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CHUILIAN LIAO

SUPPLY CHAIN RISK MANAGEMENT AND THE EFFICIENCY OF ENGINEER-TO-ORDER PROJECTS

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To my family, my support and best friend.

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ABSTRACT

Purpose

The purpose of this research is to explore how supply chain risk management influences the efficiency of ETO projects, as well as provide some theoretical and managerial implications.

Design/methodology/approach

Based on the literature review involving supply chain risk management and ETO projects, two case studies of ETO companies in the construction industry were conducted to understand the relationship between supply chain risk management in ETO projects and their efficiency. A thorough comparison and analysis were conducted to respond to the research questions.

Findings

The findings show that positive preventive risk management and positive corrective risk management can improve project efficiency and positive preventive risk management and positive corrective risk management can benefit each other.

Research limitations

It is based on two cases, which means it needs to be tested if it can be generalized to a broader level. Moreover, all the interviews were conducted by the author, causing certain limitation. Furthermore, the two companies were the Type II ETO companies. It would be interesting if researches could study other types of ETO companies to further validate the conclusions.

Originality/value

This is the first study which explores how preventive risk management (PRM) and corrective risk management (CRM) influence project efficiency in terms of project functionality, project cost, construction period and project construction respectively, and how PRM and CRM influence each other. It demonstrates that PRM and CRM are quite important to project efficiency and managers can learn from corrective risk management and make better decisions in subsequent risk prevention.

Keywords: supply chain risk management; preventive risk management; corrective risk management; ETO project efficiency.

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SUMMARY

1. INTRODUCTION

Confronted with an increasingly volatile and turbulent market, rapidly changing climate and smaller decision-making timeframes, effective supply chain management of complex projects has become increasingly important due to the large quantity of uncertainties and complexities during their implementation.

Complex projects, such as construction like shipbuilding, are engineer-to-order (ETO), which involves the supply of a low volume of highly-customized products to meet specific unique customer requirements (Hicks et al., 2001; Mello et al., 2015). ETO companies serve niche markets, with few competitors and customers willing to pay a high price for a product or service that exactly attends their needs. ETO firms comprise approximately 25% of all North American manufacturers (Grabenstetter, and Usher, 2014). Moreover, according to the Bureau of Economic Analysis of the US Department of Commerce, the construction industry accounted for an average of 4.3% of GDP and 4.9% of full- and part-time employees from 1997 to 2013 (BEA, 2014).

Because of their rarity and customization, ETO companies usually do not have products or services in stock to immediately satisfy the needs of customers (Stavrulaki & Davis, 2010). It starts with a new design required by the customer order and then follows the production process. Thus, ETO projects mainly involve tendering, design, manufacture, assembly, construction and commissioning (Konijnendijk, 1994; McGovern et al., 1999; Hicks et al., 2001; Cameron & Braiden, 2004; Chen, 2006; Mello et al., 2015; Birkie et al., 2017). Supply chains of ETO projects are formed once the design of the offering has been defined, and tend to last for the entire project duration.

ETO (engineer-to-order) project management is associated with chaotic production (Gosling & Naim, 2009; Yang, 2013). The whole process of physical stages (manufacture, assembly and construction) and non-physical stages (tendering, engineering, design and process planning) is marked by high complexity and high uncertainty situations (Gosling & Naim, 2009). Sanderson & Cox (2008) showed, with

a case study, the existence of radical unpredictability of demand introduced by the design and building process. In the construction industry, Denicol (2014) indicated the need to utilize a multicriteria approach for the selection of critical suppliers. Rudolf & Spinler (2018) also showed that there is a very high inherent risk exposure associated with the nature of large-scale projects.

High levels of complexity and customization leads to higher risks (Hicks et al., 2000 a, b) in these supply chains. Many factors need to be considered while making decisions due to the dynamism and unpredictability of the ETO context (Muntslag, 1994; Cameron & Braiden, 2004; Birkie et al.,2017). Therefore, supply chain risk management in the context of ETO projects seems to be particularly relevant. The effective supply chain risk management of complex projects is becoming increasingly important, as its lack has repeatedly been identified as one of the main causes of failure of large-scale projects (Flyvbjerg, 2011) and the effective management of operations is vital for a company's survival (Kozjek, Vrabič, Rihtaršič & Butala, 2018). Hicks & McGovern (2009) explored the characteristics of ETO supply chain and mentioned that it incurs political, construction, operational, revenue, finance and legal risks, and the mitigation of these risks is quite important to a project's financial viability.

However, a literature review of 58 articles focused on supply chain risk management of complex projects showed that little attention has been given to the impact of effective supply chain risk management on the efficiency of projects, which can be assessed in terms of timely delivery of projects, within the budget, as well as smooth implementation with limited operational failures. Thus, a question emerges: ***How, if at all, does supply chain risk management influence the efficiency of ETO projects?***

The literature on supply chain risk management of complex projects demonstrates that supply chain risk management of complex projects can be divided into four parts: measurement, preventive strategies, corrective strategies and subsequent preparation. Compared with preventive risk management (measurement and preventive strategies), corrective risk management (corrective strategies and subsequent preparation) research

has been largely ignored, representing less than 20% of the whole body of published supply chain risk management research. Moreover, there are few studies on the relationships between preventive risk management and corrective risk management, and how they influence the efficiency of ETO projects.

Therefore, the specific objectives are:

1) Understand the importance of preventive risk management for the efficiency of ETO projects;

2) Understand the importance of corrective risk management for the efficiency of ETO projects;

3) Explore the relationship between preventive and corrective risk management in ETO projects.

In order to carry out such an investigation, the definition of all the components of preventive and corrective risk management, as well as the corresponding phases of ETO projects, is reviewed. The intention is to have a basic knowledge of supply chain risk management in ETO projects. Also, research involving supply chain risk management and the efficiency of ETO projects is reviewed to know more about their connection and integration. Then, two case studies of ETO companies in the construction industry were conducted to further understand the relationship between supply chain risk management in ETO projects and their efficiency. A thorough comparison and analysis were conducted to respond to the three specific objectives mentioned above. Finally, a summary with some conclusions on the objectives is used to create propositions to be investigated in future research.

Despite the growth and importance of ETO projects, most of the published supply chain management research has failed to attend the needs of the ETO sector (Gosling & Naim, 2009; Yang, 2013; Willner et al., 2016), and limited attention has been dedicated to effective supply chain risk management. The lack of research on risk management in this context is surprising, given the complexity of the context and the

importance of supply chain risk management in general. A recent survey on the importance of supply chain risk management has shown that 90% of firms felt threatened by supply-side risks, while 60% were not confident or knowledgeable enough about supply risk issues (Snell, 2011). Many researchers also claim that further study of supply chain risk management is crucial (Marle et al. 2013; Cabral et al. 2012; Blome & Schoenherr 2011; Aqlan & Lam 2015; Ivanov et al. 2017; Kamil J Mizgier 2017; Fontoura Blos et al. 2018; Das & Lashkari, 2015). The results help address this gap in the literature and provide guidelines for practitioners.

This document is structured as follows: First, a brief contextualization and presentation of the topic and research questions are mentioned in the Introduction. Next, a literature review is presented with definitions of preventive risk management and corrective risk management, the corresponding phases of ETO projects, and integration of both supply chain risk management and ETO projects. Then, in the third section, the methodological steps used in the research are described. Following this, the principal findings are presented in the fourth section. The final section provides a discussion and summary of the research.

2. LITERATURE REVIEW

2.1 Supply chain risk management

Supply chain risk management (SCRM) is the management of risk that indicates strategic and practical insights for transient and permanent assessment. It refers to risks that can influence part of the process or efficient information flow, materials and products within a supply chain (Lavastre et al. 2014).

It focuses on measuring, mitigating and monitoring potential risks in the supply chain to reduce negative impacts of uncertainty on supply chain operations (Zsidisin & Ritchie 2008; Lavastre et al. 2014; Ojha et al. 2018; Lee et al. 2013; Dietrich & Cudney 2011; Blome & Schoenherr 2011; Aqlan & Lam 2015; Ivanov et al. 2017; Inman & Blumenfeld 2014; Das & Lashkari 2015).

The next section explores supply chain risk management in complex projects based on a literature review of 58 articles (published over the last 20 years, 1998-2018), which address both empirical and theoretical studies on risk management and complex projects. The focus was articles written in English, retrieved from the EBSCO platforms and Google Scholar databases, with the English descriptors, "complex projects", "complex product systems", AND "risk management", "enterprise risk management", "event risk", "ambiguity risk", "viability risk", "risk process", "risk analysis", "complex projects", "project continuity management", "risk in projects", "external risks", "financial risks", "technical risks" and "project resilience". The search was limited to the title and abstract. Only papers published in journals with an ABS rating greater than 3 were selected.

2.1.1 Risk measurement

Risk measurement is the evaluation of the possibility and magnitude of risks. It can be addressed from numerous different, though not mutually exclusive, aspects (Ritchie & Brindley 2007). Here the research focuses on the five main phases of risk

measurement, namely, risk identification, risk classification, risk quantification, risk analysis and risk assessment.

2.1.1.1 Risk identification

Risk identification is the process of determining possible events that could impact project objectives, and collecting potential supply risks concerned with a certain supply chain aspect (Marle et al. 2013; Lee et al 2013; Blome & Schoenherr 2011).

