subcontractor that did this work
*Main civil construction	123	10/01/2007	01/31/2008	15CC
Steel structure materials entrance	30	01/01/2008	01/31/2008	PFSH, EASH, and IADJ
*Steel structure making and erection	60	02/01/2008	03/31/2008	PFSH
Machinery and electrical equipment entrance	31	03/01/2008	03/31/2008	LEOG and IADJ
*Machinery and electrical equipment erection	214	04/01/2008	10/31/2008	PFSH, 15CC, and LEDJ
Single equipment test run	20	11/01/2008	11/20/2008	CNBM, 15CC, PFSH and LEOG
Combined test run	10	11/21/2008	11/30/2008	CNBM, 15CC, PFSH and LEOG

Note. The sub-work with * are used for the study and the information in the table is adapted from CNBM (CNBM, 2007)

The grinding equipment, gas-treatment equipment, and other assorted electrical equipment are erected together during the sub-work of machinery and electrical equipment erection; this also included the erection of the vertical mill. These kinds of equipment belong to ETO products, because the size, function, and capacity should be engineered to satisfy the owner's need. The supplier who signed the contract with the main contractor takes charge of all of the work including engineering, producing, and delivering. In this case, CNBM was responsible for inspecting the equipment in accordance with specifications during the manufacturing period, and testing the equipment in accordance with functional performance during the commissioning period. The vertical mill was made by LEOG and used to grind and mix the raw materials on the production line.

Platforms are needed to erect and join the equipment on the production line. The sub-work of "steel structure making and erection" is to build the platforms. The precast steel structure manufactured in the Chinese factory belongs to the product of MTO, because the manufacture is performed after signing a contract with the main contractor. In this case, the precast steel structures were fabricated by PFSH in accordance with CNBM specifications. Afterwards, the precast steel structures were fabricated to various steel structures on the construction site. The size and shape of the steel structure should match the equipment's size and weight, as well as fit into foundation. PFSH was responsible for producing and delivering the steel structure to the EASH in Shanghai and in providing skilled workers on construction site for erection.

It should be mentioned that a cement plant project needs a great quantity of civil construction work, which is not only for storage silos and the center control building, but also for some supporting structures and foundations of the equipment and steel structure. The sub-work of main civil construction in RMGEGT workshop is to build the concrete supporting structure and foundation. The main construction materials are brick, cement, sand, gravel and steel bar. These materials provided by Chinese or the project's local suppliers in this project were always produced in advance and stocked in the suppliers' warehouse. Therefore, these materials belong to MTS products. These materials usually have high demand and are always procured with a certain amount of lead time in order to guarantee the delivery on time during construction. When the suppliers sign an agreement with the main contractor and receive the order to deliver the materials, they transfer the stock materials and transport them to the construction location. The steel bar supplies was selected for the study. Due to the lack of qualified steel bar suppliers in Ethiopia and the free tax on imported products of this project, the supplier (CSBC) was selected from China.

The REGEGT model presented can be depicted by **Figure 4**. Three kinds of products: steel bar

(MTS), precast steel structure (MTO), and vertical mill (ETO), which are provided by three suppliers and used for three critical –sub-work during construction period. The general description is also showed in **Figure 4**.

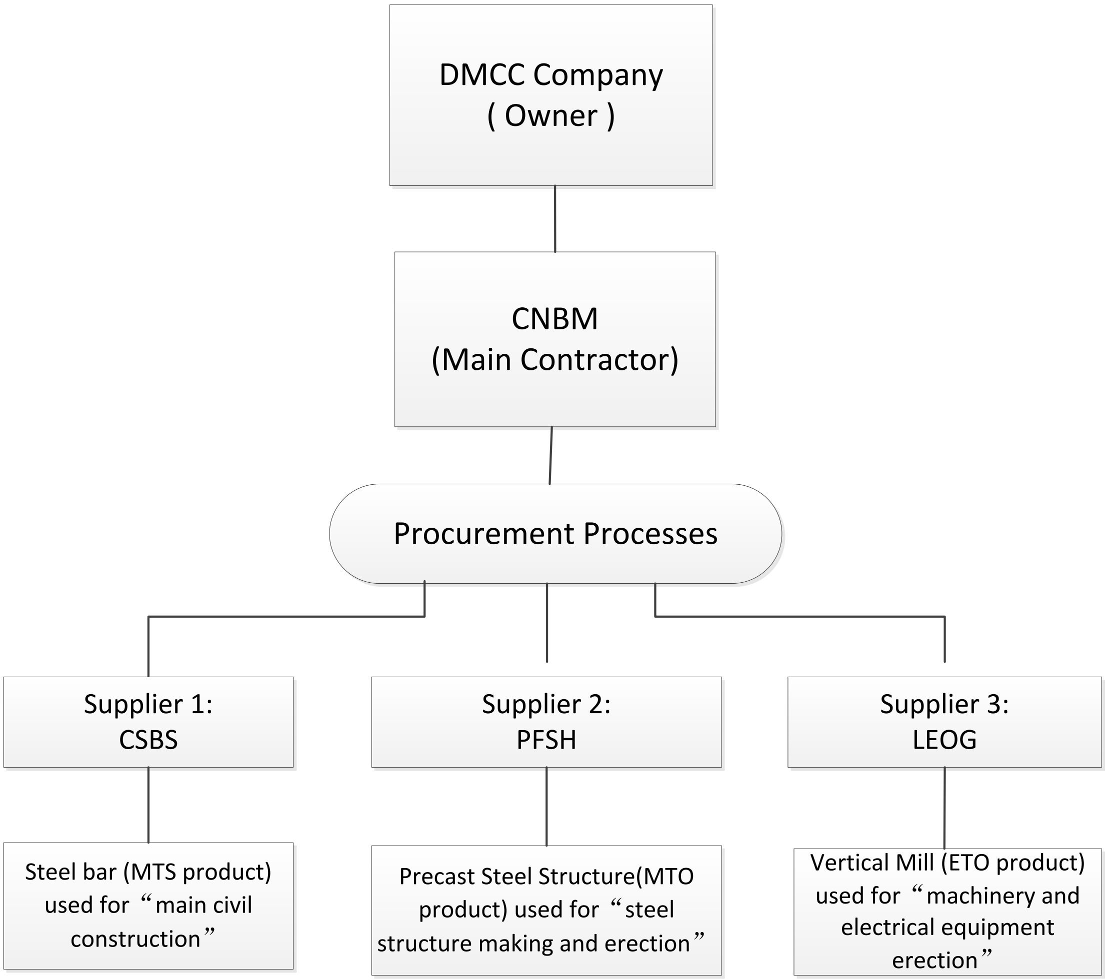

Figure 4. Stakeholders in the cement plant model RMGEGT

3.2 SCOR Model Analysis

The main purpose for the construction of a supply chain model is to help in analyzing the performance of the supply chain management during the procurement period, as well as in studying the inter-relationship among stakeholders. The configuration of the supply chain is based on the three levels SCOR model. The SCOR model level 1 identifies the general work done by each stakeholder, and then the SCOR model level 2 divides the general work into process types, finally the SCOR model level 3 divides every process type into detailed process units. The SCOR model divides every process type in level 2 into detail process units in level 3 and explains each of them by steps, and then describes the supply chain into a process network. Each detail step in SCOR model level 3 will be identified and used to check the reasons for the future possible problems happened in the supply chain. Not only will processes be identified step by step, but also the correlations between each two steps and between each two locations are presented.

The performance of the supply chain is measured by using the total inventory cost for the three types of products. Based on the supply chain models of steel bar, precast steel structure, and vertical mill, the locations where inventory cost may occur and the factors that may influence the cost will be identified.

3.2.1 Steel bar. Due to its available amount and huge consumption, some project managers think that the steel bar has low inventory cost. It may be suitable in a simple building construction project, however, this cannot be agreed on in a complicated international EPC project because of the number of stakeholders involved the complex delivery process.

In the beginning of the procurement of the case, CNBM had a procurement plan to decide the type and quantity of steel bars according to the preliminary design of the civil construction. After that, CNBM asked potential suppliers to submit offers responding to the requirements. Then CNBM headquarters compared and evaluated each offer from suppliers. Based on that, the final approved supplier—CSBC—was picked out and placed the order directly. On receiving the order, CSBS would deliver the stocked or produced steel bars to the Shanghai port where they turned over the qualified steel bar to the EASH employed by CNBM. After receiving the steel bar, EASH was responsible for the export custom clearance and shipment arrangement. When this batch of steel bar arrived at the Djibouti port, IADJ working for the main contractor took charge of the import custom clearance and inland transportation to the construction site. When the steel bar entered the site, CNBM working there received, stocked, and handed over them to the civil subcontractor—15CC—for civil construction. The procurement process of steel bar can be seen in detail in **Figure 5**.

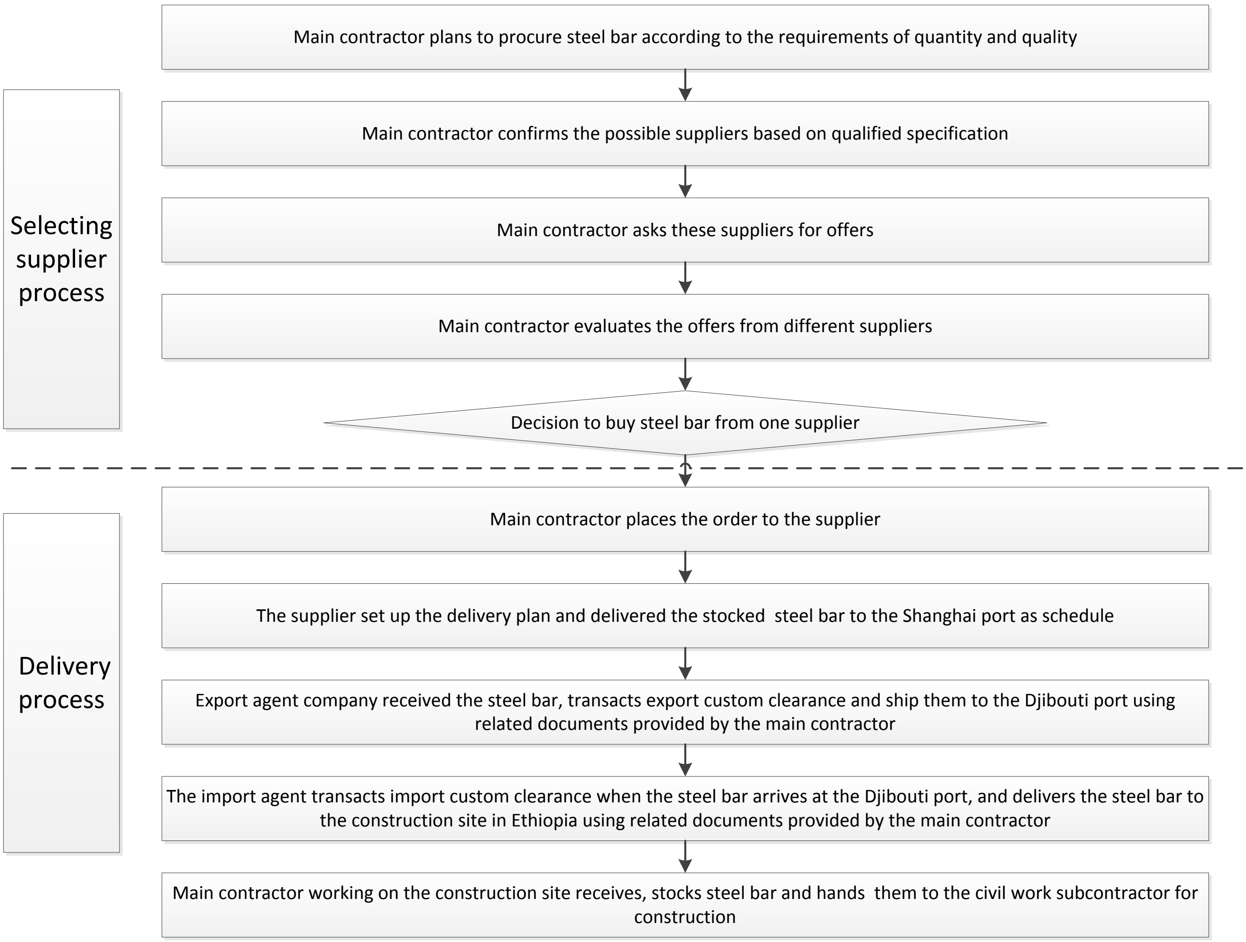

Figure 5. Procurement process of steel bar

3.2.1.1 SCOR model configuration. The SCOR model level 1 is showed in **Figure 6**, and it can be seen that all the stakeholders involved in the procurement of steel bar: CSBC, CNBM in headquarters, CNBM on construction site, EASH, and IADJ. At the same time, the model defines the main work of plan, source and delivery done by each stakeholder (**Table 3).**

Figure 6. SCOR model level 1 for steel bar

Table 3.

Description of Work for SCOR Model Level 1 for Steel Bar

Stakeholder	Plan	Source	Delivery
CSBC	Plan transferring and delivery of steel bar	Sign contractor with CNBMIE and receive the order of delivery	Deliver steel bar to Shanghai port
EASH	Plan custom clearance and shipment	Receive and verify steel bar	Delivery steel bar to Djibouti port
CNBM in Chinese headquarter	Plan the whole supply chain and procuring procedures of steel bar	Prepare delivery schedule	
IADJ	Plan custom clearance and in-land transportation	Receive and verify steel bar	Delivery steel bar to construction site
CNBM on construction site		Receive and verify steel bar	

The SCOR model level 2 (**Figure 7**) identifies the steel bar procurement process types done by each stakeholder, which is more detail than Level 1. For example, Level 1 model only identifies that CNBM in Chinese headquarter should do the work of plan, but does not illustrate what kinds of plan work that CNBM should do. However, Level 2 describes that CNBM should do the work of P1 (plan supply chain) and P2 (plan source). P1 is to make a plan for arranging the whole supply chain procedures, and the P2 is to make a plan for doing source work. Besides, in Level 2 model, the source work of steel bar is specifically identified as S1 (Source steel bar), which includes the work of setting up delivery schedule, receiving steel bar, verifying steel bar, and transferring steel bar. These processes will be identified in Level 3 model. Meanwhile, the delivery work of steel bar is also specifically identified as D1 (deliver steel bar). More detail working process for delivering steel bar will be identified in Level 3. Moreover, Level 2 model represents the delivery flow and information flow between each two specific work, which interprets the direction and route of the steel bar flow, and correlation between any two stakeholders through communication. The steel bar was delivered from CSBC to EASH, and then from EASH to IADJ, and finally from IMDJ to CNBM working on site. The information flow includes outer communication and inner communication. For example, when CNBM in Chinese headquarters set up supply chain plan (P1), CNBM communicated with CSBC for the work of S1. At the same time, CNBM communicated with EASH and IADJ for the work of plan delivery (P4). Except for these outer communications, CNBM also communicated with the CNBM inner department that was responsible for establishing the plan of sourcing steel bar (P2).