It has evolved a lot since its beginning. First, Davis (1993) identified three sources of uncertainty: demand, manufacturing process and supply uncertainty, in which demand uncertainty can be split into end-customer demand and demand amplification. Then, control uncertainty is added into the circle by Mason-Jones & Towill (1998). Later, Wilding (1998) introduced a sixth source of uncertainty - parallel interaction. In 2005, Prater delved deeper into the complexity model of Geary et al. (2002), highlighting four macro uncertainties and identifying eight micro uncertainties, which are grouped into a seventh uncertainty - decision complexity. Van der Vorst and Beulens (2002) mentioned four further uncertainties caused by chain configuration, infrastructure and facilities, order forecast horizon, information technology complexity and human behavior.

In addition, many researches concern some specific risk identification, such as risk of single sourcing (Rajesh et al. 2015), risk of project design and project culture (Van Marrewijk et al. 2008; Flyvbjerg et al. 2002) and risk of counterfeiting (Dimase et al. 2016), which are out of the ordinary risks.

2.1.1.2 Risk classification

Risk classification, according to Rangel et al. (2015), refers to grouping different risks taking into account aspects like their estimated cost, possible impact, likelihood to occur, or measures to take as precautions. A clear risk taxonomy and classification can be quite helpful to understanding the multi-perspective and complex risk issues (Singhal et al. 2011). Piyush Singhal and his colleagues implemented a thorough

exploration and illustration of risk classification, classifying supply chain risk into five categories: risks related to operational characteristics, those related to market characteristics, those related to business characteristics, those related to product characteristics, and miscellaneous risks.

Many other researches have also explored the theme of risk classification. Rajesh et al. (2015) identified 12 major risks: supply chain design, forecast, procurement, technology, capacity, inventory, transportation, disruptions, delays, system, receivables, IPR. Simangunson et al. (2013) divided risks into three groups: risks from the focal company; internal supply chain risks; and external risks from outside the supply chain. In Lavastre et al. 2014, the authors made a summary of the research on risk classification and proposed some management practices for supply chain management.

2.1.1.3 Risk quantification

Risk quantification, according to the PMI (Project Management Institute) Standards Committee, is a process of evaluating the risks identified and developing the necessary data to make decisions (Nogueira et al. 2014).

Risk quantification can be achieved with risk modelling so that they can be effectively compared and prioritized. Furthermore, risk modelling can be used to identify the mitigation strategies, as well as monitor and control the risks (Aqlan & Lam 2015; Zhang et al. 2009; Timothy Ch. U. Kalu, 1999; Dillion et al. 2005; Soo-Haeing & Eppinger 2005; Garber & Paté-Cornell 2012). Researches about risk modelling are focused on improving or optimizing the process of quantification and performance. For example, in order to improve organization performance predictability and shorten the process duration of a collaborative product development project, Zhang et al. (2009) described an agent-based integrated simulation model representing human behavior, organizational interaction, and task networks. Dillion et al. (2005) presented a dynamic advanced programmatic risk analysis and management (DAPRAM) model aimed at optimization of resource allocation during project development. Comparing

with developing models for some specific phase or project, Soo-Haeng & Eppinger (2005) proposed a design structure matrix model for better project planning and control, and applied the model as a tool for project management by extending the previous model design process analysis.

2.1.1.4 Risk analysis

Risk analysis is a process of prioritization according to its probability and impact, with the tool of risk evaluation categorization in terms of criticality. The most widely used method of risk analysis is probabilistic analysis, which can describe uncertainty arising from stochastic disturbance, variability conditions and risk considerations (Blackhurst et al. 2004). The result of risk analysis is usually presented in the form of a list or graph, enabling decision-makers to categorize them in terms of an indicator – high, medium or low (Marle et al, 2013).

Even with the advent of more and more authentication methods, in a resource-limited environment, a risk-based prioritization approach becomes critical (Dimase et al. 2016). Also, it is necessary for risk analysis methods to advance in parallel to novel technologies.

2.1.1.5 Risk assessment

Risk assessment is the process in which managers analyze the potential impacts on the organization, and assess the adequacy of existing security and controls relative to the potential threats to the organization. Managers should identify the related threats, and manufacturers should quantify the potential impacts with models and present probability distribution. With effective risk assessment, management can better understand risk sources, and stipulate an appropriate migration plan and re-evaluate the consequences (Lee et al. 2013; Dietrich & Cudney 2011). Krishnan et al. (2009) explored through introduction of a facility layout problem, and concluded that the risk assessment procedure and the layout generation have mutual benefits for each other. Loutchkina et al. (2014) unfolded a novel system integration technical risk assessment model (SITRAM) for technical risk assessment. Also, as mentioned above, Zhang et al.

(2009) developed an agent-based modelling and simulation methods for risk assessment. Risk assessment and risk quantification have great relevance, both serving decision-making and sometimes overlapped, but the risk assessment focuses more on the result, while the risk quantification emphasizes more the modeling process.

2.1.2 Mitigation strategies

Mitigation strategies can be divided into two categories: uncertainty-reduction strategies and coping-with-uncertainty strategies. The former emphasizes reducing uncertainty at its source - preventive strategies, such as pricing or incentives that may buffer demand fluctuation. The latter, instead of trying to alter the source, is intended to adapt and attenuate the impact of uncertainty - corrective strategies, such as developing forecasting techniques to enable better prediction and less forecasting errors (Simangunsong et al. 2012).

2.1.2.1 Preventive strategies

With the supply chains becoming increasingly lengthy and complex, adopting proactive mitigation strategies becomes extremely important and indispensable in tackling changing risks and vulnerabilities inherent in supply chain systems. Due to the interlinkedness of the supply chain, one small proactive approach may reduce a series of ripple effects (Rajesh et al. 2015).

Davis (1993) mentioned three uncertainty-reduction strategies: total quality control, new product design and supply chain redesign, with the first two aimed at reducing process uncertainty (Gerwin 1993, Geary et al. 2002), and the latter destined to reduce uncertainty related to supply and demand. In addition, Van der Vorst and Beulens (2002) proposed two other uncertainty-reduction strategies – collaboration with the principal suppliers and customers (Helms et al. 2000; Charu & Sameer, 2001) and setting a limit to the role of humans. Another well-known approach to reducing demand uncertainty is pricing strategy (Lee et al. 1997; Gupta & Maranas 2003). It is suggested that it is effective to reduce the bullwhip effect. Finally, Fisher (1997)

introduced responsive stock replenishment by reducing uncertainty about innovative products that typically have a short product life cycle and wide variety.

2.1.2.2 Corrective strategies

On the other hand, coping with uncertainty strategies mainly involves supply chain flexibility (Prater et al. 2001; Sawhney 2006, Gosling et al. 2010, Ivanov et al. 2018), postponement (Lee and Billington 1995, Yang et al. 2004, Yang and Yang 2010, Carbonara & Pellegrino 2018), information sharing among participants of the supply chain (Lee et al. 1997), ICT support, buffer stocks (Davis 1993, Helms et al. 2000) and lead-time management.

The classification of mitigation strategies has been explored by many researches. Rajesh et al. (2015) identified 12 major risks and 21 practical mitigation strategies; Simangunsong et al. (2013) expounded 10 approaches to reduce uncertainty at source and 11 approaches to cope with uncertainty by minimizing its impact. Lavastre et al. (2014) presented five flexibility strategies to reduce the magnitude of supply chain risks: multiple sourcing, flexible supply contracts, flexible manufacturing processes, postponement. Inman & Blumenfeld (2014) also made an effort to distinguish disruption prevention strategies, such as a parts inventory or local sourcing, and disruption mitigation, such as investing in logistics and material tracking systems (Rajesh et al. 2015; Simangunsong et al. 2012; Lavastre et al. 2014; Inman & Blumenfeld 2014).

2.1.3 Subsequent preparation

The subsequent preparation emphasizes reflection from risk occurrence and correction and enhancement of its ability to cope with future risks. Two of the most important competencies are supply chain risk resilience and supply chain flexibility. The former is the ability of a supply chain to deal with unexpected disturbances, recover its original state or achieve a new more desirable state after a disruptive event (Carvalho & Machado 2009, Cabral et al. 2012; Dimase et al. 2016; Zhang et al. 2002; Das & Lashkari 2015; Ivanov et al. 2018), providing flexibility in the supply chain capability

due to the uncertainty of risks, while the latter is a capability enabling timely responsive reactions to changes in the SC environment, and is interrelated to resilience (Ivanov et al. 2018; Das & Lashakari 2015; Zhang et al. 2002). For example, Baroud et al. (2014) introduced stochastic metrics of network resilience for overseeing the reliability and resilience of critical infrastructure following disruptive events, while Ivanov et al. (2018) classified four major flexibility drivers: disruption risks, resilience and the ripple effect in the supply chain; digitization, smart operations and e-supply chains; sustainability and closed loop supply chains; and supplier integration and behavioral flexibility.

Based on the aforementioned literature review focused on supply chain risk management of complex projects, below there is a brief summary presented as a circular array.

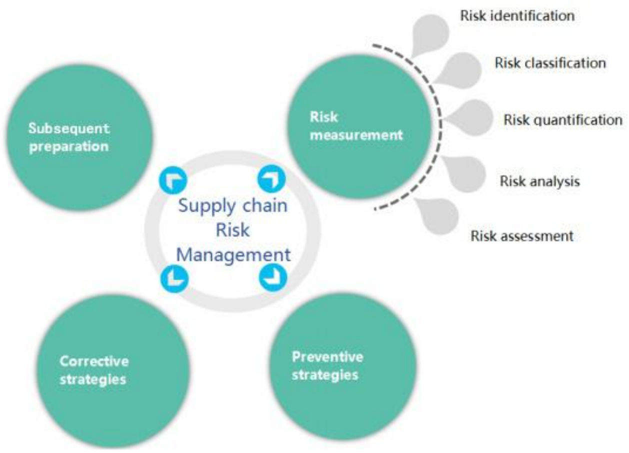

Figure 1 Supply chain risk management structure

Source: proposed by the author

As can be seen in Figure 1, supply chain risk management is composed of mainly four phases: risk measurement (including risk identification, risk classification, risk quantification, risk analysis and risk assessment) preventive strategies, corrective strategies and subsequent preparation. It is a constant cycle, as it never ends.