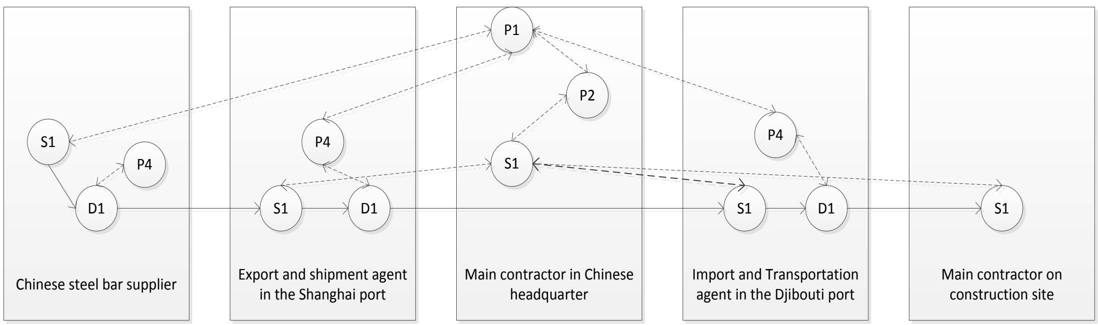

Figure 7. SCOR model level 2 for steel bar. " ⟶ ": the steel bar flow; " - - → ": the information flow

Although the main contractor did not deliver the steel bar, it was very important for the main contractor to prepare all related documents for the steel bar cargo and provide them to the export agent and import agent , which is the S1 work done by CNBM in Chinese headquarters. The agents could not do anything about custom clearance and transportation without the cargo documents, which always include bill of lading, duty free certification, shipping list, cargo invoice and so on. Providing cargo documents on time is a very important factor influencing the inventory cost, so the communication about the cargo documents and delivery condition between the main contractor and agents is the main information flow in this supply chain. In order to find the specific locations where inventory cost happened and the possible operations that may result in inventory cost overspending, SCOR model level 3 has been worked out and presented in **Figure 8**.

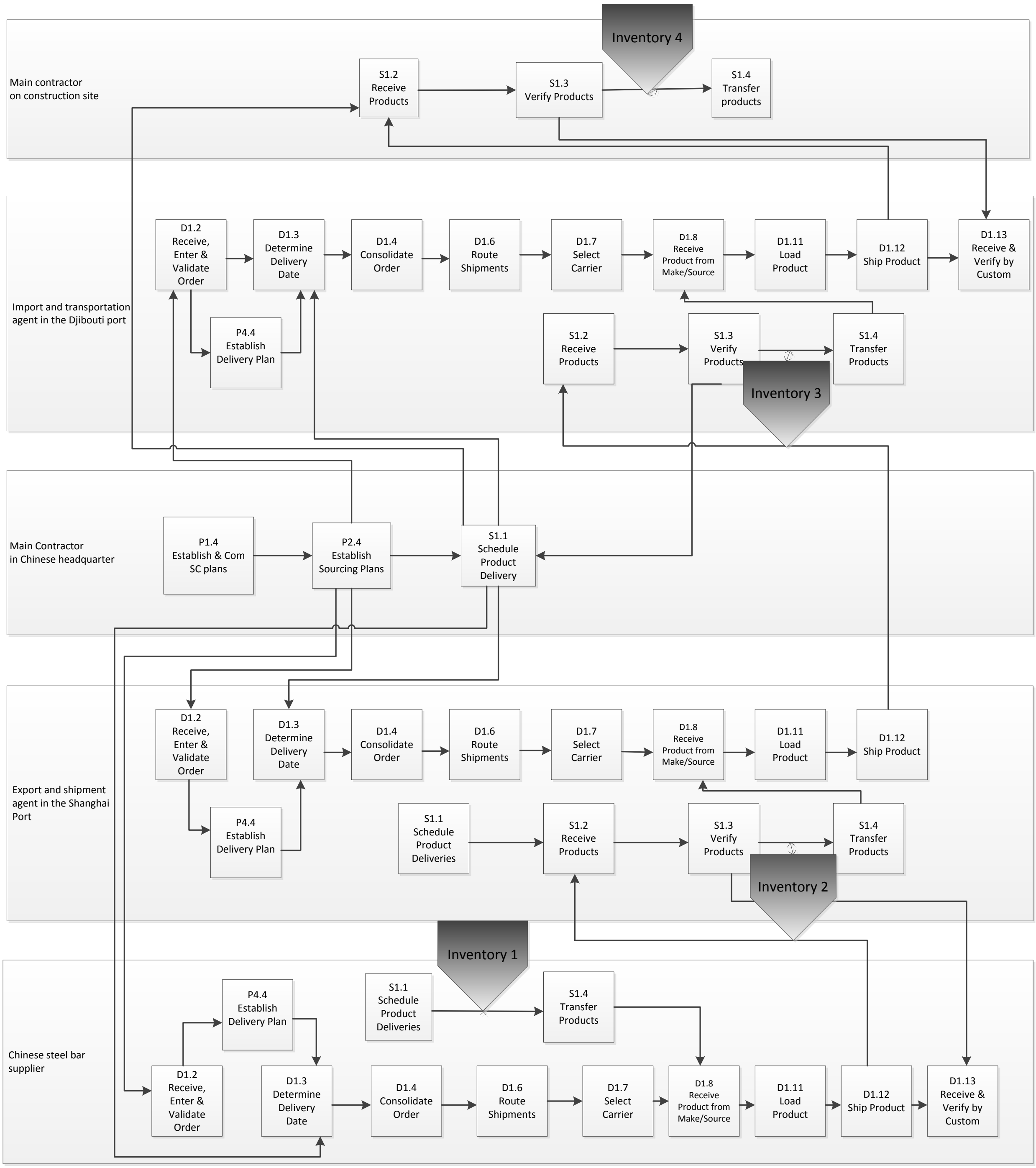

Figure 8. SCOR model level 3 for steel bar

P1 in Level 2 model is refined to a more detail unit of establishing and confirm supply chain plan (P1.4), which is the start of the procurement process of steel bar. P2 is also refined to a unit of establishing sourcing plan (P2.4). In the case, CNBM in Chinese headquarters worked for the schedule of the steel bar delivery (S1.1). At the same time, CSBC, EASH, and IADJ began to establish their delivery plans (P4.4). The determine delivery date (D1.3) established by each stakeholder should have associated with the main contractor’s delivery schedule (S1.1). D1 in Level 2 model is divided into several detail process units, which are from receiving validated order (D1.2) to receiving the verification that the products have arrived at the following partner (D1.13). S1 in Leave 2 model is divided into four detailed process units, which are schedule product deliveries (S1.1), receive products (S1.2), verify products (S1.3), and transfer products (S1.4). The locations where inventory cost of steel bar may happen are during the period of source work.

3.2.1.2 Inventory types and cost. There are four locations where the inventory cost undertaken by CNBM may happen in the SCOR model level 3 for steel bar: the CSBC factory, the Shanghai port, the Djibouti port, and the construction site.

3.2.1.2.1 Inventory 1. The first location where the inventory cost may happen is in the CSBC factory. Generally, the inventory cost occurs because the supplier does not transfer the steel bar (S1.4) for delivery according to the steel bar delivery schedule (S1.1). In other words, the steel bar is stocked in the supplier’s factory before being transferred to delivery because of the late order from the main contractor. Commonly, the inventory cost in the supplier’s factory will not be seen as the cost that should be undertaken by the main contractor, because the supplier stocks the steel bar in its own silo and waits for someone to come to buy. However, the inventory cost will be paid by the main contractor when the delivery order arriving date comes later than the date given in the contract.

3.2.1.2.2 Inventory 2. The inventory cost will happen in the Shanghai port if the storing time of steel bar exceeds the specified free time. In other words, the time that the export agent transfers the steel bars (S1.4) for shipping is more than the specified free time of the port. The reasons leading to inventory cost in the export port mainly come from two perspectives: one is the main contractor and the other is the export agent company. Once the steel bar left the CSBC factory, CNBM needs to hand all the related steel bar documents over to EASH for custom clearance and shipment. If these documents were submitted late to EASH, the steel bar has to be stored in the Shanghai port until all the documents are delivered to EASH. Once obtaining the document, the EASH can do the transactions of custom clearance and shipment arrangement

From the SCOR model level 3, we also can see some steps operated by the export agent may increase inventory cost. The first one is the late verification (S1.3) of the steel bar because of poor communication with the steel bar supplier. The second one is the late transferring (S1.4) of steel bar from the port silo onto the ship because of the bad delivery plan or the late custom clearance transaction. The third one is missing the planned shipment carrier because of the late custom clearance transaction or steel bar being late entering port. The steel bar entering port late may be due to the main contractor’s late order, the supplier’s late delivery plan, or the transportation problems on the way. All the reasons discussed above are classified into the following **Table 4.**

3.2.1.2.3 Inventory 3. The inventory cost will happen in the Djibouti port if the storing time of steel bar when exceeding the specified free time. In other words, the time that IADJ transfers the steel bars (S1.4) for in-land transportation is more than the specified free time of the port. IADJ also needs the same steel bar documents for import custom clearance as the export agent company, including bill of lading, tax free certification, original certification, invoice and check list. The custom department would keep the steel bar on the port until all the required documents are received. If the steel bar is kept to beyond the specified free time, the port administration office will charge a very high inventory fee. Besides, the communication between CNBM and IADJ is also very important. CNBM should keep in touch with IADJ about the shipment schedule and give notice to IADJ at the first time when the ship with the steel bar arrives at the port (P2.4 Level 3 model).

Table 4

Factors Influencing the Inventory Cost of Steel Bar in the Location of Inventory 2

Inventory cost issues	Reasons caused by each stakeholder			
	CNBM	EASH	CSBC	Others
Steel bar was stored in the Shanghai port when exceeding the specified free storing time or waiting for the shipment	Late handover of documents	Late verification of poor communication	Poor communication	Shipment carriers change schedule
	Late orders of delivery from the supplier	Bad delivery plan	Bad delivery plan	Transportation problems on the way
		Late transaction of custom clearance		
		Late transaction in order to miss the planned shipment		

The inventory cost may happen because of the late transaction by IADJ for custom clearance and inland transportation. If IADJ is not able to complete the custom clearance work or does not have a good relationship with the custom department, the steel bar is very easy to be kept beyond the specified free time. So choosing a competent import agent is very crucial for saving time and inventory cost in the port.

Cultural difference is also a very critical factor that may influence the transaction efficiency. Ethiopian companies have different business habits from Chinese companies. They prefer to get 100% advance payment before working for custom clearance and do not like to execute contracts strictly.

Their unprofessional business behaviors made it very hard to ask for compensation for the inventory cost caused by them. All possible reasons that may lead to the increasing of inventory cost in the Djibouti port are showed in **Table 5**.

Table 5

Factors Influencing the Inventory Cost of Steel Bar in the Location of Inventory 3

Inventory cost issues	Reasons caused by each possible stakeholder		
	CNBM	IADJ	Others
The steel bar was stored in the Djibouti port when exceeding the specified free storing time or waiting for the transportation to construction site	Late handover of documents	Late verification of poor communication	Cultural difference
	Bad communication with agent	Bad delivery plan	
	Choosing nonqualified agent	Late transaction of custom clearance	
		Late transaction of planning transportation	

3.2.1.2.4 Inventory 4. The overspending inventory cost may happen if the steel bar was stocked on site when exceeding the estimated inventory time. To avoid the material shortage for the construction requirement, the steel bar was commonly planned to be delivered to the site with a certain amount of leading time and stocked on the open yard. In this case, the planned finish date of the steel bar entering the site was 09/20/07 and the start date of the main civil construction of the raw material grinding workshop was 10/01/07. It means that the minimal inventory time for the steer bar as planned was 10 days. If the steel bar was not used after the planned inventory time, the inventory cost would be overspent and the procurement cost would increase.

There are multiple reasons for the delay in using the steel bar. Firstly, other main construction materials, such as cement, entered the site late. Secondly, the previous work on the critical path had not been completed on time. For example, the completion date of the foundation excavation was delayed because the excavator was broken-down. Thirdly, there may be other uncontrolled factors, such as bad weather.

3.2.2 Precast steel structure. Precast steel structure is produced based on specific design and manufactured from precast steel structure. In this case, due to the lack of raw materials and the high producing cost, the precast steel structure was very hard to produce on construction site, so CNBM preferred to find a Chinese precast steel structure supplier who could manufacture precast steel structure in China, deliver the precast steel structure to Shanghai port, fabricate the steel structure using the precast steel structure on the site, and provide the erection service on the site.

The precast steel structure is often not stocked on the site by the main contractor due to high manufacture and inventory cost. It also interprets the reason why the main contractor prefers to choose one company who can provide an overall service on steel structure. Once the precast steel structure enters site, the main contractor hopes that the supplier can complete the secondary fabricating work as soon as possible, because the supplier is more familiar with the precast steel structure, more effectively to fabricate the steel structure, and more efficiently to complete the erection work. For the same reason, the supplier still does not keep stock, but begin their production of precast steel structure after getting the order from the main contractor. Therefore, the main contractor should consider the order time very carefully for avoiding the production time from delaying the construction schedule.

In the real case, the precast steel structure was planned to enter the construction site on 01/31/08 at latest. With no leading time, the steel structure making work had to start on 02/01/08 and erection work must be completed within 60 days (before 03/31/08), because the vertical mill was planned to start erecting on the production line on 04/01/08. The tight schedule plan also indicated that the main contractor was worried about the high inventory cost caused by the precast steel structure on the site.

In the beginning of the procurement of this case, CNBM should submit preliminary parameters of steel structures to the consultancy company (HOLT) in order to get the approval. Only when receiving the approving notice from the consultancy, CNBM can set up the procurement plan and ask potential suppliers for submittals. CNBM has to adjust the standard design parameters till passing the examination from the consultancy. After the evaluation process for the submittals, the final and qualified steel structure supplier is identified.

In international EPC projects, the main contractor always invites one eligible supplier to bid for the steel structure supplying, making and erecting work. The main contractor prefers to choose a competent supplier with quality strength and high reputation as a long time cooperator, because the steel structure work requires the supplier to have an integrated capability of designing, manufacturing and erecting. Meanwhile, the requirements of quality and skill are very high. In this case, the steel structure erection of RMGEGT workshop needed special working aloft abilities for the erection workers. Moreover, inviting an eligible supplier can decrease the evaluating process and reduces the tender cost. So finding a qualified steel structure supplier in shortest time and with lowest cost is the most important thing to the main contractor. A procurement process of precast steel structure is showed in the follow **Figure 9**.