In addition to the aforementioned formation of SCRM, of the 22 articles especially focused on supply chain risk management of complex projects, only one focuses on subsequent preparation, 3 on corrective strategies, 15 on measurement and 16 on preventive strategies. In other words, corrective risk management researches take up less than 20% compared with the majority of preventive risk management ones.

2.2 Supply chain risk management and project risk management

Supply chain risk management of complex projects was mentioned in the previous section, so what is the difference between supply chain risk management and project risk management?

Risk in the supply chain is a variation in the distribution of likelihood, outcomes and relevant values associated with inbound supply failure, causing inability to purchase to meet end-users' requirements (March & Shapira, 1987; Zsidisin, 2003). Its management includes risk measurement (risk identification, risk classification, risk quantification, risk analysis and risk assessment), preventive strategies, corrective strategies, and subsequent preparation with the purpose of controlling its exposure to risk and reducing its negative influence.

Project risk management refers to the processes of risk management planning, risk identification, risk analysis, risk response planning, controlling and monitoring risk in a project (PMBOK GUIDE, 2013). Many project managers indicated that risk begins in the early stage of the project, such as estimation of the cost and negotiation of commercial and technical terms, and then it must be carefully managed in the execution phase and then in the following (Laurence 2017). Also, accepting re-design or not according to customer needs can be critical for the business, as it is necessary to balance the prospective benefits to future operation, adaption cost and risk (Fernando 2018).

Supply chain risk management is part of project risk management, as the latter is required to consider the overall risks and individual supplier risks in addition to the supply chain variation (Figure 2).

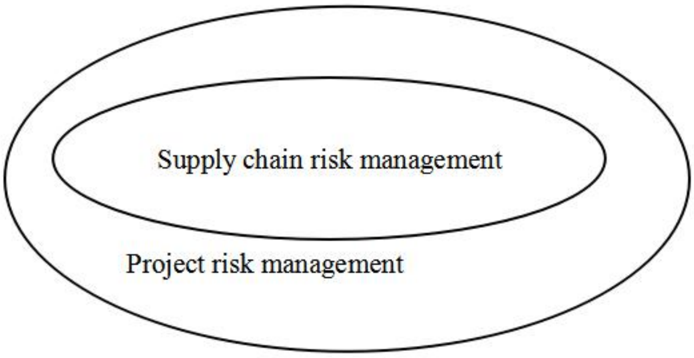

Figure 2 Relation between supply chain risk management and project risk management

Source: proposed by the author

2.3 ETO projects

Complex projects are conducted by ETO companies and to understand SC risk management in this context, it is necessary to understand its relevant characteristics. In general, the non-make-to-stock companies are classified into three types: assemble-to-order, make-to-order and engineer-to-order (Amaro et al. 1999; Rahim & Baksh 2003; Gosling & Naim 2009). Compared to assemble-to-order, which allows some degree of different option sets with plenty of standardized parts in stock, and make-to-order, which can only be initiated upon receipt of a customer order with a higher capacity for customization, engineer-to-order requires specific significant customization to meet the exact needs of customers (Hill 1993; Amaro et al. 1999).

In the ETO context, companies know little about what to order before receiving a customer order and relevant engineering specifications, namely, the production flow is controlled by customers orders with the decoupling point situated at the design stage (Gosling & Naim 2009). This point is referred to as the customer order decoupling point (CODP) (Wikner & Rudberg 2005; Donk & Doorne 2016; Gosling et al 2001), sometimes also understood as the order penetration point (OPP) (Olhager 2003; Wikner & Rudberg 2005). Quite different from the upstream of CODP, where activities are usually standardized and aggregated, the downstream of CODP is more

involved with individuation and customization (Donk & Doorne 2016; Gosling et al. 2017).

2.3.1 ETO Supply chain structure

The principal phases of ETO supply chain encompass tendering, design, manufacture, assembly, construction, and commissioning (Konijnendijk 1994; Hicks et al. 2001; Cameron & Braiden 2004; Chen 2006; Carvalho et al. 2015; Mello et al. 2015). For example, in a traditional building industry background, first, respective contracts are negotiated between contractors and designers. Upon receipt of the drawings, the contractor then executes the design, often accompanied by subcontractors and suppliers of materials and equipment. Such a temporary coalition continues until the completion of projects with each party responsible for its own part, but also sharing knowledge to some degree (Voordijk et al. 2000).

2.3.1.1 Tendering

Selecting the right contractor is an important strategic choice in the whole process as 85-90% of the cost is agreed at the tendering stage (Hicks et al. 1999) and it lays the foundation for the whole execution. Furthermore, according to Konijnendijk (1994), the tendering success rate for many companies is less than 30%. To have a successful tendering, it is necessary to have a detailed understanding of customer orders aside from its own capability of execution and management. To attend the customer requirement, a conceptual design is often produced, as well as technical specification, delivery terms, price, commercial terms and quality requirement (Hicks et al. 2000b; Hicks & McGovern 2009). The specification management is important as it stipulates the technical attributes and performance in terms of characteristics, processing and limiting conditions, and exclusions. It defines in detail the requirements of customers, and is often used to mitigate and manage risk. As it is established in the early stage of the contracting process, it serves as a reference and benchmark for the subsequent implementation of projects for checking, verifying and even justifying whether the execution is reasonable or adequate, which has a large influence on performance, risk

and operating costs (Hicks & Govern 2009). The more rigid the specification, the less the choice reserved for designing, and the higher the implementation cost.

2.3.1.2 Design

According to Stavrulaki & Davis (2010), an ETO supply chain serves a niche market with few competitors, and customers that are willing to pay a high price for a product or service that exactly fits their needs. ETO companies do not have finished goods in stock to immediately attend the customers' need (Bertrand & Muntslag 1993). To reach this goal, some degree of engineering work is necessary to adapt an existing design or even create a new one (Mello et al. 2015).

Unlike a common job, whose lead-time can be controlled by manipulating the number of relevant workers as long as the job can be decomposed into several independent parts, engineering is difficult to plan or control due to its limited flexibility and high degree of uncertainty (Konijnendijk 1994). In the initial stage, according to the preliminary understanding of customer orders, a conceptual design can be produced. However, along with more profound communication with customers and development of the process, designs may have to be changed due to initial misunderstandings or accidents emerging later or lack of full consideration etc. In the case of the aforementioned situations, it could be quite risky in terms of cost, co-ordination, progress, relations or even eventual efficiency.

2.3.1.3 Implementation (manufacture and assembly)

According to Konijnendijk (1994), there is a relatively high flexibility in terms of manufacturing as most of the components are standardized and can be outsourced, which perfectly fits the make-to-stock manufacturing type. Despite its standardization, customers can make it complex by demanding more functions, shorter delivery periods, longer periods of quality guarantee etc. Also, depending on operation mechanisms, customers may have more requirements such as a quality certificate, an inspection report, sample materials.

The assembly and construction usually require various professional suppliers that co-operate together to implement the programmed design at the same time. In this critical stage, co-ordination among different assemblers can greatly influence the lead-time. While the flexibility can be great inside the same category of assembly and construction by adding more manpower, the mix flexibility may be limited as it lies in the whole integration.

2.3.1.4 Correction

Testing, as the final phase of production, cannot be implemented before all the others are readily performed, and may lead to additional work due to repairs in assembly or construction. However, not only in this phase can correction be implemented, but also in the whole production development process, correction can be done at any time. For large ETO projects, the earlier the correction, the better. In case of design change, which constitutes 5-8% of the cost of a typical civil engineering project (Cox et al., 1999), its effective management can be an opportunity to improve competitiveness.

Corresponding to supply chain risk management, the tender and design management can be considered as preventive risk management, while the implementation and correction management can be regarded as corrective risk management.

2.3.2 Typologies of ETO companies

ETO companies gain competitive advantage through thorough understanding of customer requirements, incorporating them into specifications, and integrating them into products (McGovern et al., 1999).

The level of involvement of physical stages (manufacture, assembly etc.) and non-physical stages (tendering, engineering, design etc.) varies from company to company. According to Hicks et al. (2001), ETO companies can be categorized into four main types according to the level of vertical integration (see Table 1). The various processes related to the physical stages and non-physical stages should be co-ordinated to minimize the total risk and increase the overall efficiency.

	Type I	Type II	Type III(i)	Type III(ii)
Definition	Vertically integrated	Design and assembly	Design and contract	Project management
Core competencies	Design, manufacturing, assembly, project management	Design, assembly, project management	Design, project management, logistics	Project management, engineering expertise, logistics
Competitive advantage	Product and process knowledge; integration of internal processes	Systems integration; co-ordination of internal and external processes	Systems integration; co-ordination of internal and external processes	Reputation; engineering knowledge
Vertical integration	High	Medium	Low	Very low
Supplier relationships	Adversarial	Partnership	Partnership	Contractual
Environment	Stable	Uncertain	Dynamic	Dynamic
Type of risks	Capacity utilisation, return on capital, under-recovery of overheads	Lack of manufacturing may undermine design capability. Sharing core knowledge with suppliers makes them potential competitors	Overall contractual risk, capability and performance of suppliers	Loss of reputation

Table 1   Four Ideal Types of ETO Companies

Source: Hicks et al. 2001

As seen in the Table 1, Type I is a vertically integrated company, with its core competencies in design, manufacturing, assembly and project management. It has professional process knowledge and is noteworthy not only due to its successful integration of internal processes, but also its high overheads and capital utilization. Type II is a design and assembly company, whose core competencies are in design, assembly and project management. Its competitive advantage lies in the integration and co-ordination of internal and external processes, but a lack of manufacturing may undermine design capability, and sharing knowledge with suppliers may lead to potential competitors. Type III (i) is a design and contract company with core competencies in design, project management and logistics. However, due to the lack

of capability possessed by Type I and Type II, overall contracts pose a greater risk, and it depends a lot on the capability and performance of suppliers. Type III (ii) is a project management company, a typical consultancy whose core competencies lie in project management and logistics. It usually has a high reputation in the market. As it contracts all sub-contractors to complete the production process, on one hand, it has to co-ordinate and supervise the subcontractors, and on the other, as it has no hardware capability, it puts a lot of effort into maintaining its reputation (Hicks et al., 2001).

2.4 Integration of supply chain risk management and complex projects

Veiga & Silva (2018) conducted a systemic literature review of risk management, and grouped more than 500 risks into 25 categories with their corresponding percentages, as set out below (Table 2).

	25 constructs	source of risks (quantity)	%
1	Budget, bidding and financial problem	75	13.9%
2	Design / Project	60	11.2%
3	Skills / experience / team effectiveness	55	10.2%
4	Delays / schedule	45	8.4%
5	Bureaucracy / law / rules and regulations of the government	38	7.1%
6	Project Leadership	38	7.1%
7	Environmental risk	34	6.3%
8	Change of scope / goals	24	4.5%
9	Team production capacity / team size	23	4.3%
10	Customers or demand risk	22	4.1%
11	Safety	18	3.3%
12	Supplier	18	3.3%
13	Inadequate communication	17	3.2%
14	Conflicts	10	1.9%
15	Documentation or process management	10	1.9%
16	Contracts	9	1.7%
17	Inappropriate change management	8	1.5%
18	Risks related to quality	8	1.5%
19	Necessary technology	6	1.1%
20	Company Reputation	5	0.9%
21	Project Management Methodology	4	0.7%
22	Contingency risk	4	0.7%
23	Stakeholders	3	0.6%
24	Culture	2	0.4%
25	Storage / Stock Capacity	2	0.4%

Table 2 25 management risk categories

Source: Veiga & Silva, 2018, translated version

Of the 25 models of risk, 56% are applied in the area of civil construction and information technology (Veiga & Silva, 2018), i.e., this kind of categorization can be applied in the risk analysis of ETO projects.

These 25 categories can be extremely useful and applied as implications of codes in the analysis of interview texts and may be applied directly in the tree layout (ATLAS ti).

2.5. Efficiency of projects

Project success can be measured by “efficiency” and “effectiveness”, in which the former refers to the accomplishment of short-term project objectives related to time, quality and cost (Atkinson, 1999), and the latter refers to the attainment of end-user satisfaction in relation to long-term project objectives (Chan and Chan, 2004). Regarding the efficiency of measurements, Atkinson et al. (1997) argued that it is correlated with life-cycle cost, time frame, quality, functionality and delivery performance standards. In order to determine the efficiency of projects, De Graaf & Loonen (2018) applied a Tender Quality Review that verifies whether designers and contractors complete the project according to the relevant requirements and demands. Also, in exploring the project efficiency in the NEC (new engineering contract) Engineering and Construction, Wright & Fergusson (2009) applied a case study with interviews focusing on questions of clarity, cost, time and relationships.

Although researches exist about supply chain risk management in complex projects in ETO companies, few have explored how risk management is related to project efficiency, which is the purpose of this research.

3. METHODOLOGY

Case study was the methodology used in this research (Yin, 2003). It allows questions, such as why and how, to be answered with a relatively complete understanding of the nature and complexity of the whole phenomenon. In addition, it permits an early exploratory investigation, in which the constructs are still unknown, and the phenomenon still not fully comprehended (Meredith, 1998). In this case, the constructs of the efficiency of projects that influence each other are not clearly defined. Besides, the combination of supply chain risk management and efficiency of ETO projects is quite complicated, and few references exist for this exploratory analysis. Therefore, the case study research method was adopted.

3.1 Context of analysis

The research is conducted around two ETO Brazilian companies - EE and SS (the real names of the companies were disguised for confidentiality), aiming to deepen the understanding of how preventive risk management influences corrective risk management, and how they impact the efficiency of ETO projects respectively. Both companies are the Type II ETO companies with core competency in design, assembly and project management, and with the same supply chain structure - tendering, design, execution and correction. Both have met the quality control evaluation standards of BB (the real name of the company was disguised for confidentiality), a Chinese company, situated in Mato Grosso do Sul State. They have participated in the projects administrated by BB, which has been investing in the construction of a starch factory in Maracaju.

EE was contracted for the construction of a unit to receive grain, whose total value was about 20 million reals. It covered the service of civil work construction, supply of material, labor and electrical equipment at an EPC (Engineering Procurement Construction) modality with more than 7 equipment design & assembly subcontractors, It had a limited time of 210 days for the unit construction and an additional 60 days for

the industry expedition (source from the project contract and the commercial proposal). SS was contracted for the construction of a power-supply substation, with a total value of about 8 million reals. It covered the service of construction and assembly of the substation, the supply of equipment, materials and labor, with only 1 subcontractor for the transformer assembly, and there was a limited time of 270 days (source from the project contract and the commercial proposal). Both companies have implemented some practices for preventive and corrective project risk management and completed their projects, both projects have experienced exactly the four phases of ETO projects - tendering, design, execution and correction with a limited time of 270 days, all of which above allows a better exploration and understanding of the research theme. The practices are adequate for the risk management analysis, and it is expected that the EE project would be riskier than the SS one.

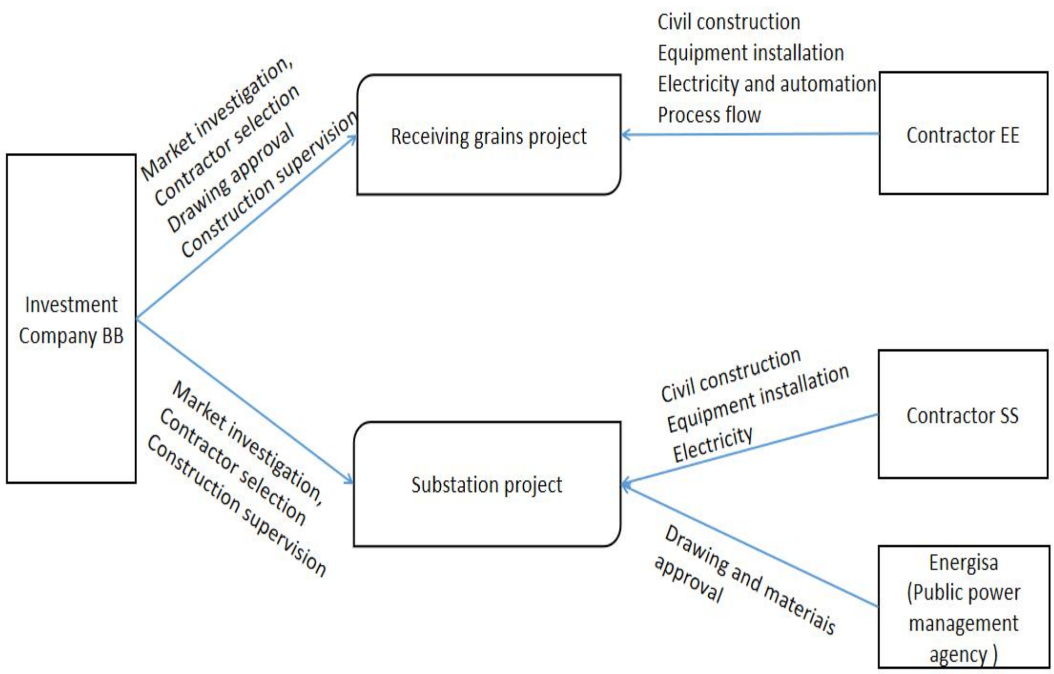

Figure 3 Company relations

Source: proposed by the author

3.2 Data collection

The information is focused on gathering preventive and corrective management practices adopted by EE and SS to guarantee project construction, and how they influence project efficiency in the tendering, design, execution and correction phases. For this purpose, interviews were conducted with engineers (civil construction, electricity and equipment etc.), project managers and EE and SS directors. The interview method allows exploration of subjects that can be very complex to investigate by quantitative means, and requires consideration of a reflexive attitude in the research process. It starts from the conception of the question and the identification and assembly of interviews with the informants, to the interview itself, including the work done to turn an interactive meeting into a written research paper (Godoi, 2012). In total, 13 interviews were conducted, which altogether lasted 7 hours and 14 minutes (see Table 3 for the interview data summary).