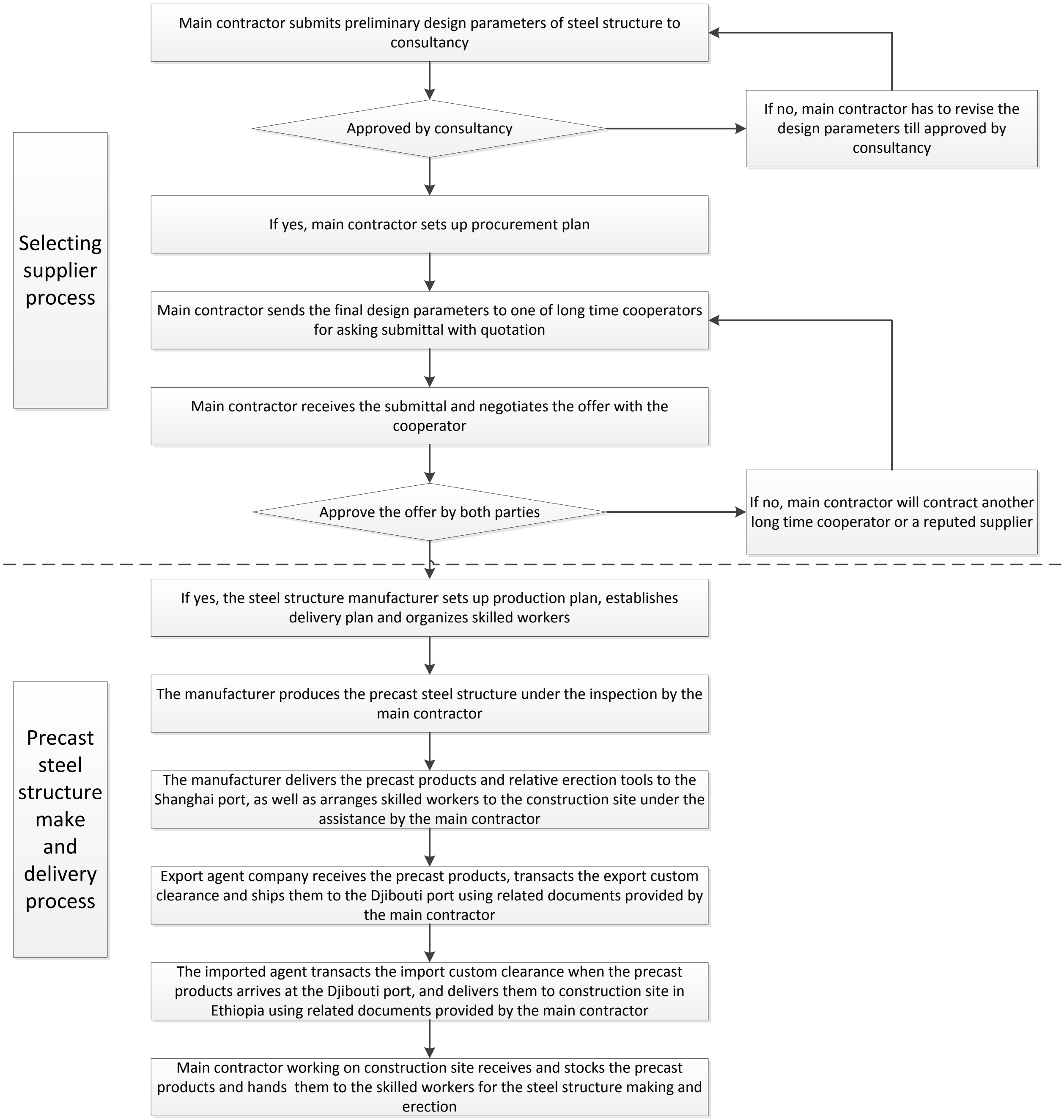

Figure 9. Procurement process of precast steel structure

3.2.2.1 SCOR model configuration. The SCOR model level 1 and 2 for precast steel structure are established in **Figure 10 and Figure 11** based on 5 stakeholders: PFSH in China, CNBM in Chinese headquarter, CNBM on construction site, EASH and JADJ. Level 1 and 2 models for precast steel structure are almost the same to the Level 1 and 2 models for steel bar. CNBM was still not involved into the delivery of precast steel structure, but only overall took charge of the whole process including setting up general delivery plan and preparing critical documents for custom clearance. EASH and IADJ also did the same work as steel bar.

Figure 10. SCOR model level 1 for precast steel structure

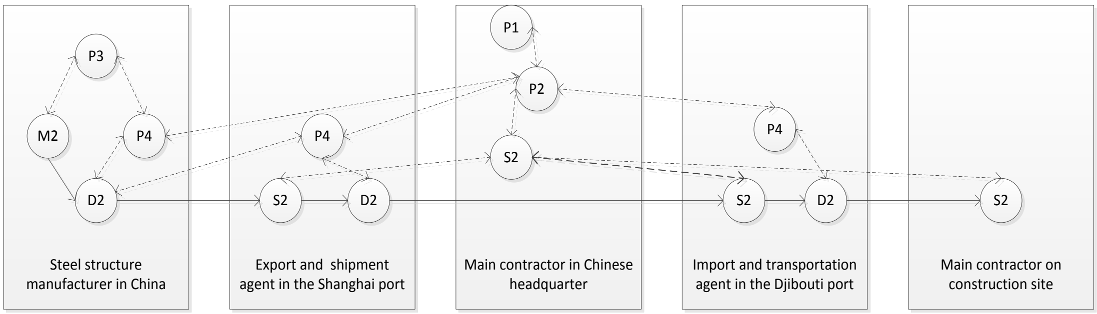

Figure 11. SCOR model level 2 for precast steel structure.

The differences between the models of precast steel structure and steel bar mainly center on the supplier's part. Level 1 model clearly shows the "Make" operations are included in the PFSH's job. Level 2 also explain why "Source" operations are not suitable to precast steel structure. For steel bar, supplier only needs to source existed and stocked steel bar for delivery when receiving the order from the main contractor; whereas the precast steel structure manufacturers must set up production plan (P3) and establish delivery plan (P4). These two plans should be associated with each other and according to the project general schedule (P2 by main contractor in Chinese headquarters). After that, "Make" takes the place of "Source". In the case, PFSH started producing the precast steel structure according to the production plan. During the producing period, the quality of the precast steel structure needed to be inspected by CNBM before leaving factory. The more detail process units of precast steel structure are showed in SCOR model level 3 in **Figure 12**.

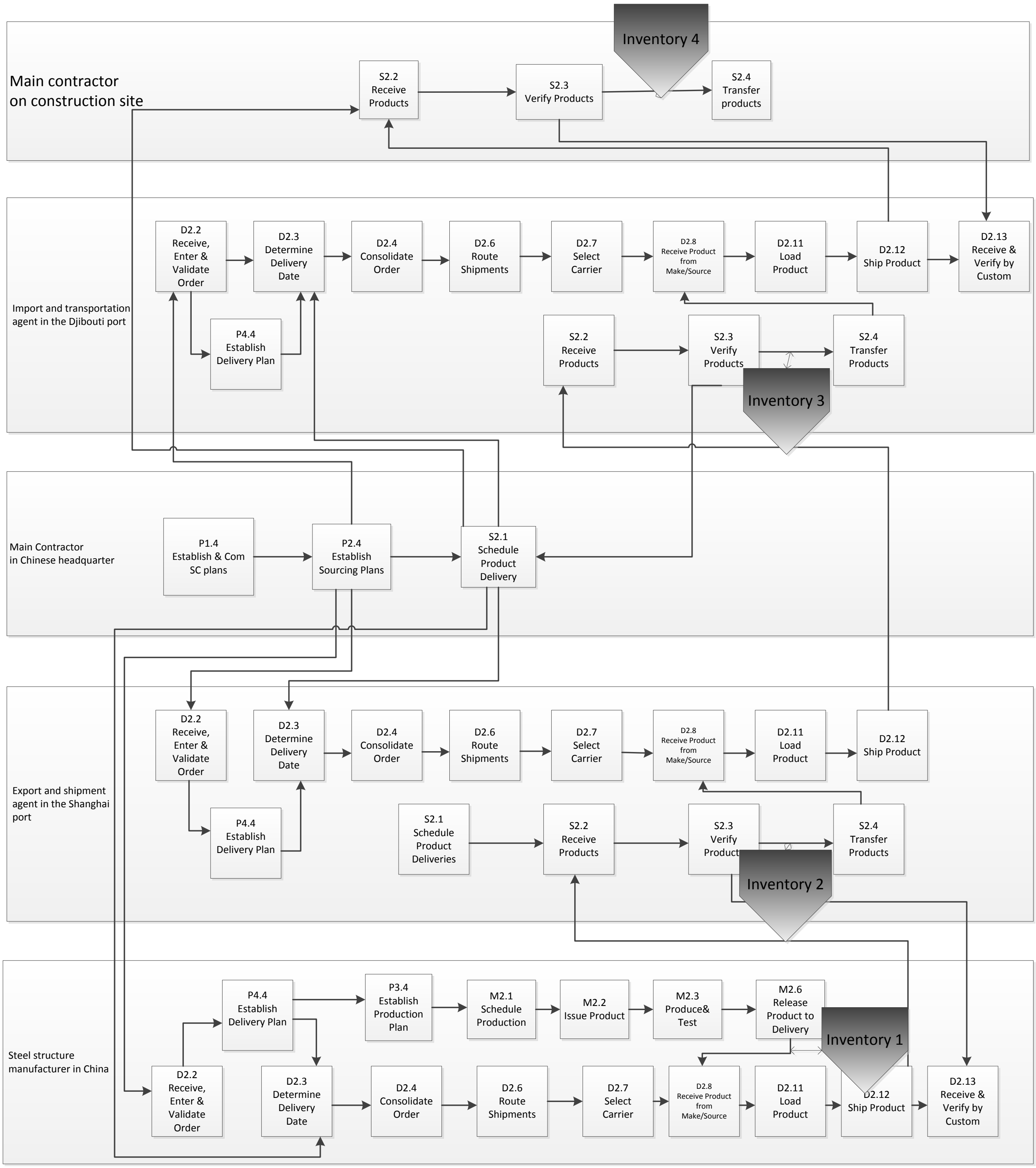

Figure 12. SCOR model level 3 for precast steel structure

Comparing to the Level 3 model of steel bar, the Level 3 model of precast steel structure refines the P3 to the detail process unit of establishing production plan (P3.4), and divides the M2 into four detail process units: schedule production(M2.1), issue product (M2,2), produce and test (M2.3), and release product to delivery (M2.6). The model indicates that the production plan should be based on and followed by delivery plan (P4.4). Besides, the product producing and delivery arranging can be operated parallel. In addition, the inventory cost in the manufacturer's factory may happen after making work and before delivery work (between M2.6 and D2.8).

3.2.2.2 Inventory types and costs bv. There are also four locations where the inventory cost undertaken by the main contractor may happen in the SCOR model level 3 for precast steel structure. The inventory cost happening in locations of Inventory 2 and 3 are the same as the steel bar because EASH and IADJ did the same work on custom clearance and arranging transportation. However, there are some different points in Inventory 1 and 4.

3.2.2.2.1 Inventory 1. The inventory cost will happen in PFSH's factory if the PFSH does not release the completed precast steel structure to delivery (M2.6) according to the established delivery plan, but keeps the precast steel structure in the silo. Generally, the reasons for keeping the produced precast steel structure are mainly caused by two stakeholders: one is the main contractor and the other is the manufacturer itself. As Level 3 model presented, both a bad plan for delivery (P4.4) and a bad plan for making (P3.4) established by the manufacturer may cause unnecessary inventory cost. The bad quality of the precast products can also block transferring (M2.6) to delivery.

The main contractor sometimes orders the supplier to stop transferring the produced precast steel structure to delivery and asks the manufacturer temporarily to stock the products in the silo due to some special conditions. For example, other critical work before the work of "steel structure making and erection" has not been completed during the leading time, when the precast steel structure is planned to enter the site. In this case, the inventory cost of precast steel structure was higher on the site than in PFSH's factory, so CNBM should has preferred to keep the precast products in China and adjust the general delivery plan. For the same reason, CNBM should has kept the precast steel structure in the

PFSH's factory when there was not available ship for delivery reported by EASH. The possible reasons causing the inventory cost of precast steel structure in manufacturer's silo are showed in **Table 6**.

Table 6

Factors Influencing the Inventory Cost of Precast Steel Structure in the Location of Inventory 1

Inventory cost issues	Reasons caused by each possible stakeholder	
	CNBM	PFSH
Precast steel structure was stocked in the manufacturer's silo	Order to stop transferring to delivery due to high inventory cost in other locations, such as on site or in the Shanghai port	Bad "make" plan
		Bad "delivery" plan
		Bad quality

3.2.2.2.2 Inventory 4. The inventory cost will happen on site if the precast steel structure is stocked on the site without transferring them for the work of steel structure making and erection. Commonly, the first reason is the skilled workers or working tools enter the site later than the precast steel structure. Organizing enough qualified workers to enter the site on time is always the critical factor influencing the inventory cost. The reasons leading to workers entering the site late include the visa or flight ticket problems that should be handled by the main contractor, and the organization problems that should be figured out by manufacturers.

Besides, the steel structure cannot be made and erected on the production line because the previous critical work has not been completed. In this case, the previous critical work was the main civil construction, so the delay of the completion of civil work directly resulted in the inventory cost of the precast steel structure.

It is to be observed that the manufacturer can make up the inventory cost loss of Inventory 1 on the construction site. If the manufacturer's skilled workers work more effectively and complete the "making and erection work" before the latest finishing date, they will save the estimated inventory cost and remedy the increased inventory cost happening in the location of Inventory 1. That is another advantage of subcontracting the whole erection work to one manufacturer.

3.2.3 Vertical mill. Vertical mill is one of the most important main production equipment on a cement production line. In this case, the vertical mill was the core equipment of the raw material grinding workshop. It was used to grind the raw materials of clinkers, such as limestone. For this reason, all of other work (civil construction work and steel structure erection work), and other equipment (electrical equipment and mechanical equipment) serviced for vertical mill. Due to the importance of vertical mill, the vertical mill engineering must obey the requirements from DMCC and be approved by HOLT. At the same time, the possible suppliers must be approved by DMCC and HOLT, but not be decided by CNBM only. So the owner and consultancy have a hand in the procurement of main plants. The qualified and approved supplier of vertical mill should be competent to engineer, produce and deliver.

Due to the complicated technics and critical functions in the cement production line, commonly the vertical mill suppliers need to provide some engineering advice to the main contractor based on their professional technic background. Meanwhile, the suppliers may provide some matched mechanical and electrical parts for erecting the vertical mill into the production line. More than that, the supplier always dispatches professional erecting engineers for guiding and directing the erection of vertical mill on project sites. So the supplier of vertical mill is also involved into the procurement process and the erection work on site.

Another specific condition in the vertical mill procurement is its logistic process. The international reputed suppliers of vertical mill are always come from Europe, so they always are responsible for the shipment from their countries to the project located country. In this case, the vertical mill supplier coming from German (LEOG) was responsible to deliver the completed vertical mill from German directly to the Djibouti port. The IADJ received the plant at the port, noticed to CNBM and delivered it to the site. After that, CNBM working on the site took charge of the unloading and inventory of vertical mill. The procurement process of vertical mill is showed in **Figure 13**.