Company	Position	Interview duration	Key points
BB	Equipment engineer	12min 13s	Corrective risk practices
BB	Vice general manager	44min 2s	Preventive&Corrective risk practices
BB	Senior engineer	16min 38s	Corrective risk practices
BB	Construction director	51min 32s	Preventive&Corrective risk practices
BB	Construction executive	39min 30s	Preventive&Corrective risk practices
BB	Electrical engineer	27min 33s	Corrective risk practices
BB	Civil engineer	41min 39s	Corrective risk practices
EE	Resident engineer	26min 33s	Preventive&Corrective risk practices
EE	Construction director	42min 24s	Preventive&Corrective risk practices
EE	Project manager	32min 15s	Preventive&Corrective risk practices
SS	Civil engineer	22min 17s	Corrective risk practices
SS	Construction director	48min 16s	Preventive&Corrective risk practices
SS	Construction supervisor	29min 52s	Corrective risk practices

Table 3 Interview data summary

Source: summarized by the author

According to Yin (2003), the following procedures were adopted to ensure the quality of the research. Specific interview protocols were developed depending on which phase (preventive and corrective management) the interviewee participated in to ensure the reliability of the data collected (Appendix A). Of the 25 types of risks listed in Table 2, only design risk, safety risk, quality risk, archive&process risk, contract administration risk, personnel administration risk, cultural difference risk, subcontracting risk, credit&financial risk, communication risk and divergence risk (in total 11 risks) were selected as the rest of risks were not relevant or applied in these projects. The questions were focused on the risks experienced, the way that influence project efficiency and practices adopted for preventive and corrective risk management in the projects. In case that interviewees experienced only preventive or corrective project risk management, they would only be questioned about the corresponding phase. In case that interviewees experienced both preventive and corrective project risk management, they would be questioned about both phases.

To improve the data validity, all the interviews were recorded with permission and transcribed. As the author is a Chinese and knows both Chinese and Portuguese, all the interviews were held by the author, but the transcription was executed by two people - the Chinese version by the author and the Portuguese version by a native Brazilian to increase accuracy. Then the transcripts were sent back to the interviewees for confirmation, doubts clarification and suggestions. To further validate the research data, interviews were also held with the corresponding engineers, managers and decision-makers of BB, who supervise and control the projects construction. Also, as corrective risk is a sensitive topic, some interviewees tried to cover up the corrective risk practices and strengthen the preventive risk practices. In order to reduce this effect and increase the authenticity, the author not only partly participated in the project construction as a translator for 8 months, but also searched for some secondary documents such as contracts and commercial proposals as supplementary references for the corresponding projects. In other words, the interview was the main source of the research, with secondary documents as a complementary reference. The triangulation was achieved based on BB's interview data, field observation and the

author's experience. According to Yin (2018), there are four principals for increasing reliability and validity: Use multiple source of evidence; Maintain a chain of evidence; Create a case study data base; Exercise care when using data from social medium. In this qualitative research, three principles are used with the specific information in the Table 4 below.

Methods of increasing reliability and validity		
Methods by Yin(2018)		Methods used in the research
Use multiple source of evidence		Data triangulation of interviews and observation
Maintain a chain of evidence	Interviews	Protocols based on literature review
	Documentation	Contracts and commercial proposals
	Direct observation	Transcription of different languages by natives
	Participant-observation	Participant observation by the author
Create a case study data base		ATLAS.ti

Table 4 Methods of increasing reliability and validity

Sourse: summarized by the author

3.3 Data analysis

The data were organized, managed and analyzed using qualitative data analysis software (ATLAS.ti). Interview texts were encoded using a predefined code list that was expanded during the theoretical analysis to capture emerging topics. The use of the software and data coding facilitates and systematizes qualitative data analysis procedures and protects against information processing bias (Eisenhardt, 1989; Miles and Huberman, 1994).

First, data were coded from each case with the points mentioned in the theoretical literature to create the first-order categories with the support of ATLAS.ti. Then the categories were reviewed to assimilate the similar ones and eliminate duplication. Then, the first-order categories were grouped into higher-order themes resulting in 11 types of risks (see Figure 4) and 4 types of project efficiency (see Figure 5).