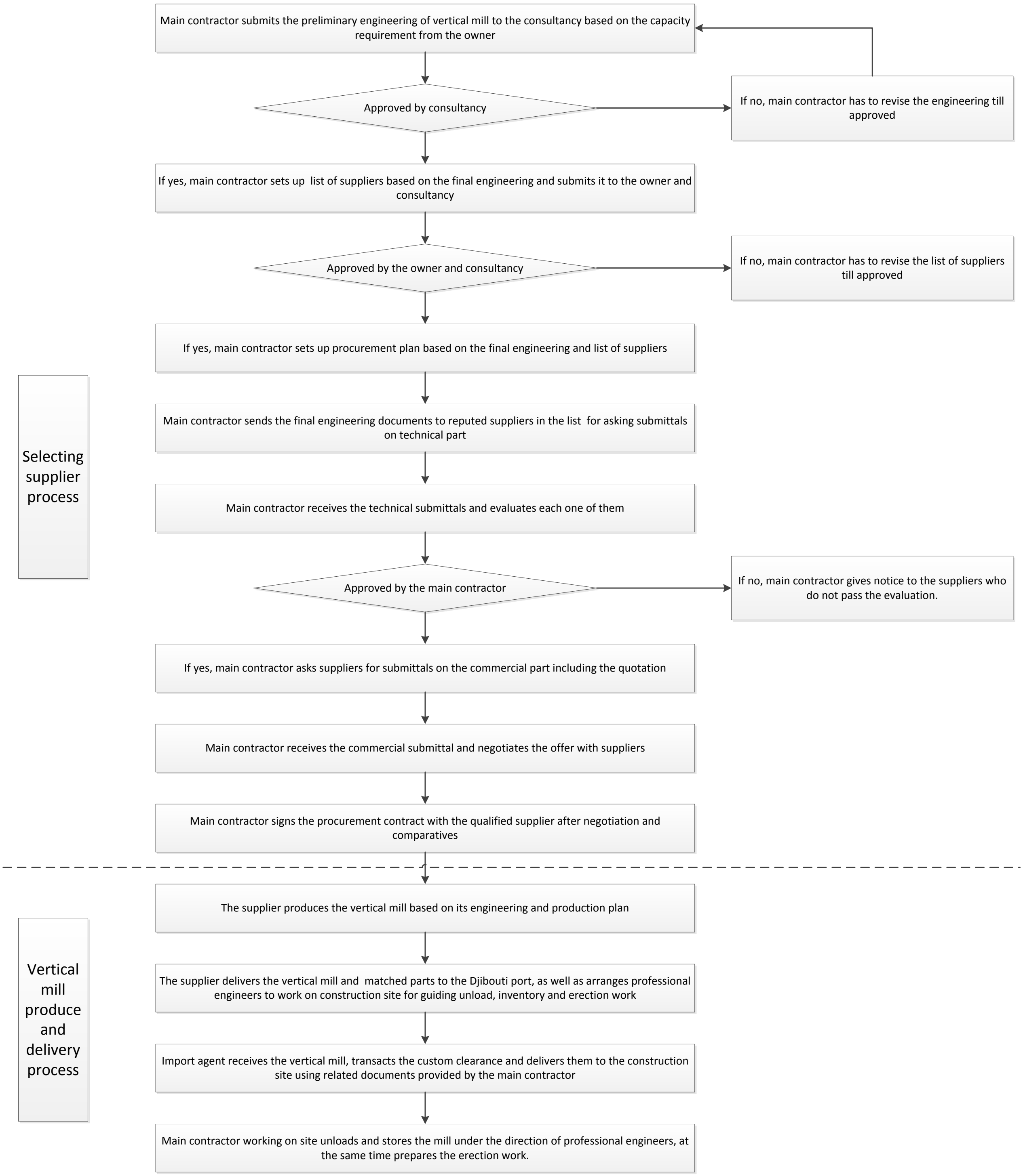

Figure 13. Procurement process of vertical mill

3.2.3.1 SCOR model configuration. Figure 13 indicates that EASH working for CNBM was not involved into the delivery process of vertical mill. It means that there are 4 stakeholders in the supply chain network: LEOG in Germany factory, CNBM in Chinese headquarters, IADJ in the Djibouti port and CNBM on construction site. The SCOR model Level 1 and 2 are showed in **Figure 14 and 15**.

Except for the lack of location of the Shanghai port, the elements in Level 1 and 2 are almost the same to the one belonging to precast steel structure. But the detail process units divided from M3, D3 and S3 will be different because the vertical mill is a kind of ETO product. The SCOR model level 3 with different process units and detail steps is showed in **Figure 16**.

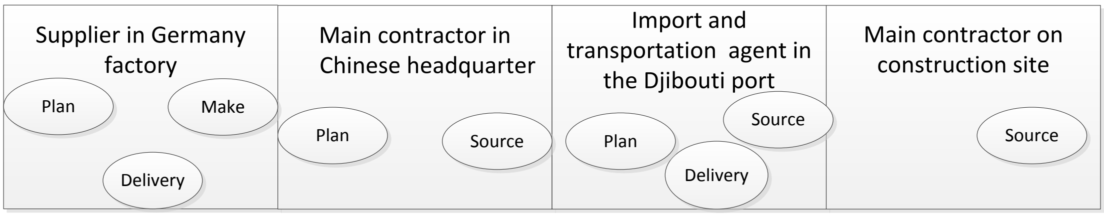

Figure 14. SCOR model level 1 for vertical mill

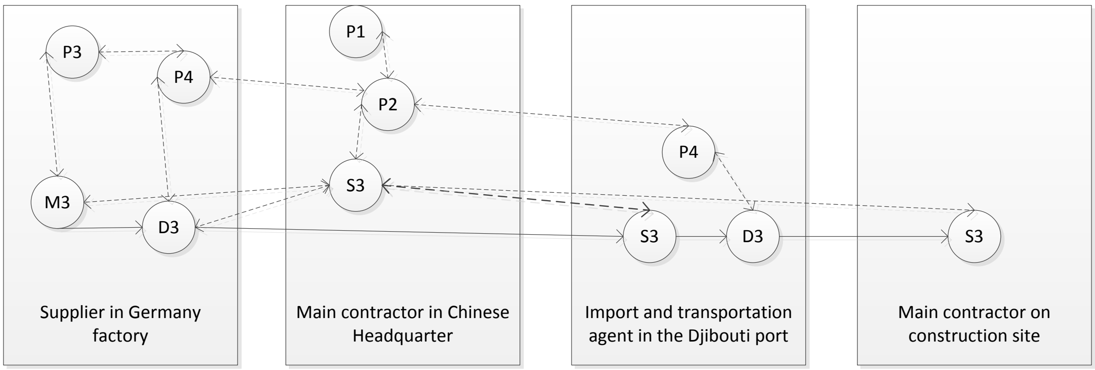

Figure 15. SCOR model level 2 for vertical mill.

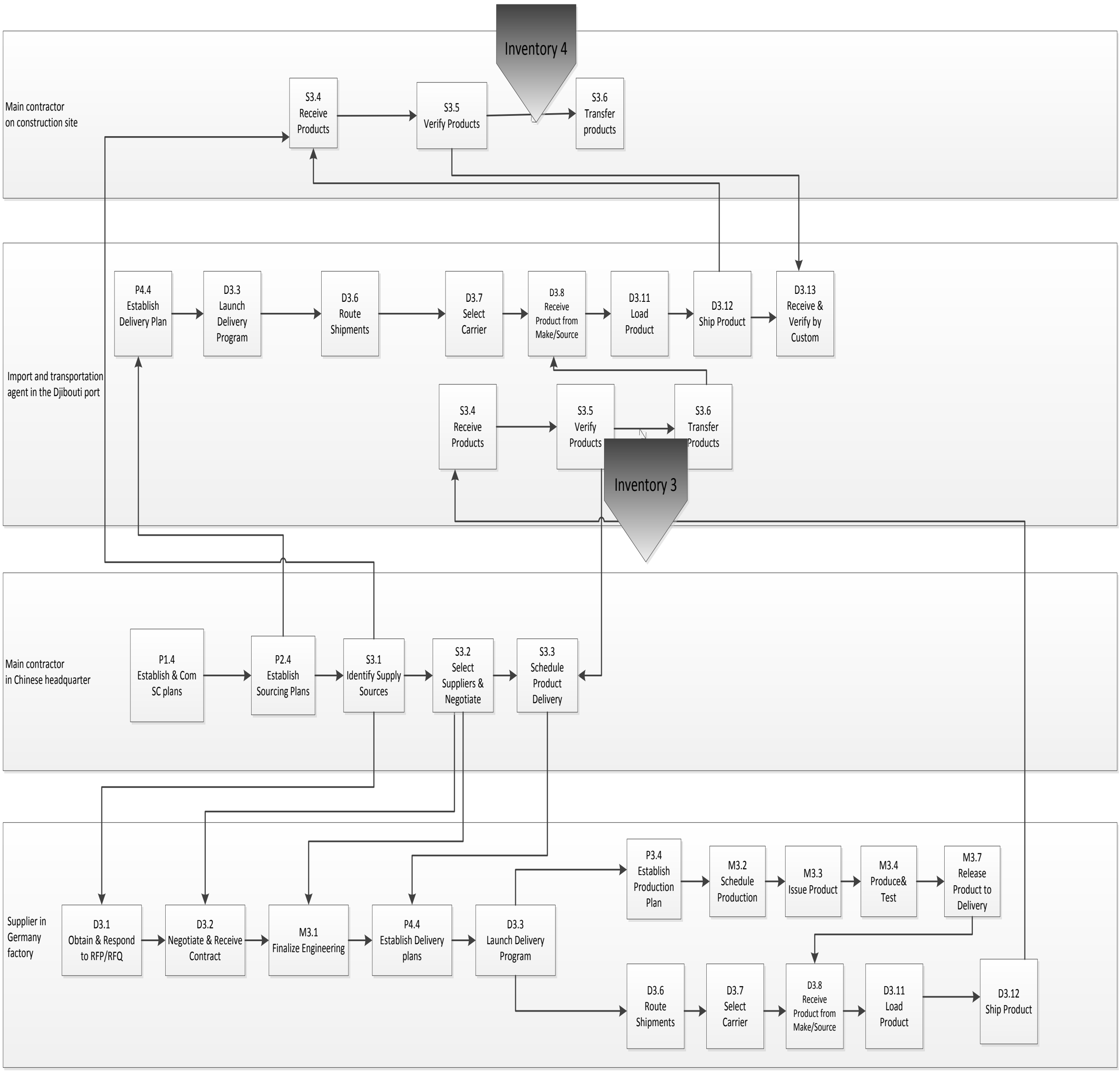

Figure 16. SCOR model level 3 for vertical mill

Among the detail steps under the S3, SCOR model level 3 adds the steps of S3.1 (Identify supply sources) and S3.2 (Select suppliers and negotiate) into the “Source”. It indicates that the selection of suppliers of ETO products is very important for the whole supply chain and sometimes it will directly decide whether or not the project is successful. In practice, CNBM preferred to choose the vertical mill supplier with good relationship, rich experiences, high technical strength and excellent world reputation, but not considered price as the main factor.

The owner always likes to approve the main contractor to buy the ETO products from international famous company in order to guarantee the project quality. It is worthy to mention that the relationship with ETO products, such as vertical mill, supplier is very important to the main contractor because the supplier make the product based on its own engineer, own parts, own standard and own schedule. The main contractor must prepare or adjust the project general schedule basing on the completed schedule of ETO products; at the same time it is very hard for the main contractor to control the supplier's production, especially when the supplier comes from other countries.

In the case, not only adding the new steps under the S3 for CNBM, the new steps D3.1 and D3.2 for LEOG were also added into the "Delivery" process. It also emphasized the importance of the process of confirming the supplier. In the "Make" process, M3.1 (Finalize engineering) is added before the step of planning the delivery plan. It accounts for the engineering for the vertical mill was the precondition of setting up plans of production and delivery. Without qualified and approved engineering, LEOG could do nothing.

3.2.3.2 Inventory types and cost. The supply chain model of vertical mill indicates that there may be two locations where inventory cost will happen, one is in the Djibouti port (Inventory 3) and the other is on the site (Inventory 4). The inventory costs happening in the locations of Inventory 1 and 2 are not applied to vertical mill, because the vertical mill is delivered to the Djibouti port by LEOG directly.

3.2.3.2.1 Inventory 3. The inventory cost may happen because of the same reasons as the steel bar and precast steel structure. A special issue worth noticing is that some ETO products are very big with a large amount of weight. The floating cranes in some African countries' ports are small and do not have enough capability to lift up and down the huge ETO products. In this case, the vertical mill needed to be lifted by three floating cranes and transported by special vehicles to the site. It needed more time to wait for multiple floating cranes and special vehicles to be available. Therefore, the huge ETO products sometimes cause more inventory cost in the import port.

3.2.3.2.2 Inventory 4. Figure 3 shows that the vertical mill and some specialized machines were planned to enter the site before 03/31/08. Without overmuch considering the leading time for inventory, the erection work for the vertical mill started on 04/01/08. Meanwhile, before starting the erection work of vertical mill, the civil construction work and steel structure making and erection work had to be completed. If not, the inventory cost of the vertical mill might happen when waiting for the completion of these two types of work.

3.2.4 Contribution of the SCOR models. The SCOR model has described the procurement processes from 3 levels in systematic networks separately for steel bar, precast steel structure and vertical mill. The three levels' models help the main contractor to identify each step in the supply chains of the procurement processes in an international EPC project and the correlations among all the steps.

Besides, the SCOR models can help the main contractor to check the procurement status associated with the project schedule. For example, the project schedule in Microsoft Project can tell what time the product enter the Shanghai Port; while the SOCR model level 3 can show the "Source" steps on the port including receiving, verifying and transferring, which is more detail and concrete to describe the process and let the main contractor know what the real condition and position the product is at that point.

Moreover, the SCOR models help the main contractor to find the possible locations occurring inventory cost and factor influencing inventory cost in the whole supply chain. In this case, inventory cost of steel bar and precast steel structure may happen in four locations in the supply chain; while the vertical mill inventory cost only may happen in two locations. At the same time, the factors influencing the inventory cost can be found in the steps near the locations.

In addition, the SCOR models can help the main contractor to accelerate the transaction. Through analyzing the factors influencing the inventory cost at different locations, it is observed that the more flexible the transaction constraints, the faster the transaction operation, and the lower the inventory cost happening in the supply chain. Some good examples happened in the case study. As we know, in order to decrease the inventory cost of the vertical mill, the PFSH had to work harder to complete the erection of the steel structure. A constraint to complete the work in a shorter time is the lack of more skilled workers. PFSH dispatched more workers to work on the site to make the constraint flexible, and then the inventory cost decreased in the end. The maximum lifting capability in the Djibouti port is another constraint to the step of "verifying the vertical mill" entering port. IADJ communicated with the port office in advance and arranged the special vehicle to wait near the ship. The port office arranged three floating cranes together to lift the vertical mill and load directly on the vehicle, and then the vehicle delivered the vertical mill to the site without storing the vertical mill in the port. The special arrangement made the constraint flexible and saved the inventory cost and secondary loading fee. CNBM should also understand that the cargo documents are the constraints to transact the custom clearance for the steel bar in the "Source" of Level 3 model. Choosing only one import agent is easy to make the constraint more serious.

At last, the SCOR models can help the main contractor to improve communication through controlling and managing the information flow with other stakeholders. In the case, effective communication with PFSH helped the CNBM adjust the delivery plan at any suitable time. Bad communication broke the relationship with the previous import agent and result in transaction constraints. Communication exists in the operation of nearly every step in supply chain models. The information flows make the direction of communication clear and guarantee the information visible.

3.3 MonteCarlito Simulation Analysis

3.3.1 Introduction. As mentioned before, the performance measure selected for the supply chain analysis is inventory cost. Table 7 shows the inventory costs occurring at the four locations for the three products. The inventory cost had been estimated and planned twice. The first time was at the beginning of the project (P1), and the other time was during the project operation (P2). The actual costs are listed under the C column.