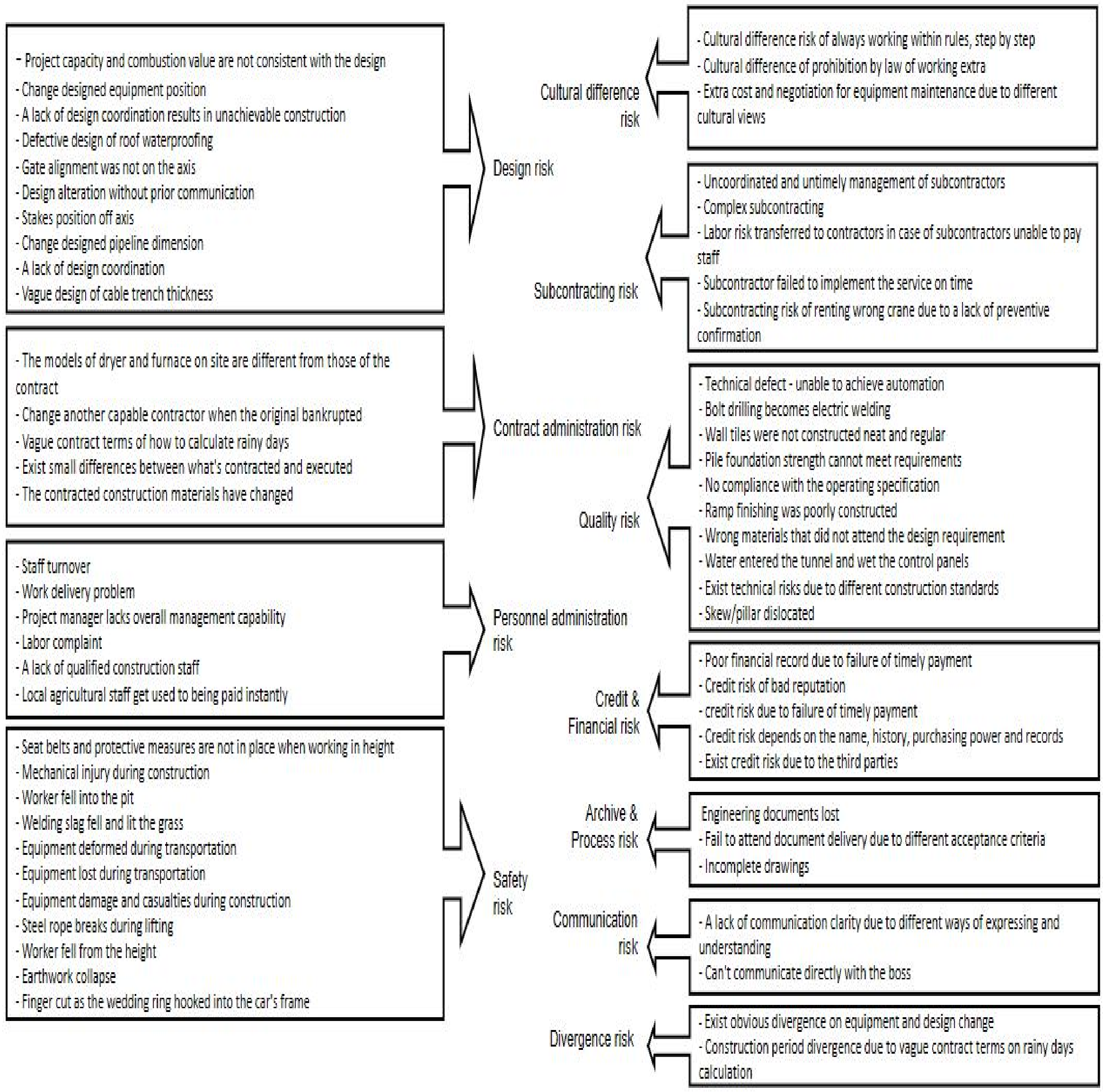

Figure 4: Risk classification

Source: proposed by the author

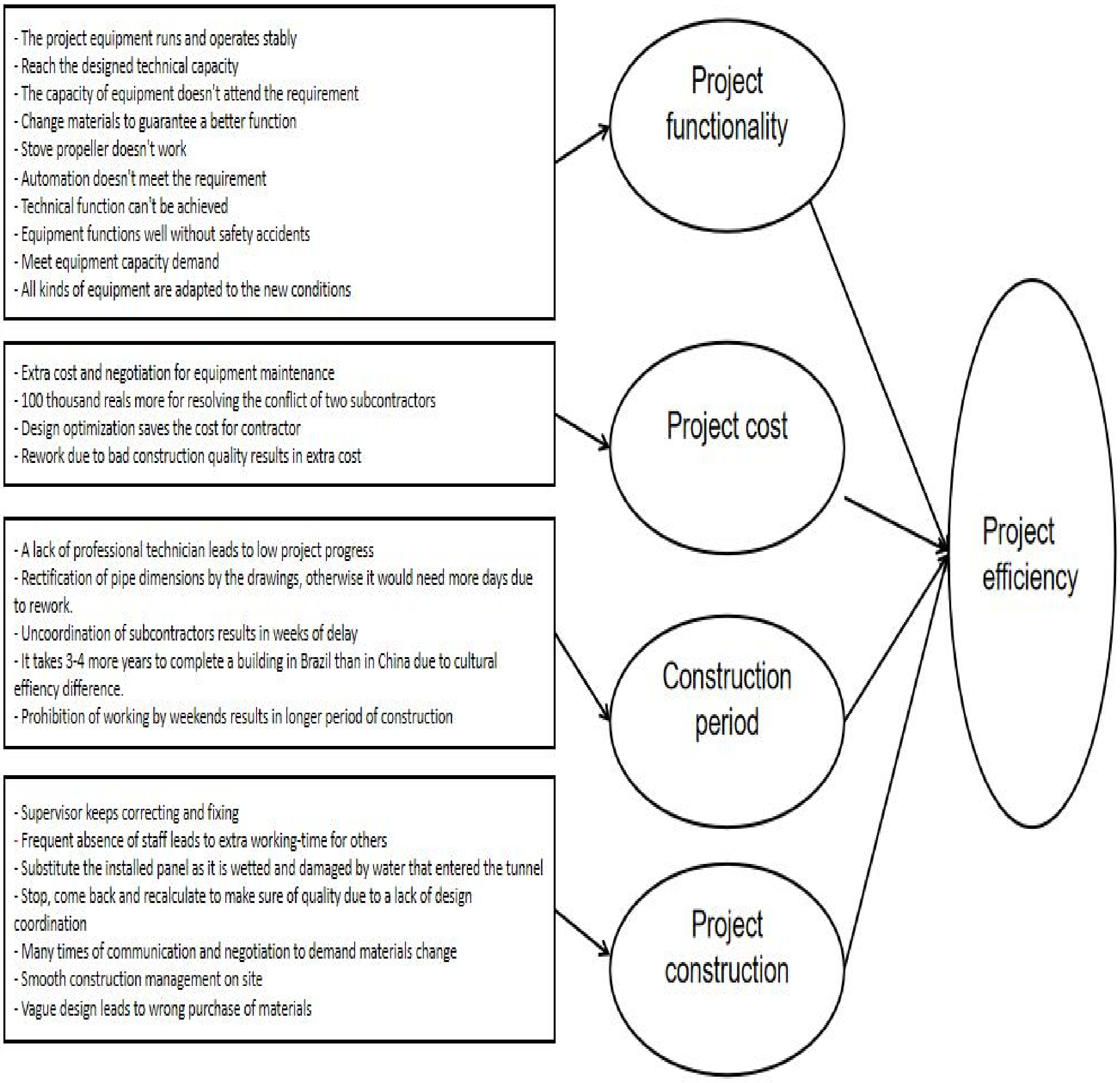

Figure 5: Project efficiency

Source: proposed by the author

With the same method, the first-order categories of management practices were created, and then grouped into higher-order themes depending on whether they were positive or negative and whether they were preventive or corrective. Through this endeavor, 10 types of positive risk practices associated to risk prevention and 10 types of positive risk practices associated to risk correction were identified, thus linking to the theoretical background. Finally, they were grouped into two main concepts (see the data structure from the above analysis in Figures 6 and 7).

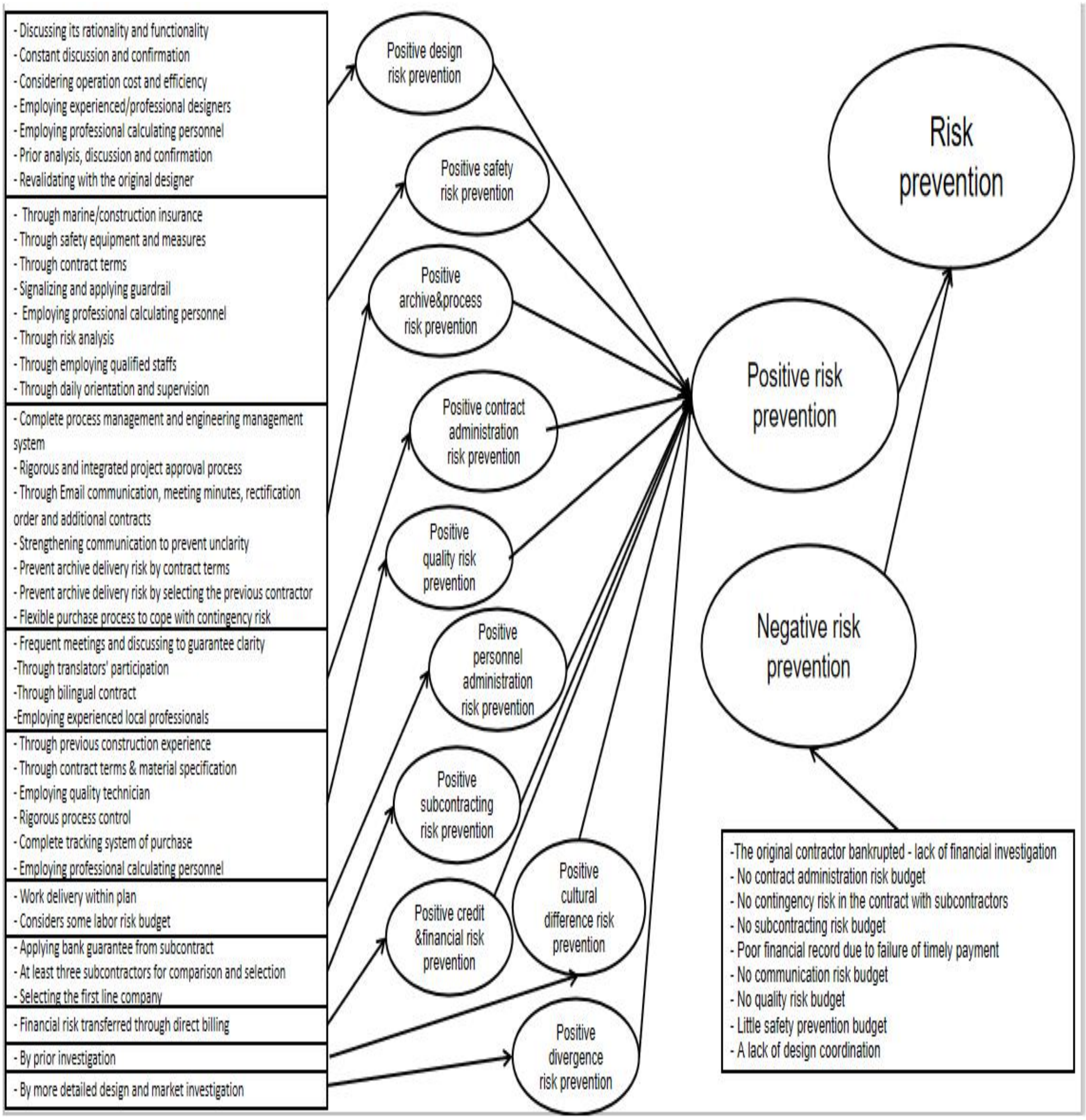

Figure 6: Risk prevention

Source: proposed by the author

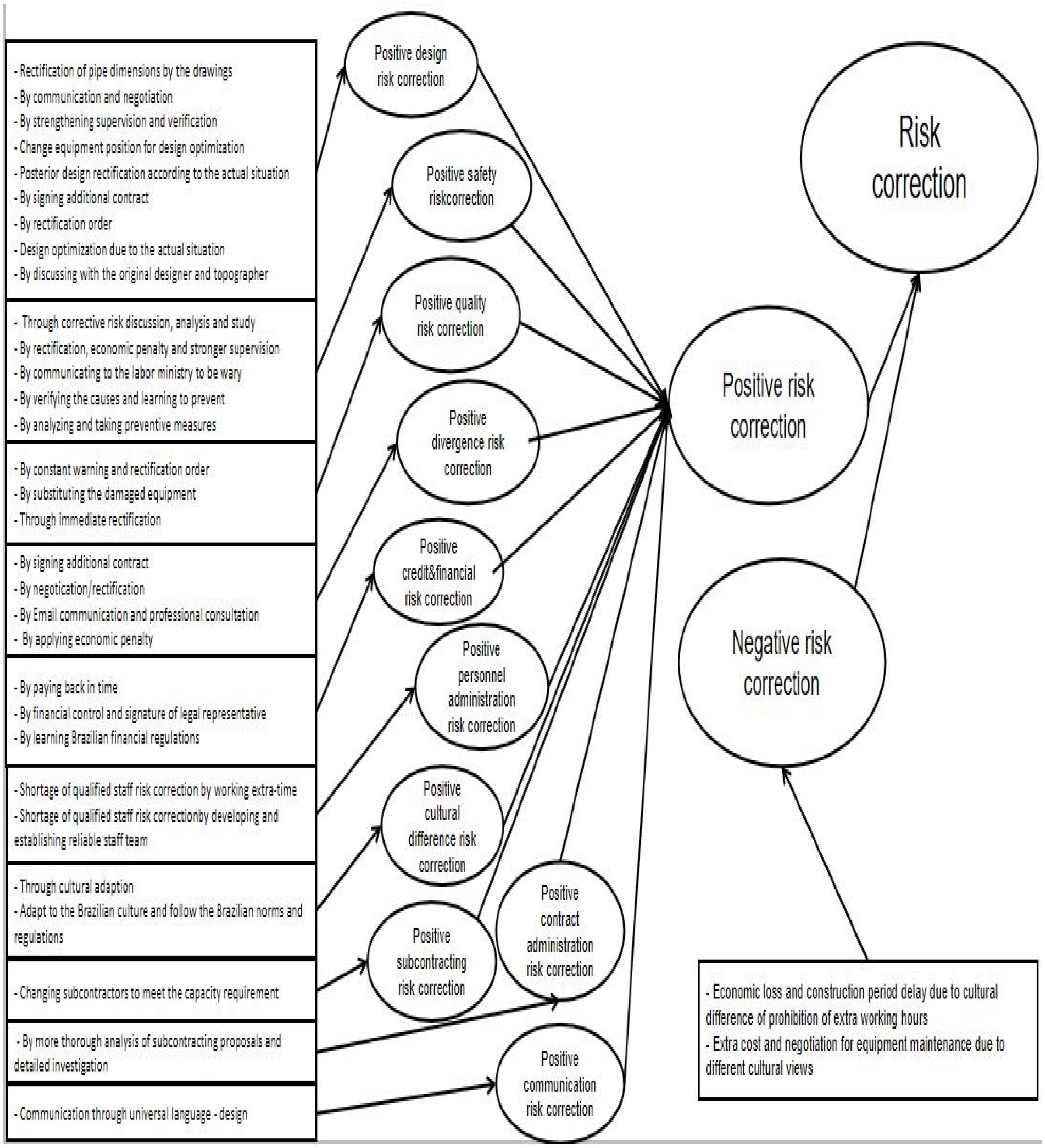

Figure 7: Risk correction

Source: proposed by the author

After a thorough exploration and understanding of the definitions of risks and preventive & corrective risk practices as well as project efficiency, the next step was to explore the relations among preventive risk management, corrective risk management and project efficiency.