The inventory costs under P1 and P2 for the steel bar in the location of Inventory 3 were both zero; however, the actual inventory cost (C) for the steel bar in Inventory 3 was 48,000 USD. The inventory cost was due to irrelevant causes; it was due to the bad relationship between the original import agent and CNBM. The import agent did not transact the custom clearance work of the steel bars and kept them in the Djibouti port for nearly 2 months, which resulted in a serious delay for the steel bar to enter the site, and led to unpredicted delay in starting the work of main civil construction. The total actual inventory cost of the vertical mill (3,760 USD) did not exceed the planned inventory cost (3,800 USD under P1 and 3,900 USD under P2), and was almost the same as the planned cost. This good performance was because CNBM hired a new import agent (IADJ), who worked very well and decreased the inventory cost compared to plan. Besides, PFSH did very well in the work of making and erecting steel structure on the site, which caught up on the schedule and avoided the vertical mill waiting for a long time on the site.

Table 7

Inventory Cost at Different Locations: Planned Cost at the Beginning (P1), Planned Cost During Operation (P2), and Actual Cost (C).

Item	Inventory cost of each products in different locations (USD)											
	Inventory 1			Inventory 2			Inventory 3			Inventory 4		
	P1	P2	C	P1	P2	C	P1	P2	C	P1	P2	C
Steel bar	0	0	0	0	0	0	0	0	48000	3000	1500	0
Precast steel structure	0	0	0	0	0	0	400	0	0	4800	2880	7840
Vertical mill							800	800	160	3000	3100	3600
Total	0	0	0	0	0	0	1200	800	48160	10800	7480	11440

Based on the above analysis, the steel bar and vertical mill will not be considered in the simulation. The simulation only focuses on the inventory cost that the main contractor should manage and undertake. In the case, to catch up on the project schedule and prevent the same delay from happening again, CNBM ordered PFSH to start delivering this batch of precast steel structure on 11/18/07, which was 17 days earlier than the planned date (12/05/07). However, the early delivery plan did not really catch up on the schedule, and resulted in an actual inventory cost of 7,840 USD for the precast steel structure in the location of Inventory 4, which exceeded the planned cost (4,800 USD under P1 and 2,880 USD under P2). Therefore, the simulation only chooses the precast steel structure to analyze its supply chain.

3.3.2 Simulation model. Based on this real case, a simplified supply chain model of the precast steel structure is established to describe the procurement process from the manufacturing factory to the construction site. This supply chain diagram used for simulation is showed in Figure 17.

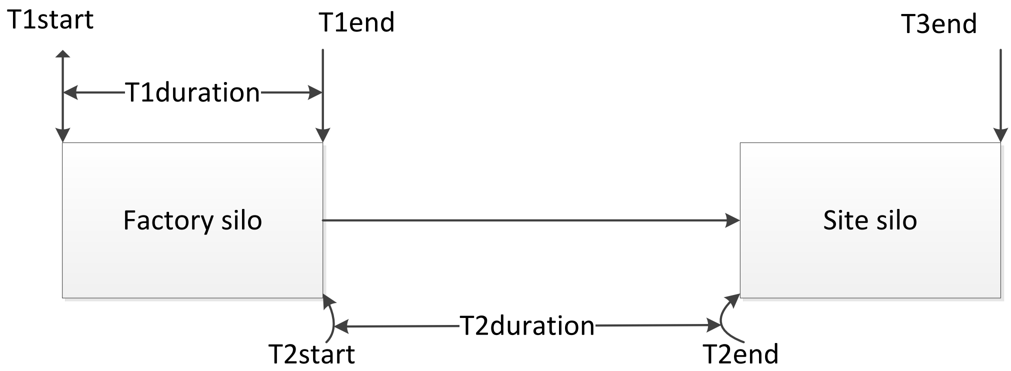

Figure 17. The logical diagram of precast steel structure supply chain used for simulation

The supply chain simplifies the original precast steel structure supply chain model of the procurement process in **Figure 12**. In this simulation model, there are only two inventory locations: the factory silo (Inventory 1) and the site silo (Inventory 4). It neglects the Shanghai port and Djibouti port, where inventory cost rarely occurred during the project's operation. The delivery records of 11 batches of precast steel structure are showed in **Table 8**, which reports the transportation and transaction duration after each batch of precast steel structure left the factory.

The data in the first column will affect the inventory cost occurring in Inventory 1. If the starting delivery date is earlier than planned, there will be no inventory cost happening in the factory silo. Conversely, if the starting delivery date is later than planned due to CNBM, the inventory cost will happen. The actual starting delivery date will be a variable in the inputs of the simulation.

The data in the third and fifth columns will separately affect the inventory cost occurring in Inventory 2 and Inventory 3. Because the standard stocking free time in the Shanghai port and the Djibouti port is 7 days and 15 days, only the eighth batch of precast steel structure had a one-day inventory time in the Shanghai port. At the same time, the whole 11 batches of precast steel structure only had five days of total inventory time in the Djibouti port, and in many cases, port administrators do not charge for exceeding the standard stocking free time by one or two days if the agent has a good relationship with the port administrators. Based on the above two reasons, this supply chain model neglects the inventory time in these two ports and pays more attention to the inventory time happening in the factory and on the site.

Table 8

Starting Delivery Date and Delivery Time (in days) for the 11 Batches of Precast Steel Structure

Batch of precast steel structure	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
	Starting delivery date compared to plan	To Shanghai port	In Shanghai port	Shipping	In Djibouti port	To construction site	Total delivery time
1	17 days early	2	6	30	14	3	55
2	20 days late	1	4	30	11	3	49
3	21 days late	3	7	35	15	3	63
4	18 days late	2	6	37	15	3	63
5	24 days late	2	6	37	15	3	63
6	15 days late	4	7	40	16	5	72
7	20 days late	3	7	38	15	4	67
8	19 days late	4	8	46	17	6	81
9	23 days late	3	7	44	16	4	74
10	22 days late	2	6	35	14	3	60
11	18 days late	4	7	45	16	4	76

Note. The information in the table is from the actual delivery schedule of the Ethiopian cement project (CNBM 2007). Column 1, 3, 5, and 7 will affect the inventory cost at Inventory 1, 2, 3, and 4, but not the real inventory time.

The data in the seventh column is the sum of the data from the second column to the sixth column, and represents the total delivery time from the PFSH factory to the site. It will affect the inventory cost occurring in Inventory 4. When the main civil construction work has not been completed in accordance with the schedule, the short delivery time will result in inventory cost occurring on the site, because the precast steel structure has to wait for the completion of civil main construction. The delivery time will be a variable in the inputs of the simulation.

3.3.3 Purpose of the simulation. Assume performance of supply chain based on the inventory cost. The MonteCallito simulation tool will be used and applied to the precast steel structure.

3.3.4 Variables and parameters of the inputs. The framework of the precast steel structure supply chain simulation model is showed in **Figure 18**, which consists of input, transitional output, and output. The transitional outputs are generated by the simulation model based on the inputs and used to calculate the outputs of the model together with the inputs. There are eight inputs in the framework, including four variables and four parameters.

- The "Planned time to leave factory (T1start)" is a parameter. According to the date from the real case, the date was 12/05/2007. The simulation identifies this date as the parameter value "0."
- The "Waiting duration in factory (T1duration)" is a variable. It means the duration of waiting the delivery order from the main contractor. The value is confirmed by comparing the "T1duration" to the "T1start." For example, if the main contractor orders the precast steel structure to leave factory on 12/06/2007, the value of "T1duration" is equal to "1;" on the contrary, if the main contractor changes the leaving date on 12/04/2007, the value of "T1duration" is equal to "-1." The range of "T1duration" is from "-20" to "58." The minimal value is "-20," because the precast steel structure finishing production date was 11/15/2007, which is 20 days earlier than the "T1start." In other words, "-20" represents the first day when the precast steel structure is available to start

delivery. The maximum value is "58," because if the order delivery date is later than 02/01/2008, the whole project will stop to wait for this batch of precast steel structure, so the whole project schedule will be definitely delayed again. In other words, "58" represents the last day when this batch of steel structure must leave the factory. The "T1duration" follows a uniform distribution, which is used for the situation when we cannot confirm the probability of picking out a value in a range. The possibility selecting a value from "-20" to "58" as the date of leaving factory is unknown, so "T1duration" can be identified as the uniform distribution with the range of -20–58.

- The "Delivery starting time (T2start)" is a variable and it has the same value to "T1end." As discussed above, the precast steel structure supplier started delivering the products once receiving the order from the main contractor.

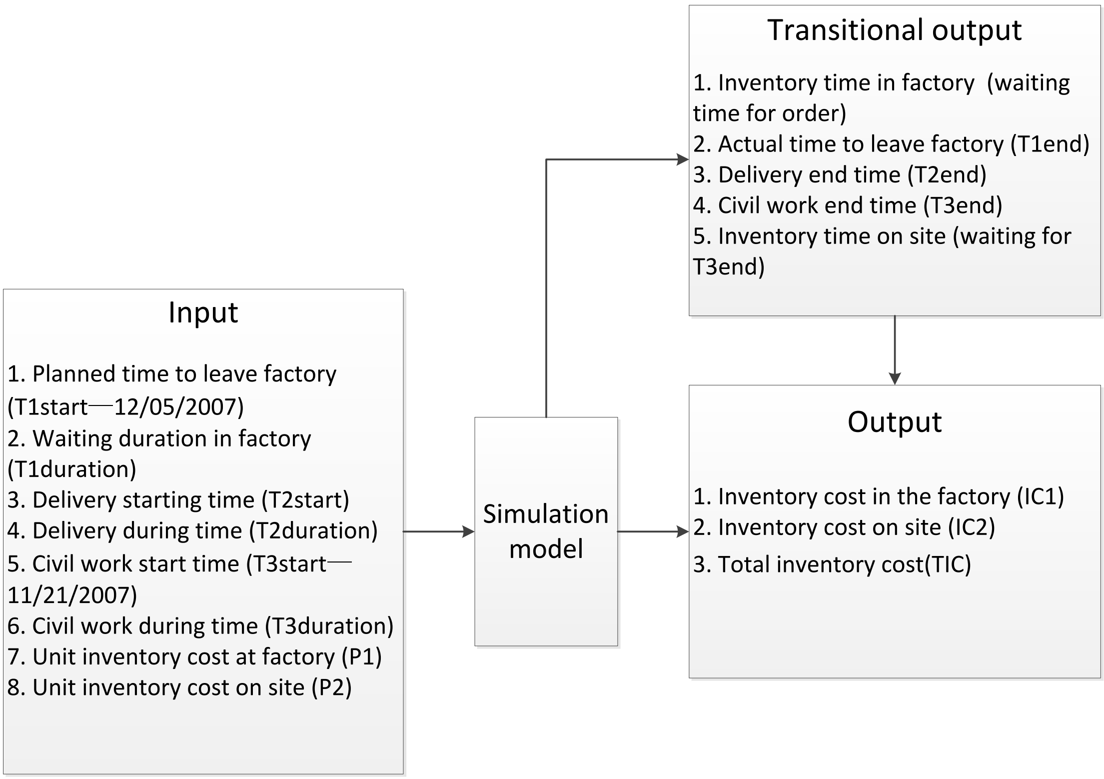

Figure 18. Framework of the simulation model used to describe the input, transitional outputs, and output, as well as their relationships

- The "Delivery during time (T2duration)" is the duration from the precast steel structure leaving factory to entering the site. The supply chain model simplifies the delivery from five specific processes to one general process. Table 8 describes that there are five delivery durations, including duration of delivering to the Shanghai port, duration of delivering onto a ship, duration of delivering to the Djibouti port, duration of delivering onto a vehicle, and duration of delivering to the site. All of these five durations can be considered as the activity duration in the construction project, so the total inventory time consisted by these five durations also belongs to activity duration. As mentioned in the literature review about the application of triangular distribution, it is decided to use triangular distribution for the data to analyze the T2duration. Based on the data in the last column of Table 8, we can see the mode is "63," the upper limit is "81," and the lower limit is "49." So these three values are used to identify the triangular distribution of the "T2duration (49, 63, 81)."

- The "Civil work start time (T3start)" is a parameter. It is the second day after the steel bar entering site. In the case, the date of steel bar entering site was 11/20/2007, so date of "T3start" should be on 11/21/2007. Comparing to the "0" value of the "T1start", the value of "T3start" should be "-15."
- The "Civil work during time (T3duration)" is a variable. It belongs to a kind of construction activity duration, so it also can be represented by triangular distribution for the same reasons as "T2duration". Based on an interview with 20 experienced engineers about how long the civil construction work of the raw material grinding workshop took to complete in their projects, "90," "103," and "123" are identified as the lower limit, mode, and upper limit. The interview results about the project name and the finishing time of the civil construction work of raw material grinding workshop are showed in **Table 9**.

- The last two inputs—inventory unit costs at factory and on site—are viewed as two parameters. Their values are 80 USD/day and 160 USD/day in the real case.

The variables and parameters are presented in **Table 10** with their descriptions, values, and units.

Table 9

Actual Civil Construction Finishing Time of the RMGEGT Workshop in 15 Cement Projects

No.	Project name	Finishing time of civil construction work of the raw material grinding workshop (days)
1	Derba Midroc Cement Project	103
2	Pakistan Lucky Project (line 1)	123
3	Pakistan Lucky Project (line 2)	98
4	Najran Cement Project (Phase I)	110
5	Najran Cement Project (Phase II)	99
6	North Region Cement Project	90
7	Berber Cement Project	113
8	Atbara Cement Project	103
9	Al Mafraq Cement Plant	96
10	Ali Abdullah Alesayi Cement Project	107
11	Al-Douh Cement Plant	103
12	Northern Jordan Cement Plant	96
13	Pakistan Attock Project (line 1)	118
14	Pakistan Attock Project (line 2)	103
15	Fezan Wadi Alshati Mahrug Cement Project	120

Note. The information in the table is from an interview to 20 experienced engineers

Table 10

Description list of the Variables and Parameters

Symbol	Attribute	Unit	Description	Values or distribution
T1start	Parameter	day	Planned time to leave the factory	0 for 12/05/2007
T1duration	Variable	day	Duration of waiting for the delivery order in the factory	-25–58 (Uniform Distribution)
T2start	Variable	day	Start delivery date	Equal to T1end
T2duration	Variable	day	Delivery during time	49,63,81 (Triangular Distribution)
T3start	Parameter	day	Start date of the civil construction work	-15 for 11/21/2007
T3duration	Variable	day	Civil construction finishing time	90,107,123 (Triangular Distribution)
P1	Parameter	$/day	Unit inventory cost in the factory	80
P2	Parameter	$/day	Unit inventory cost on the site	160

3.3.5 Transitional outputs and the inventory cost decision rules. There are two locations where inventory time is designed to happen in the simulation model, as showed in **Figure 17**. The first inventory time happening in the factory silo depends on the "Duration of waiting for the delivery order in the factory (T1duration)," which means the time period that the precast steel structure supplier waits for the delivery order coming from the main contractor. If the duration is a value from "-20" to "-1," it means the delivery order happens before the "Planned time to leave the factory," and the inventory time in the factory will not happen and is equal to "0," because stocking the products before the planned leaving date is the responsibility of the supplier. On the contrary, if the duration value is a positive value from "1" to "58," it means the order happens later than the plan. In this situation, the inventory time will happen and it is equal to the positive value, because the main contractor intends to delay the leaving date. The simulation identifies the "Waiting time for order" in Excel to present the inventory time in the factory.

The second inventory time happening on the site depends on the time when the precast steel structure enters the site and when the civil work is completed. The entering site time is identified as the "Delivery end time" in the simulation model and represented as the "T2end" in Excel; while the civil work finishing time is identified as the "Civil work end time" and represented as the T3end in Excel. If the T2end value is larger than the "T3end" value, the inventory time on site will not happen and is equal to "0." When the precast steel structure enters the site, the civil work has been completed and the steel structure work can be directly used on the working site for the critical follow-up work of "steel structure making and erecting." On the other hand, if the "T2end" value is smaller than the "T3end" value, the inventory time on site will happen and is equal to the value of ("T3end" － "T2end"). When the precast steel structure enters the site, the civil work is under construction. The precast steel structures have to be stocked in the silo until the completion of civil work, because the civil work is on the critical path and before the steel structure making and erecting work as showed in Figure 3. The simulation identifies the "Waiting time for T3end" in Excel to present the inventory time in the silo on site.

3.3.6 Simulation data and results. According to the above discussion on the inputs, decision rules, and logical relationship on the supply chain, the simulation model is established in Excel and operated by the MonteCarlito simulation tool. **Figure 19** is the Excel spreadsheet for the simulation.

Inventory cost Simulation Model								Summary Statistics								
								Number n	100							
T1 order duration (Uniform Distribution)				Planned start leaving dat	12/05/2007	0		Number Waiting in the facto	81			MonteCa	day	day	$	%
Smallest	-20							Probability of Waiting in fac	0.81			avg waiting time in th		waiting time on	avg TIC	Prob >4800
Largest \	58			T3 Start date	11/21/2007	-15		Average Waiting Time in fac	23		1	-400	23.00	13.25	3972.80	24.00%
								Number Waiting > 10 days	62			Mean	21.20	14.24	4016.66	23.33%
T2 duration (Triangular Distribution)				Unit cost in the factory	80							Standard er	0.10	0.08	8.06	0.20%
Lower	49							Number Waiting on site	56		2	Median	21.00	14.21	4023.20	23.00%
likely	63			Unit cost on the site	160			Probability of Waiting on si	0.56		3	Standard	1.95	1.58	161.21	4.03%
Upper	81							Average Waiting Time on si	13.25		4	Variance	3.80	2.49	25988.11	0.16%
				Planned inventory cost	4800			Max Waiting Time on site	63		5	Skewnes	0.17	0.11	0.17	12.58%
T3 duration (Triangular Distribution)											6	Kurtosis	2.95	3.17	3.11	319.04%
Lower	90							Average IC1	1685.44							
likely	103							Average IC2	2120			-CI	17.2952692	11.08946232	3694.2474	14.824389504989700%
Upper	123							Average TIC	3972.8			+CI	25.09	17.40	4339.08	31.825610495010300%
								Number TIC>4800	24							
Simulation								Probability of over burget	0.24							
	T1Start	T1Duration	T1End	Waiting time for order	T2Start	T2Duration	T2End	Waiting for T3 End	T3Start	T3Duration	T3End	IC1	IC2	TIC		
1	0	-7	-7	0	-7	49	42	46	-15	103	88	0	7360	7360		
2	0	16	16	16	16	66	82	6	-15	103	88	1280	960	2240		
3	0	27	27	27	27	69	96	6	-15	117	102	2160	960	3120		
4	0	52	52	52	52	59	111	0	-15	97	82	4160	0	4160		
5	0	-4	-4	0	-4	58	54	27	-15	96	81	0	4320	4320		
6	0	41	41	41	41	56	97	0	-15	102	87	3280	0	3280		
7	0	49	49	49	49	66	115	0	-15	97	82	3920	0	3920		
8	0	40	40	40	40	68	108	0	-15	92	77	3200	0	3200		
9	0	31	31	31	31	68	99	0	-15	111	96	2480	0	2480		

Figure 19. Data and results of simulation.

At first, the simulation model randomly extracts 600 samples (from 1 to 600 in Column A). The results of the last 100 samples (501–600) are chose as the stable values to calculate the important output in the column of summary statistic. And then, four critical performance measures related to inventory cost are selected to put in the MonteCarlito simulation tool. They are “average waiting time in the factory (23),” “average waiting time on the site (13.25),” “average total inventory cost (3972.8),” and “the probability of total inventory cost more than 4800 USD (24%).” Overall, the simulation runs the four results 400 times by the MonteCarlito tools and the simulation results are obtained in **Figure 20.** After running the MonteCarlito simulation for 400 times, the mean (X) and standard deviation (SD) of the four performance measures are obtained, which are highlighted in Figure 20. By the results of the X and SD, the confidence interval (CI) can be calculated as showed in Figure 20. The calculating methods and the discussion based on the CIs will be described.

	MonteCarlito	day	day	$	%
		avg waiting time in the factor	avg waiting time on site	avg TIC	Prob >4800
1	-400	23.00	13.25	3972.80	24.00%
	Mean	21.20	14.24	4016.66	23.33%
	Standard error	0.10	0.08	8.06	0.20%
2	Median	21.00	14.21	4023.20	23.00%
3	Standard devia	1.95	1.58	161.21	4.03%
4	Variance	3.80	2.49	25988.11	0.16%
5	Skewness	0.17	0.11	0.17	12.58%
6	Kurtosis	2.95	3.17	3.11	319.04%
	-CI	17.29526924	11.08946232	3694.24744	14.824389504989700%
	+CI	25.09	17.40	4339.08	31.825610495010300%

Figure 20. Simulation results of four performance measures of average waiting time in the factory silo, average waiting time in the site silo, average total inventory cost (avg TIC) and probability of the inventory cost higher than 4,800 USD (Prob>4800).

3.3.7 Discussion of results. The CI can indicate that the true mean of the performance measure is a value between the intervals with 95% confidence. For the first three performance measures about time and cost, the CI can be calculated through the simulation results of mean (X) and standard deviation (SD) by Formula 1. For the fourth performance measure about the probability of inventory cost higher than 4,800 USD, the CI can be calculated through the simulation results of mean (P) by Formula 2

$$CI_{(\text{time or cost})} = X \pm t_{(0.05,99)}\,\sigma_X = X \pm 2SD \quad (1)$$

$$CI_{(\text{prob})} = P \pm z_{(0.975)}\,\sigma_P = P \pm 2\sqrt{P(1-P)/99} \quad (2)$$

For the performance measure of "average waiting time in the factory", Figure 20 shows that the X is equal to 21.20 and the SD is equal to 1.95, so the CI is between 17 and 25. It means that we have 95% confidence that the true mean of the "average waiting time in the factory" is between 17 days and 25 days. Using the same method, Figure 20 includes the calculated CIs for each performance measure. The CI of "waiting time on the site" is between 11 and 17; and it indicates that we have 95% confidence that the true mean of waiting time on the site is between 11 days to 17 days. The CI of "average of "TIC" is between 3694 and 4339; it can be explained that we have 95% confidence that the true mean of the TIC is between 3694 USD and 4339 USD.

Based on Formula 2, the CI of “the probability that total inventory cost more than 4800” is between 14.82% and 31.83%. It indicates that we have 95% confidence that the true mean of the probability exceeding the planned total inventory cost is between 14.82% and 31.83%.

The validation refers to testing the computer program to ensure the simulation is correct. Specifically, it is also a check to see whether the simulation adequately represents the real system (Chase, Jacobs, Aquilano, & Ren, 2006). The CI of the “inventory time in the factory” indicates that the main contractor made an incorrect decision to order the first batch of precast steel structure earlier than plan **as showed in Table 8**. Moreover, the first column of **Table 8** also shows the actual inventory time in the factory happened to the follow-up 10 batches of precast steel structure in the real case. The range of the actual inventory time of these 10 batches of precast steel structure is from 15 days to 24 days, and the inventory time 15 days only occurred once. In other words, the range of the actual inventory time of the precast steel structure in the factory is very close to the CI result (17–25) calculated by the MonteCarlito simulation tool.

The confidence interval of average waiting time in the factory (17–25) can indicate that the main contractor has enough time to adjust the delivery plan when the previous critical work is delayed. It also tells the main contractor that hurrying the suppliers to complete producing materials earlier than the planned schedule is not advisable. When the main contractor plans to delay the leaving date, it should give more time to the suppliers to complete the production. Extending the production time between the confidence interval will not influence the project schedule, and it can increase the production quality and enhance the relationship with the suppliers. Meanwhile, the confidence interval suggests that the main contractor should negotiate with the supplier to extend the time that the inventory is free in the factory before signing the contract. In this case, if the free time had been extended to 26 days (12/31/2007), the inventory cost in the factory would have decreased significantly.

Generally speaking, it is very hard to make just-in-time delivery in international EPC projects, so stocking products on the construction site is very common. The confidence interval of waiting on the site (11–17) is an accepted range for project management. Especially when some materials are not available enough in the market, stocking a certain amount of such materials is very necessary in practice. When establishing the construction schedule, two or three weeks' inventory safety backup should be considered, and it is very common to see in the real project.

The confidence interval of the average waiting time on the site (11–17) indicates that decreasing the civil work duration time is a very useful and direct method to reduce inventory cost on the site. If we want to complete the civil work in a shorter time, the main contractor should increase the working productivity of the civil work sub-contractor

The confidence interval of the average total inventory cost (3,839–4,175) indicates that there is 95% confidence that the true mean of the total inventory cost will not exceed the planned total inventory cost (4,800). Not only that, we also have 95% confidence that the true mean of total inventory cost will be less than the plan. The results tell us that the main contractor can prepare a low-cost plan with less predicted inventory cost. It is very helpful to decrease the bidding price when negotiating with the owner to win a project. It is also benefit to increase the profit due to the low-cost plan.

3.3.8 Sensitivity analysis. The simulation model for the supply chain of precast steel structure undergoes sensitivity analysis to determine how the three variables—T1duration, T2duration and T3duration—affect the total inventory cost in the two locations. To conduct the sensitivity analysis with respect to these three variables, three different scenarios are considered to each variable. The three scenarios of T1duration are "likely duration," "bad duration," and "good duration." The three scenarios separately for T2duration and T3duration are "good duration," "middle duration," and "bad duration." These different scenarios for each variable are showed in Table 11.

Table 11

The Scenario and its Draft Description of the T1duration, T2duration, and T3duration

Variable	Scenario code	Scenario name	Distribution	Values
T1duration	T11	Likely duration	Uniform	-20–58
	T12	Bad duration	Uniform	-20–0
	T13	Good duration	Uniform	10–30
T2duration	T21	Good duration	Triangular	49, 55, 60
	T22	Middle duration	Triangular	61, 63, 70
	T23	Bad duration	Triangular	71, 76, 81
T3duration	T31	Good duration	Triangular	90, 96, 101
	T32	Middle duration	Triangular	102, 103, 110
	T33	Bad duration	Triangular	111, 118, 123

3.3.8.1 T1duration. The first factor to be investigated was the duration waiting the delivery order from the main contractor. T1duration is based on uniform distribution with the range -20–58. It means that the duration can be any value in this range. In other words, it is the most likely range. So the "likely duration" for T1duration is -20–58. The "bad duration" is identified as the initial transportation dates that may cause the total inventory cost to exceed the plan. According to the case study, when the precast steel structure left the factory 17 days earlier than plan, the total inventory cost exceed the plan. So "bad duration" is identified to be the range -20–0. The "good duration" is identified as the initial transportation dates that may not cause the total inventory cost over budget. **Table 8** shows the range of inventory time in the factory from the second batch of precast steel structure to the last batch is from 15 to 24, and the total inventory cost that happened in the two locations did not exceed the plan in the practice. Considering more possible dates that may satisfy the situation of "good duration," this range is identified to be 10–30.

3.3.8.2 T2duration. The second factor to be investigated was the "delivery during time," which obeys the triangular distribution with the mode of 63, upper limit of 81, and the lower limit of 49. Three different scenarios about duration are established to contact the sensitivity analysis. The first scenario is the "good duration," which means that the precast steel structure is delivered from factory to site within a shorter time. It also obeys triangular distribution and needs three values to identify the distribution. Based on the real project data in **Table 8**, the shortest time delivering from factory to site is 49 days and the mode is 63 days. So the lower limit and upper limit for "good duration" are identified to be 49 and 60. The mode of "good duration" is identified as the value of 55 because the T2duration is 55 days for the first batch of precast steel structure. The other two scenarios are the "middle duration," and the "bad duration," which mean that the precast steel structure is delivered from factory to site within a normal time and a long time. The identification of the three values for the "middle duration" and the "bad duration" triangular distribution applies the same method to the "good duration" and also refers to the real project data in **Table 8**. So the "middle duration" obeys the triangular distribution with the mode of 63, the upper limit of 70 and the lower limit of 61; the "bad duration" obeys the triangular distribution with the mode of 76, the lower limit of 71 and the upper limit of 81.

3.3.8.3 T3duration. There are also three different scenarios for the T3duration: "good duration," "bad duration," and "middle duration." All of these three durations obey the triangular distribution and are identified through applying the real project data in **Table 9**. The "good duration" means a short time to finish the civil work of the raw material grinding workshop, the "middle duration" means a normal time to finish the civil work, and the "bad duration" means a long time to finish the civil work. Based on the data in **Table 9** from 15 different cement projects, the lower limit, mode, and upper limit of each triangular distribution are identified. The method used to identify the three values is the same as the

T2duration. So the "good duration" obeys the triangular distribution with the mode of 96, the upper limit of 101, and the lower limit of 90; the "middle duration" obeys the triangular distribution with the mode of 103, the lower limit of 102, and the upper limit of 110; and the "bad duration" obeys the triangular distribution with the mode of 118, the lower limit of 111, and the upper limit of 123. Finally, each scenario and its description are showed in **Table 11**.

Selecting one scenario from each of the three variables and combining these three scenarios will construct an integrated plan within three variables, so there are 27 different plans in total. Responding to each plan, the mean of the total inventory cost can be obtained by the MonteCarlito simulation tool. **Figure 21** shows the result of the mean of the total inventory cost from the 27 plans.

T1 scenario		T2 scenario		T3 scenario	Mean of TIC by MonteCarlito
T11 (-20,58)		T21 (49,55,60)		T31 (90, 96, 101)	3931
				T32 (102, 103, 110)	4894
				T33 (111, 118, 123)	6451
		T22 (61,63,70)		T31 (90, 96, 101)	3103
				T32 (102, 103, 110)	3852
				T33 (111, 118, 123)	5179
		T23 (71,76,81)		T31 (90, 96, 101)	2368
				T32 (102, 103, 110)	2957
				T33 (111, 118, 123)	3963
T12 (-20,0)		T21 (49,55,60)		T31 (90, 96, 101)	5760
				T32 (102, 103, 110)	7250
				T33 (111, 118, 123)	9221
		T22 (61,63,70)		T31 (90, 96, 101)	4159
				T32 (102, 103, 110)	5645
				T33 (111, 118, 123)	7629
		T23 (71,76,81)		T31 (90, 96, 101)	2344
				T32 (102, 103, 110)	3834
				T33 (111, 118, 123)	5814
T12 (10,30)		T21 (49,55,60)		T31 (90, 96, 101)	2678
				T32 (102, 103, 110)	4055
				T33 (111, 118, 123)	6023
		T22 (61,63,70)		T31 (90, 96, 101)	1790
				T32 (102, 103, 110)	2580
				T33 (111, 118, 123)	4427
		T23 (71,76,81)		T31 (90, 96, 101)	1600
				T32 (102, 103, 110)	1709
				T33 (111, 118, 123)	2711

Figure 21. The result of the mean of the total inventory cost from the 27 plans

Based on the results in Figure 21, three pictures used for sensitivity analysis can be drawn out. The three pictures show the influences from the T2duration and T3duration on the total inventory cost when keeping the T1duration as a specific situation. For example, Figure 22 shows that the total inventory cost mean value is affected by different scenarios of T2duration and T3duration when keeping the T1duration as the situation of “likely duration.” Figures 23 and 24 show the same things but are based on the different T1duration scenarios: “bad duration” and “good duration.”