4. MAIN FINDINGS

To better understand project risk management practices, first, the differences of risk management practices of the two companies were discussed (see Table 5 and 6). Then, the two cases were combined to find the relations among preventive risk management, corrective risk management and project efficiency.

4.1 EE

EE is a big Brazilian construction company, with its main focus on civil construction. For this grain receiving project, it subcontracted several equipment companies implementing procurement and assembly of mechanical equipment, such as the dryer and furnace, truck weighing scales, tipper, in addition to its own civil construction. The subcontractors were respectively responsible for their own designs, procurement, installation and commission. The design of the whole project was delivered by contractor EE and approved by company BB. The correction part of the grain handling project mainly encompassed the executive design and construction. Except for a site engineer on site, the other departments were working in Campo Grande, including the board of directors. The communication with other departments was usually conducted through email.

Next, the types of risks experienced and the preventive and corrective measures adopted by EE and its project efficiency are discussed (see the summary in Table 5).

EE	Sum-up	Codes
Types of risk experienced	Cultural difference risk, safety risk, contract administration risk, design risk and communication risk	Cultural difference risk of always working within rules, step by step Cultural difference of prohibition by law of working extra Extra cost and negotiation for equipment maintenance due to different cultural views
		Worker fell into the pit Welding slag fell and lit the grass Finger cut as the wedding ring hooked into the car's frame
		The models of dryer and furnace on site are different from those of the contract Vague contract terms of how to calculate rainy days Exist small differences between what's contracted and executed The contracted construction materials have changed
		Project capacity and combustion value are not consistent with the design Change designed equipment position Design alteration without prior communication A lack of design coordination
		A lack of communication clarity due to different ways of expressing and understanding Can't communicate directly with the boss
Preventive measures	Personnel human resources training and qualification/hiring engineers/contracting first-class subcontractors/discussing the rationality and functionality in advance with the engineers.	Constant discussion and confirmation Considering operation cost and efficiency Employing experienced/professional designers Employing professional calculating personnel Through employing qualified staffs Signalizing and applying guardrail Through Email communication, meeting minutes, rectification order and additional contracts Through bilingual contract Complete tracking system of purchase Considers some labor risk budget Applying bank guarantee from subcontract Selecting the first line company Financial risk transferred through direct billing
Corrective measures	Communication, rectification and signing new contract terms	Change equipment position for design optimization Posterior design rectification according to the actual situation By signing additional contract Design optimization due to the actual situation By communicating to the labor ministry to be wary By verifying the causes and learning to prevent By analyzing and taking preventive measures By substituting the damaged equipment Through immediate rectification Changing subcontractors to meet the capacity requirement By more thorough analysis of subcontracting proposals and detailed investigation
Project efficiency	Delayed in grain receiving but timely in industry expedition /Equipment function problems/ Saved some cost by replacing the electricity subcontractor, but paid an extra 100,000 reals/Rework	The capacity of equipment doesn't attend the requirement Change materials to guarantee a better function Stove propeller doesn't work Automation doesn't meet the requirement Technical function can't be achieved
		Extra cost and negotiation for equipment maintenance 100 thousand reals more for resolving the conflict of two subcontractors Design optimization saves the cost for contractor Rework due to bad construction quality results in extra cost
		Uncoordination of subcontractors results in weeks of delay Prohibition of working by weekends results in longer period of construction
		Substitute the installed panel as it is wetted and damaged by water that entered the tunnel Many times of communication and negotiation to demand materials change

Table 5 EE's project risk management

Source: proposed by the author

4.1.1 Types of risks experienced

The main risks the EE project had were cultural difference risk, safety risk, contract administration risk, design risk and communication risk, but with little personal administration risk and quality risk. As the contracting owner is a Chinese company, both companies inevitably encountered cultural difference risks, such as differences in construction standards, as mentioned by the BB construction director.

"In terms of building foundations, in Brazil it is mainly a screw pile foundation, while in China it is mainly a cap foundation. The construction methods of the two are different, but do not have a great impact on the overall project, mainly impact project cost." (translated version)

Although the screw pile foundation is more expensive, EE had to convince BB to construct the foundation according to Brazilian construction standards.

Besides, as EE has hired more than 7 subcontractors, the co-ordination of these subcontractors is extremely important to the whole project construction. During this co-ordination process, EE did not play a good role in safety prevention and two major accidents happened, one in which a worker fell into the tipper pit, and in the other welding slag fell onto dry grass, ignited it, causing a fire (source from the author's observation).

In addition, in the case of an equipment change, namely a furnace and a dryer, EE did not reach an agreement in writing regarding the equipment models and capacity with the corresponding subcontractors, as stated in the contract with BB. When EE found that the equipment could not attend the contracted capacity, EE changed the equipment model and the corresponding civil construction design without approval from BB, causing the corresponding equipment construction to be suspended for almost two months.

On the other hand, most of EE's workers were from Ceará State, and had accumulated work experience, having been employed by EE for years. The main subcontractors EE contracted were first-class companies in the industry, such as Kepler and Saturno. Therefore, it faced little personnel administration risk and quality risk.

4.1.2 Preventive measures

EE has implemented a series of preventive risk practices, mainly in personnel human resources training and qualification, and hiring engineers, contracting first-class

subcontractors, as well as discussing the rationality and functionality in advance with the engineers.

As explained by the EE project manager,

"We always do training with employees, looking for all registered employees in their role...the company, it always seeks to guide employees, does DDS, every day, early." (translated version)

Also, the EE site manager mentioned that they hired professionals to calculate the imminent risks and take measures to avoid them.

"Before designing the projects, the calculation engineer EE hired had already foreseen all the imminent risks of the work." (translated version)

However, inevitably, a lot of inadequacies and deficiencies exist, for example, in the risk prevention for the contract administration and subcontractors. EE did not consider the equipment model and capacity in the contract with the respective subcontractor, resulting in subsequent alterations. Also, EE only had one site manager, a professional in civil construction. As to the other aspects of construction, he had to consult the appropriate engineers and persons in charge. In addition to the complexity of this project, it is quite inconvenient and takes more time.

4.1.3 Corrective measures

EE has its own way of managing corrective risk practices, mainly by communication, rectification and signing new contract terms.

This kind of risk can be grouped into two types, ones from a lack of risk prevention, and others that happened unexpectedly, without much connection to prevention. For example, the work accidents mentioned above happened because EE had not adopted enough safety prevention. The civil design change of the furnace and dryer was unexpected and had no connection with design prevention. Also, some of the

corrective measures later worked as preventive measures, such as prior communication to obtain approval by the contracting party.

4.1.4 Project efficiency

Regarding project efficiency, EE delayed delivery of the grain receiving project for a month, but was timely in terms of the industry expedition project. Due to inadequacy of the risk prevention, especially in the area of equipment operation, several equipment function problems occurred in the commissioning phase. For example, the operation routes did not work due to some wrong valve installations or a lack of lubricant. As to the project cost, EE saved some cost by replacing the electricity subcontractor, but paid an extra 100,000 reals for the co-operation of the ex-subcontractor and subcontractor of certain equipment, as explained by the EE construction director:

"Kepler was hired cheaper, but now EE has to spend more, and now, especially now, in the operation, GSI put a knife at EE's neck and said: Look, I want 100 thousand to do this integration."(translated version).

For the project construction, it was much more complicated than expected, as some unexpected risks arose. As mentioned by the EE construction director:

"Water entered the tunnel and wet the Fockink panels, and BB forced EE to replace the panels, remove the panels, take them away and then bring them back. And what happened? In that case alone, for example, it cost EE R$ 50,000 to remove the panels. Fockink took them to their factory to change the parts that had been damaged due to getting wet, and returned the panels." (translated version)

It was rework due to the quality risk that complicated the construction.

4.2 SS

SS is a medium-sized electricity construction company. Different from EE, SS involves itself entirely in the project - procurement and assembly, except for one piece

of equipment – the transformer. The substation drawings were completed by a consultancy firm and approved by the electricity authority - Energisa. The correction part of the substation project concentrated on executive construction. Its field engineer and person in charge were usually on site.

Next, the types of risks experienced and the preventive and corrective measures adopted by SS and its project efficiency are discussed (see the summary in Table 6).