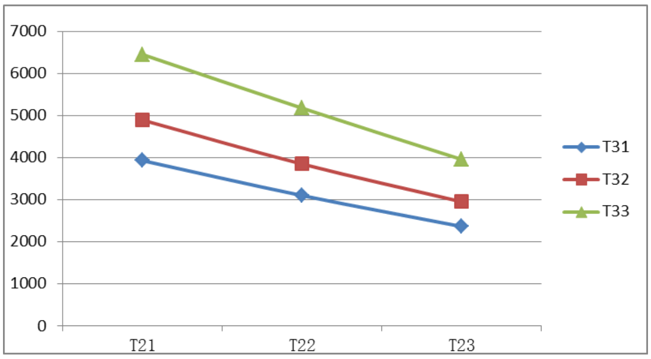

Figure 22. Effect of delivery time on total inventory cost (for T1duration between -20 and 58)

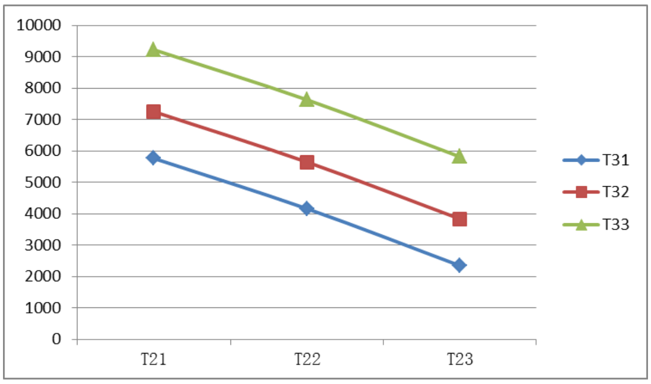

Figure 23. Effect of delivery time on total inventory cost (for T1duration between -20 and 0)

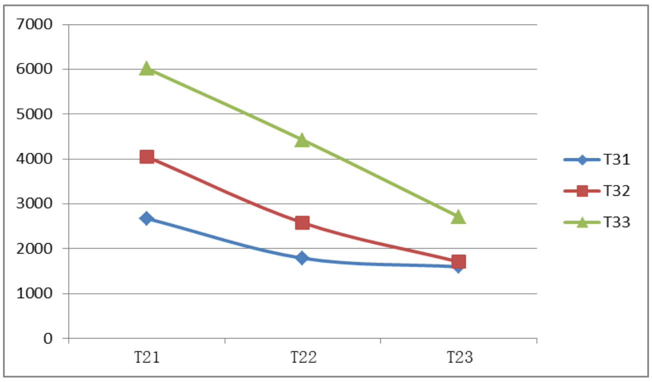

Figure 24. Effect of delivery time on total inventory cost (for T1duration between 10 and 30)

3.3.8.4 Common characteristics. In Figure 22, the three triangle values with green color represent that as the "delivery during time" changes from "good duration" to "bad duration," the total inventory cost will decrease. The decreasing trend applies to all of the three situations of the "civil work during time" (T3duration). Not only that, the trend also applies to the Figure 23 and 24 when the T1duration is in the situation of "bad duration" and "good duration". So when the previous critical work is delayed, changing the T2duration from "good duration" to "bad duration" can decrease the total inventory cost. In other words, if the civil work is delayed in starting, increasing the precast steel structure "delivery during time" can decrease the total inventory cost. It is very helpful to the main contractor to have an idea that less delivery time sometimes may cause more inventory cost. On the other hand, if the "delivery during time" increases to a value that is more than a given threshold, the precast steel structure would be seriously delayed in getting to the site, and the inventory time is only equal to the time stocking in the factory. In this situation, there is no supply chain issue.

In contrast to the T2duration, as the T3duration changes from "good duration" to "bad duration," the inventory cost will increase. All of the three figures show that the red line is under the green line, but above the blue line. It other words, the civil work during time with a "good duration" always causes a lower inventory cost than the "middle duration;" and the "middle duration" always has a lower inventory cost than the "bad duration."

The T2duration and T3duration not only have different influences on the trend of the total inventory cost, but also their degrees of influence are different. As the T2duration increases to a "bad duration," the inventory cost will decrease, but the rate of decrease becomes progressively smaller; however, as the T3duration increase to a "bad duration," the inventory cost will increase, and the rate of increase becomes progressively bigger because the distance between any two lines becomes progressively larger as showed in Figure 25. From this perspective, when the previous critical work is delayed is starting, the total inventory cost is influenced by the T3duration more largely than the T2duration.

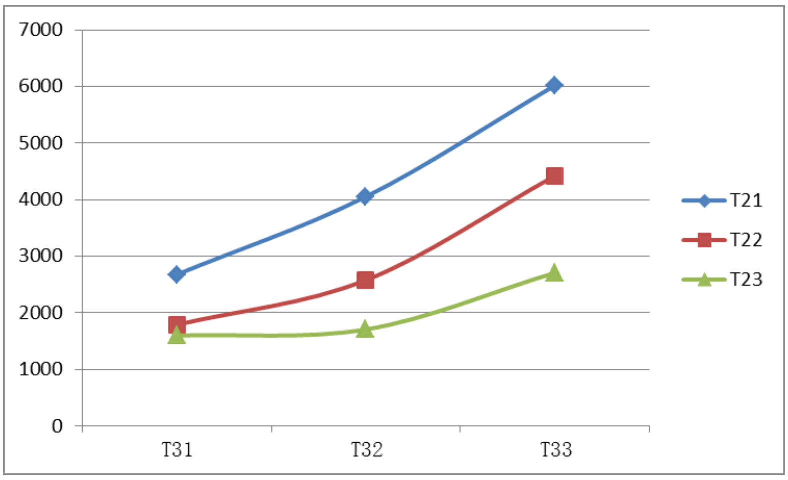

Figure 25. Effect of construction time on total inventory cost (for T1duration between 10 and 30)

3.3.8.5 Specific characteristics. When comparing the average of total inventory cost among Figure 22, 23, and 24, the highest one comes from the "bad duration" of the variable T1duration. Figure 23 shows that as the T1duration decreases to the "bad duration" and the T3duration increase to the "bad duration," the highest inventory cost situation occurs. It is very helpful to tell the main contractor that it is likely that the earlier delivery plan will increase the inventory cost, especially when the previous critical work is delayed in starting. The sensitivity analysis for T1duration also reflects the mistake that happened in the real case. Figure 23 shows all the situations in which the precast steel structure leaves factory without inventory cost. In other words, the total inventory cost only depends on the inventory cost on the site. Therefore, the total inventory cost is caused by T2duration and T3duration in this situation. Due to the highest total inventory cost happening in this situation, we can see the degree of influence by the T3duration and the T2duration is higher than the T1duration's. Because we have known that the degree of influence by the T3duration is higher than T2duration, we can conclude that T3duration has a highest influence degree to the total inventory cost.

Figure 24 shows that as the T1duration increases to the “good duration” and the T3duration decreases to the “good duration,” the lowest inventory cost situation happens. It is very helpful to the main contractor to make a decision about how to adjust the delivery plan and construction schedule. Figure 24 also very clearly shows that as the T2duration increases to the “bad duration,” the inventory cost may decrease to be a constant value. This constant value is zero, and it is only an expected value under the ideal state.

3.4 Relationship Management Analysis

3.4.1 Introduction. Returning to procurement process in the case, we can see the delayed arriving at site of steel bar is the blasting fuse for the whole overspend inventory cost. The inventory cost of the steel bar resulted from the bad relationship with the original import agent, which is generally described in the section of 3.3.1. The detail content about the high inventory cost and the bad relationship is introduced in the following paragraphs.

As planned, the procurement for the steel bar started in the middle of May 2007. CNBM gave the order that CSBC must deliver the cargo to the Shanghai port on 07/10/2007. The steel bars were delivered to the port on that day, and on the same day EASH received the cargo and started to transact custom clearance and arrange the shipment. The steel bars were lifted onto the ship within six days and delivered out of the port on 07/17/2007. The ship reached the Djibouti port on 08/18/2007, but the original import agent did not receive and verify the steel bars until the ship had to leave the port on 08/30/2007. After unloading the steel bars in the Djibouti port, the original import agent did not transact the custom clearance for these steel bars, although the agent had been given all of the related documents before the ship entered the port. The steel bars stayed on the port until 11/15/2007 and entered the site on 11/20/2007. The agent delayed the transaction and transportation nearly 75 days, which resulted in a large amount of unplanned inventory cost in the Djibouti port.

The main reason for the import agent to refuse to do its job was the bad relationship with the main contractor. Except for custom clearance and transportation, the original import agent company also contracted part of the work of “leveling and grading temporary road and construction site” and arranged a large number of workers and machines to work on the site. When the work was handed over to CNBM on the site, the original import agent company and CNBM had a big disagreement about how much the agent company had completed. CNBM refused to approve the quantities done by the agent company and refused to pay for it, because the working quantities reported by the agent company were actually false. On the other hand, CNBM agreed to pay for the other company that did the leveling and grading work as well. The original import agent company was very unsatisfied with CNBM’s decision and thought CNBM had broken their cooperating relationship. CNBM required the agent to transact the custom clearance for the steel bar cargo firstly and then talked about the payment for leveling work; however, both parties lost trust in each other at that point. CNBM tried to restart collaboration with the agent, but the agent refused to communicate with CNBM and declined to solve the problems of custom clearance. Therefore the inventory cost in the Djibouti port increased to a number that exceeded estimates.

The delayed arriving of the steel bar did not only influence the civil construction work; all of the subsequent critical work had to be delayed. For this reason, CNBM had to adjust the construction schedule to catch up on the schedule in order to complete the construction work as early as possible. However, CNBM ignored the potential increasing inventory cost in the near future and blindly ordered the other products to be delivered to the site as soon as possible.

From the detailed description of the case, we can see improving the relationships between the main contractor and suppliers (products suppliers or service suppliers) has a positive impact on the performance of the supply chain. A bad relationship can make huge trouble for a project, while a good relationship can repair the trouble. This becomes vital for international EPC main contractor companies, which have to deal with varied work including social, economical, and cultural work.

To improve the relationship management, this thesis firstly sets up a general framework including supplier selection, supplier management and supplier improvement **(Figure 26)**. Six key elements under the supplier management are selected and put together with supplier selection and supplier improvement to form a questionnaire about how to influence and improve the relationship management with suppliers. The questionnaire based on these eight key elements had been established and 38 interviewees had been interviewed. Next, based on the real case about the overspent inventory cost of steel bar, four related elements—trust, collaboration communication, and problem solving—are selected to the study. According to the feedback and data collected from the interview, a series of suggestions are issued in according with the four elements, which are to help the main contractor to build, control and manage the relationship with suppliers.

3.4.2 Relationship management framework. The key to establishing effective relationships is whether each party can overcome its strong concept of project focus and incorporate what has proven to be essential for adding value in relationships (Hartmann & Caerteling, 2010). Based on that, the framework is established. In the supplier selection, hard and soft evaluation factors are seen as the criterions to choose suppliers. The hard factors contain price, quality, completing time and delivery speed. On the other hand, the soft factors include cooperation history, reputation, ownership and culture and so on. Supplier improvement include four approaches: learning mechanism, measurement, joint efforts, and supplier participation. This thesis mainly focuses on the analysis of supplier management.

Through studying the case about the overspent inventory cost of steel bar, we can see the bad relationship between CNBM and the agent company was mainly due to the poor performance of trust, collaboration, communication, and problem solving.

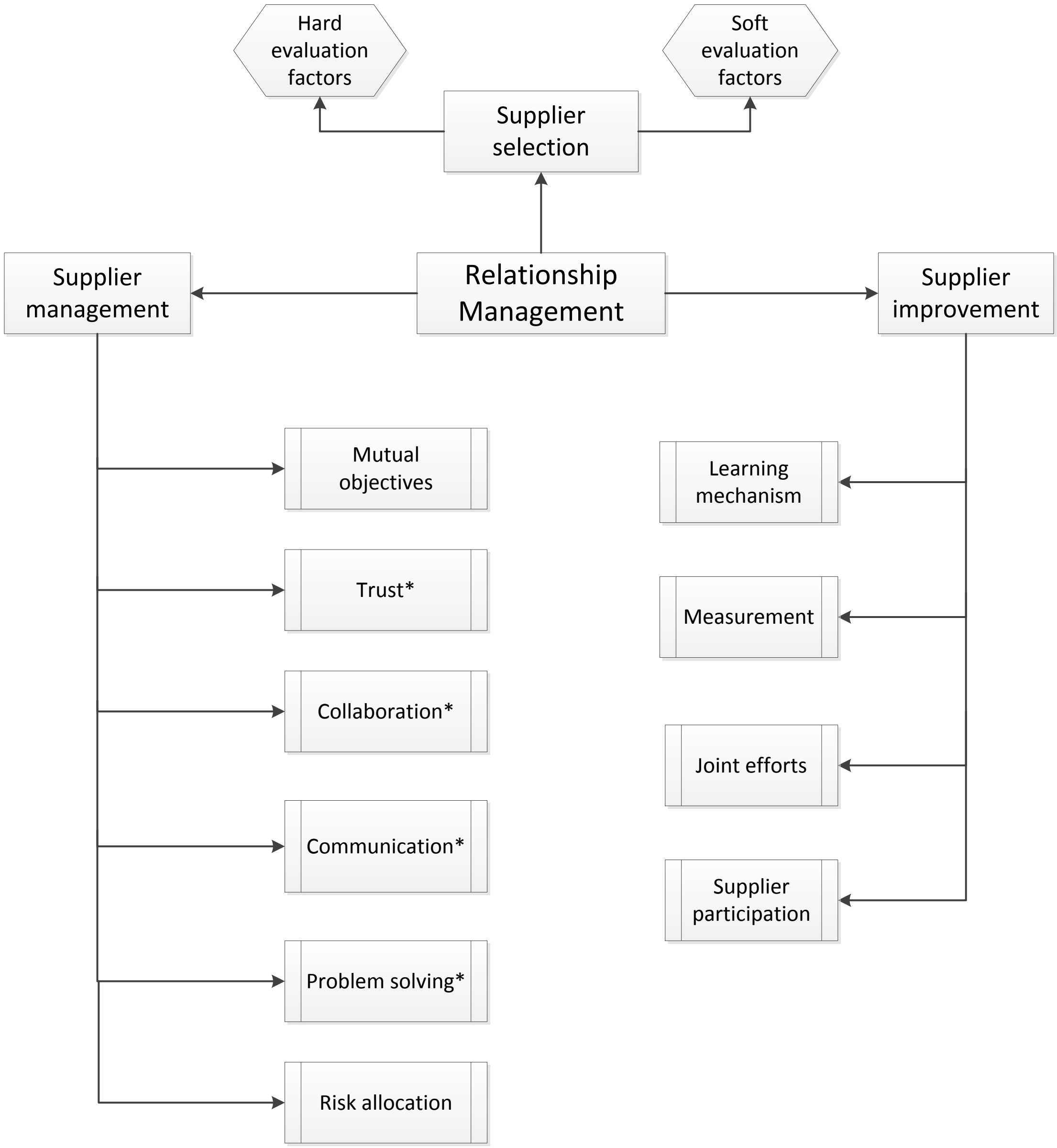

Figure 26. The framework of relationship management research. Trust, Collaboration, Communication, and Problem solving under the supplier's management are used to study for improving relationship with supplier based on the case.

3.4.2.1 Trust. Based on trust in international EPC projects, the main contractor often signs a long-term strategic cooperation agreement with some critical suppliers, such as main plants suppliers, in order to guarantee procurement performance. The agreement establishes some procurement conditions and details including price, delivery time, quality guarantee, and service for future cooperation (Khalfan et al., 2007). There are two promises to set up this kind of agreement. One is that cooperation has continual development with long-term and frequent business interactions. The other is that cooperation should be based on double win and risk sharing. From the perspective of the main contractor, the trust-based agreement is beneficial because it decreases the cost in the beginning of projects in the way of saving the money for tender and reducing the rate of down payment to suppliers. The suppliers also gain the future sales opportunities in the competing market through the agreement. At the same time, the two parties should work together to control and manage risk in the procurement process through reasonable estimation, effective communication, and timely information sharing. But in practice, strategic agreement is a kind of high level agreement without many detail conditions and concrete regulations, so the agreement should be operated based on a more trust attitude when some special issues happen.

3.4.2.2 Collaboration. A collaboration relationship is based on a collaboration attitude between each other. The main contractor should believe that the suppliers can achieve mutual objectives before starting work. Once some difficulties or reverses happen, the main contractor should work with suppliers to figure out the problems without placing blame. Suppliers also should use the joint attitude and effort to overcome difficulties and improve performance. There are two important factors to develop collaboration attitude: the trust attitude before working and the no-blame attitude after working.

3.4.2.3 Communication. The approach often used by the main contractor in communication in EPC projects is the coordination of internal communication and external communication (Baiden et al., 2006). An internet communicating platform is often set up in the main contractor's headquarters for external information exchange with each supplier. Meanwhile a company's internal information flow platform and an information database are also often set up for procurement management. There are two functions to suppliers' relationship management through internal communication. The first one focuses on transforming clear information to other project coordinators in order to achieve seamless communication with suppliers; the other one addresses taking files for each important communication. For example, the technical coordinator delivers the inspecting information to the logistic coordinator in the internal communication system and takes the files into the database. Subsequently, the logistic coordinator will contact the suppliers for transportation issues in the external communication system. Therefore, the external and internal communications work together in procurement management for relationships' development.

3.4.2.4 Problem solving. Based on trust and no-blame cooperative attitude, the main contractor should join suppliers together to solve problems happening during project operation. There are various problems that may occur in the procurement process, such as disqualification of production, delaying for beginning delivery, lacking of parts when productions enter the site and so on. Each problem is caused by two parties at least, so a joint team should be formed by experienced engineers and decision makers for figuring out problems. The joint team should have the right to make direct and final decisions to problem solving approaches. So the problems can be solved in one place and at one time, which saves time through decreasing the solving process.

The joint team constituted by the main contractor and one supplier should set up a learning mechanism for summarizing the experiences of how to solve problems. At the same time, both parties should identify the effectiveness resulting from the solving approaches. The effective approaches are very useful in the case that the same problems happen again. In addition, the joint team will hold regular meetings for anticipating possible problems which may happen in the future. For example, the main contractor may mention some important milestone issues to suppliers in order to let them complete them in due time. Suppliers may contact the main contractor for payment at the right time for the sake of influencing production.

3.4.3 Interview method. Relationship management problems are ever-changing and ever-evolving for international EPC main contractor companies. It should be addressed through ever-learning methods including surveying and interviewing methods. This thesis suggests the following questions should be developed on the trust, collaboration, communication, and problem solving.

3.4.3.1 Interview questions. There are four kinds of questions about supply chain management in relationship between main contractor and suppliers in the interview: interviewee information, project information, project completion information and relationship management. After confirming the relationship management questions discussed above, the author tried to identify the interview target and field, so the questionnaire added some other basic questions about interviewees and projects into the interview. In addition to that, the author designed the questions about project completion information and relationship management projects to be answered under three different types of projects that might be experienced by the interviewees: Project 1(highly successful), Project 2(moderately successful) and Project 3(not successful). In this way, each interviewee can answer the questions based on different experienced projects, and the function of each relationship management indicator applied in comparable projects can be seen clearly.

3.4.3.2 Interviewee. There are 38 interviewees coming from 13 companies involved in the interview. All of them are working in Chinese Government Owned Enterprises with different working fields. Each interviewee was asked to answer the basic personal information and project information before entering into the essential interview. And then, they were invited to answer the questions about project completion information and relationship management based on three kinds of projects. But due to some interviewees lacking enough experiences, not all the interviewees could answer the whole questions under all three categories, and they preferred to answer the questions under one or two categories. Through statistical analysis on the interview results, there are 30 interview results responding to Project 1(Highly successful), 24 results for Project 2(Moderately successful) and 11 results for Project 3(Not successful).

3.4.3.3 Interview results. The interview results are shown in **Figure 27**. The questions under each of four key elements are answered based on 3 kinds of projects. As summarizing above, there are 30 interviewees taking part in the interview about highly successful projects, 24 interviewees for moderately successful projects and 11 for not successful projects. In addition, there are 12 questions covering the four key elements. The possible answers to each question are 1 for strongly disagree, 2 for disagree, 3 for neutral, 4 for agree and 5 for strongly agree.

The statistic results show the number how many interviewees choose their preferred answers to each question under each kind of project. For example, for the question 13 under Project 1, there are 30 interviewees providing their answers and the interviewees’ number choosing from 1 to 5 are 0, 16, 4, 8 and 2, while question 14 under the same type of Project 1 has a different result: 0, 2, 12, 13, and 3. In this way, the results of each question for each indicator of relationship management can be compared under the same type of project, and then some conclusions can be achieved to illustrate which factors are critical to improve the indicators of relationship management.

Supplier Management	Project 1(Highly Successful) : 30					Project 2 (Moderately Successful) : 24					Project 3 (NOT Successful): 11				
	1(a)	2(b)	3(c)	4(d)	5(e)	1(a)	2(b)	3(c)	4(d)	5(e)	1(a)	2(b)	3(c)	4(d)	5(e)
Trust															
13. Do you prefer informal relationship based trust to contractural trust in managing your supply chain?	0	16	4	8	2	0	12	4	8	0	0	6	3	2	0
14. Did you assess the received information from your suppliers as reliable?	0	2	12	13	3	0	1	13	9	1	0	0	6	5	0
15. Did a high degree of trust exist in the supply chain?	0	2	6	21	1	0	0	11	13	0	0	2	3	6	0
Collaboration															
16. Did a cooperational/collaborational working relationship exist between you and your suppliers?	1	1	0	23	5	0	2	2	15	5	0	1	2	6	2
17. Did parties not blame each other when problems occurred?	1	13	9	7	0	0	15	6	3	0	0	8	2	1	0
Communication															
18. Was communication between you and your suppliers open and effective?	0	0	1	22	7	0	0	2	19	3	0	1	0	7	3
19. Did you share learning and innovation with your suppliers?	0	7	4	18	1	0	7	4	12	1	0	1	1	8	1
20. Did you and your suppliers have the cost data transparency or open book costing?	8	7	7	8	0	7	6	5	6	0	2	2	3	4	0
21. Were there any informal communications, such as dinners, private parties, etc. between you and your suppliers, besides the formal communications?	1	7	8	11	3	0	6	7	10	1	0	4	2	5	0
Problem Solving															
22. Did you and your suppliers have an early warning mechanism to bring issues to the surface when a problem was first anticipated or encountered?	1	5	5	18	1	0	3	7	14	0	2	1	4	4	0
23. Was the problem solving mechanism between you and your suppliers effective?	0	1	8	20	1	0	1	10	13	0	2	0	3	6	0
24. Did you and your suppliers have a learning mechanism to avoid the problem recurrence?	0	6	7	15	2	1	3	8	11	1	1	0	3	7	0

Figure 27. Interview questions and results of relationship management research on Trust, Collaboration, Communication, and Problem solving

The results in Figure 27 show the number of how many interviewees chose their preferred answers to each question under each kind of project. For example, Question 14 under Project 1 contains 30 interviewees providing their answers on a scale of 1 to 5. The number of interviewees who chose 1 is 0; and the number of interviewees who chose 2 is 2. In the same way, we can find that the number of interviewees who chose 3, 4, and 5 are 12, 13 and 3. However, Question 15 under the Project 1 has a different result: 0, 2, 6, 21, and 1. In this way, the results of each question for each indicator of relationship management can be compared under the same type of project, and then some conclusions can be made to illustrate which factors are critical to improve the indicators of relationship management.

At the same time, the interview results of the same question under different types of projects can also be compared by proportion because the number of interviewees involved into the interview of each type of project is different. For example, Question 14 under Project 1 has a proportion of 40% of interviewees that chose answer 3. However, Question 14 under Project 2 asks the same question but has a proportion of more than 50%, which is bigger than the one in Project 1. From this comparable result, we can see main contractor apply two different ways on assessing the information from suppliers, which may result in different results on project success. Using this kind of comparative method, some conclusions can be made to illustrate which factors are most important to improve project performance.

3.4.4 Suggestions to improve the relationships with suppliers

3.4.4.1 Trust

- The main contractor should apply supply chain management based on trust with suppliers in IEPC projects. At the same time, the main contractor should set up a certain of approaches with trust, such as signing long-tern cooperation agreement, working together for decision making and so on, to improve trust relationship.
- The main contractor had better establish clear contract clauses to regulate relevant responsibility, as well as enhancing communication for urgent and accurate information.

3.4.4.2 Collaboration

- The main contractor should establish cooperative working relationship regulation to explain some detail rules about how to work together for improving project performance, such as concrete working process about how to work together when problem come across.

- The main contractor and suppliers should focus on problems, but not blindly and contumely blame to others without considering how to figure out the problems. The quarrel and argument for problem solving can be accepted to some extent.

3.4.4.3 Communication

- The main contractor should set up an effective communication system used for sharing information with suppliers continually and urgently.
- The main contractor should set up inner regulations about information sharing degree. Responding to those useful experiences and innovations for improving performance, main contractor should actively share them with suppliers.
- The main contractor and suppliers must apply informal communication in a proper way, and use this type of communication to enhance trust relationship.

3.4.4.3 Problem solving

- The main contractor should set up a discussing policy to anticipate possible problems in regular meeting during project operation. All possible problems should be discussed in the meeting. Meanwhile, the approaches dealing with problems should be issued after meeting. Senior manager should balance all factors, such as cost, schedule, feasibility and risk level, to make the decision decide about how to deal with problems..
- When some anticipated problems happen, the main contractor may handle them as planed approaches. On the other hand, if some problems happen by chance, the main contractor should make quick response and issue applied methods with fewest decision processes. The problem solving process and principles can be added into the contract clauses or company working regulations as a continue mechanism.

- After figuring out problems, the main contractor should summary the gains from experiences and loss from interests regularly. Meanwhile, the summarized results should be learned and stored in a project database which is established in the beginning of project.

Chapter Four

Conclusion

This thesis establishes the three levels' SCOR models for MTS, MTO and ETO products. Through comparing with each two models, we can see the SCOR model level 3 of MTS and MTO are almost the same. The only difference is the MTO products have a process of "making", but the MTS products have a process of "sourcing". The SCOR model level 3 of ETO products has fewer delivery processes than MTO and MTS, because the ETO products, such as vertical mill, are delivered to the owner's country from the ETO factory directly. In addition, ETO products have more "making" processes than MTO products, because it contains an important process of engineering.

Based on the above, we can further understand that the SCOR model level 3 of these three kinds of products are almost the same at the locations of construction site, import port, and export port, so we can describe the SCOR model of one kind of product, such as MTO product, as the representative model for those three locations.

On the other hand, we also need focus on the differences in the SCOR model level 3 of the three types of products at the location of suppliers' factory. In the MTS products suppliers' factory, we should pay more attention to the process of "sourcing;" in the MTO products suppliers' factory, we should show interests in the process of "making;" and in the ETO products suppliers' factory, we should focus more on the process of "engineering."

The locations where the inventory cost may happen, the time when the inventory cost may occur, and the factors that may influence the inventory cost can be seen through the SCOR model level 3. At the locations of construction site, import port, and export port, the inventory costs of the three kinds of products almost happen at the same process, which is between the work of "verifying products" and the work of “transferring products”.

At the location of suppliers’ factory, the inventory costs of the MTO and MTS products almost happen at the same process, which is between the work of “releasing products for transportation” and the work of “receiving products for transportation”. Therefore, we also can choose one type of product, such as MTO product, to analyze its inventory cost, and time and location of occurrence.

In addition, the SCOR model level 3 also indicates that the inventory cost is likely to occur during the process between two different locations. For this reason, we should pay close attention to the delivery processes involving different locations. Moreover, SCOR model level 3 also describes the processes before the process of occurring inventory cost. These processes always play an important role to impact the subsequent inventory cost.

The MonteCallito simulation tool is applied to the supply chain performance of precast steel structure based on the inventory cost. The simulation results of the confidence interval of the mean of inventory time occurring in the suppliers’ factory and on the construction site are almost the same as the real case, which indicates that the simulation method can be applied to the supply chain performance, especially in the situation that the previous critical work is delayed to start.

The sensitivity analysis of the simulation results shows that the time for waiting delivery order and the time for delivering products have a negative correlation with the total inventory cost, which indicates that balancing the starting delivery date and the delivery time is important to control inventory cost. Besides, the sensitivity analysis shows that the time for construction has a positive correlation with the total inventory cost, and has a highest degree of influence to the inventory cost. As expected, enhancing the efficiency of construction work can decrease the construction time, and consequently inventory cost.

We can conclude that a bad relationship with suppliers may result in negative impact on supply chain. This work identifies four key elements in managing relationship—trust, collaboration communication, and problem solving—that led to unplanned inventory cost of steel bar, and applies an interview method based on a questionnaire about the four key elements. The results from 38 interviewees are refined to 10 suggestions (listed below) for the main contractor to manage, control, and improve the relationship management with suppliers. The 10 suggestions have been applied into the practice of relationship management in the international EPC projects by main contractors.

Trust
Apply supply chain management and long term cooperation approach based on trust with suppliers Establish clear contract clauses to regulate relevant responsibility
Collaboration
Focus on problems, but not blindly and contumely blame to others Accept quarrel and argument for problem solving to some extent
Communication
Set up an effective communication system for sharing information with suppliers Set up inner administrating regulations about information sharing degree Set up a normal policy to manage information sharing in a proper way
Problem Solving
Set up a discussing policy about anticipating possible problems Make quick response to problems with fewest decision processes Summary the gains and loss from experiences and share them with suppliers.

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