SS	Sum-up	Codes
Types of risk experienced	Cultural difference risk, personal administration risk and communication risk.	Cultural difference risk of always working within rules, step by step Cultural difference of prohibition by law of working extra Cultural differences due to different construction standards
		Staff turnover A lack of qualified construction staff Local agricultural staff get used to being paid instantly
		A lack of communication clarity due to different ways of expressing and understanding
Preventive measures	Practices in technical evaluation and preventive risk evaluation	Revalidating with the original designer Through daily orientation and supervision Flexible purchase process to cope with contingency risk Through previous construction experience Financial risk transferred through direct billing By prior investigation
Corrective measures	Analyzing, discussing, communicating and rectifying.	Rectification of pipe dimensions by the drawings By discussing with the original designer and topographer By communication and negotiation By analyzing and taking preventive measures Through immediate rectification Shortage of qualified staff risk correction by working extra-time Shortage of qualified staff risk correction by developing and establishing reliable staff team Communication through universal language - design
Project efficiency	Delayed 1 month/Less functionality problems/ No big change/More repetitive work	Equipment functions well without safety accidents Meet equipment capacity demand All kinds of equipment are adapted to the new conditions
		Rectification of pipe dimensions by the drawings, otherwise it will increase construction cost due to rework
		A lack of professional technician leads to low project progress Rectification of pipe dimensions by the drawings, otherwise it will extend construction period due to rework Prohibition of working by weekends results in longer period of construction
		Supervisor keeps correcting and fixing Frequent absence of staff leads to extra working-time for others Stop, come back and recalculate to make sure of quality due to a lack of design coordination

Table 6 SS's project risk management

Source: proposed by the author

4.2.1 Types of risks experienced

The main risks that SS project faced were cultural difference risk, personal administration risk and communication risk. There was little design risk and quality risk, and no safety risk.

As mentioned above about EE, the same issue existed between BB and SS. Due to the cultural differences in construction standards, BB had to accept them, although BB did not think it a good option, as mentioned by the BB electrical engineer.

"The Chinese and Brazilian standards are inconsistent. Cobblestones are usually used in Chinese substation construction, but light coarse stones are generally used in substation construction here. The surface is sharp and not suitable for substation use." (translated version)

Also, in the detailing of drawings, engineers from different sectors (structure, architectonic, hydraulic and electrical) did not communicate well with each other, causing several instances of interference, as mentioned by the SS construction supervisor:

"The drains. We had a very serious problem with the drain and the electrical part, because everything was going at the same level ... So, it is this divergence that I am telling you about. If I am with an architectural engineer telling me that I have a drain passing 60 cm deep, from 0 to 60, and I can't have anything in between. Anything I design I have to design outside that area, because that area is the drain area. But these are things that have been resolved in the area. But this is not the correct thing. The correct thing is to implement the projects without this interference. There was a lot of interference." (translated version)

Moreover, as SS mostly hired local people in Maracaju, where people are used to working daily in the agricultural fields and lack professional construction skills, there exists a great personnel administration risk, and this seriously impedes the project construction and progress.

4.2.2 Preventive measures

SS has implemented a series of preventive risk practices, mainly in technical evaluation and preventive risk evaluation, as explained by the SS construction director:

"Technical evaluation. We have an engineering team that technically assessed whether all types of equipment were adapted to the new conditions...All risk assessment procedures were implemented, not only for our company at that time, but also for the client's enterprise, stability, socio-economic stability, socio-political stability, the client's internal and external relations with the business." (translated version)

However, inevitably, some inadequacies and deficiencies exist, for example in the personnel administration area. To save cost, SS mostly hired locals, without professional knowledge and practices, thus lowering the construction quality and frequently causing rework.

4.2.3 Corrective measures

In the case of SS, risks arose mainly due to a lack of prevention, such as the incapability of workers and low quality of construction work. Immediately after those events, SS adopted corrective measures according to its experience or at the request of BB, mainly by analyzing, discussing, communicating and rectifying. As explained by the SS civil engineer, after it was identified that the stake markings of the transformer were deviated, SS organized a lot of discussions about this issue and rectified it with the joint effort of the original designer, surveyor, local engineers etc.

"This issue was discussed a lot here. A check was made of all the points of the work. What was right and what was not was questioned. A check of the points was made ... Also, with the original designer. With the surveyor, who is the one who makes the marks and locations, meetings were held, and, from these meetings, the decision was made that moving away would be better and could return to the original position." (translated version)

4.2.4 Project efficiency

Regarding project efficiency, there was also a delay of 1 month for SS to deliver the substation project. Compared with the EE project, it had less functionality problems due to the prior supervision and approval of the principal designs and equipment. The project cost did not change much, as SS had only one subcontractor and did not replace it as EE did. As for the construction process, SS did more repetitive work than EE, as the company hired mostly local agricultural workers with less technical skills.

In spite of the differences in complexity between these two projects, in both cases some features were found in common in the relations among preventive risk management and corrective risk management, and in the project efficiency.

4.3 Preventive risk management, corrective risk management and project efficiency

4.3.1 Preventive risk management and project efficiency

As mentioned above in Figure 5, the project efficiency can be divided into 4 categories, namely, project functionality, project cost, project construction and construction period. Project functionality means the function of project equipment and equipment capacity. Project cost means the money utilized for the construction. Project construction means the activities carried out during the construction. Construction period means the time used to complete the construction. Thus, the relationships between preventive risk management and project efficiency will be discussed along these lines.

In the case of EE, the company adopted a specific process to discuss the design of projects that led to smoother operations. The BB vice-manager explained:

"For example, in the design phase, in terms of the design process for warehouses and grain receiving projects, we repeatedly discussed the design route, the rationality of

the design, and the degree of automation so as to ensure that the project can be put into operation smoothly after completion. " (translated version).

The result was that the previous discussion worked and the operation routes were quite clear in the commissioning phase, and it had a high degree of automation, which meant the majority of the routes could be operated by one button.

In other words, the adoption of positive preventive risk management improves the project functionality.

In the case of SS, the company adopted tests to guarantee the operational safety of the equipment, as the SS construction director mentioned:

"We are doing the circuit breaker tests ...... If a circuit breaker explodes, kills a person, and you are not willing to take over, this is a very serious business." (translated version)

If SS did not conduct the tests, some work accidents would be likely to happen, possibly influence the equipment functionality and paralyze the whole project.

Both cases explain that it was better to check for erroneous ideas at the outset. The above conclusion has led to the development of the following finding (see Table 7 for more references):

Positive preventive risk management is associated with high project functionality.

Finding	Codes	Projects
Positive preventive risk management is associated with high project functionality.	Design risk prevention by discussing its rationality and functionality	EE
	Design, quality and safety risk prevention by employing professional calculating personnel to guarantee functionality	EE
	Adequate distribution of budgets to ensure stable functionality	EE
	Material specified in the contract change for better project functionality	EE
	Safety risk prevention by tests to guarantee project functionality	SS
	Technical risk prevention by prior analysis and evaluation of equipment to guarantee functionality	SS

Table 7 Relationship between preventive risk management and project functionality

Source: proposed by the author

In both the EE and SS cases, BB adopted a series of communication measures, which facilitated the construction management. As the construction executive explained:

"For overseas projects, the company (BB) has recruited many Portuguese translators. Considering this problem, when signing the contract, everyone communicates in English as much as possible to make the communication more thorough and clearer. At the same time, we require the negotiating representative of the other party to speak English, and the signed contract is a Portuguese-English version. In the later period, as the translation increased, the contract became an English-Portuguese version. And in terms of communication with the contractor's construction management staff, we also involve Portuguese translators throughout the process. In terms of on-site construction management communication, there were no problems due to poor language communication." (translated version)

The communication risk due to misunderstandings or a lack of clarity would be prevented or reduced through translator participation and bilingual contracts in project construction.

Also, in case of SS, as mentioned above, a lack of communication between designers in detailing drawings resulted in a series of checks and revisions. It also happened to the EE project, which can be seen from the following explain by the BB vice-manager about a chimney installation problem, caused by a lack of communication between designers of different subcontractors.

"The current furnace chimney is designed by one unit, but the steel structure shed of the furnace is designed by another unit. Due to the lack of communication between the two companies, the two designs of the furnace cannot be combined normally during the implementation process. It is necessary to cut out a part of the steel structure on the roof and re-strengthen the roof to extend the chimney out of the roof. This is a problem of subsequent construction caused by poor design in the early stage." (translated version)

Both cases explain that adoption of proper preventive risk practices can be helpful to avoid rework. Conversely, improper or no preventive risk practices can lead to rework . The above conclusion has led to the development of the following finding (see Table 8 for more references):

Positive preventive risk management is associated with smooth project construction, and negative preventive risk management is associated with complicated project construction.

Finding	Codes	Projects
Positive preventive risk management is associated with smooth project construction, and negative preventive risk management is associated with complicated project construction.	Prevent communication risk of unclarity through translators' participation and bilingual contract, which leads to no misunderstandings in project construction	EE
	Contractor selection considering strength and convenience of construction	EE
	A lack of design coordination complicated the project construction	EE
	Prevent communication risk of unclarity through translators' participation and bilingual contract, which leads to no misunderstandings in project construction	SS
	Contractor selection considering strength and convenience of construction	SS
	A lack of design coordination complicated the project construction	SS
	Vague design dimension influences project construction	SS

Table 8 Relationship between preventive risk management and project construction

Source: proposed by the author

Regarding all the contracts BB signed, the construction executive emphasized:

"It is necessary to agree on some detailed schedule requirements, detailed payment processing nodes and default provisions." (translated version)

These contract details indeed avoided many disputes and trouble in these two projects, but there also existed some inadequacy in both projects that contributed to the late delivery of projects, for example, the vague contract terms of calculation of the number of rainy days. BB did not agree with the calculation of rainy days presented by EE, as nobody had stipulated the criterion beforehand.

Both cases indicate that proper preventive risk management practices can be helpful to achieve a timely conclusion, whereas no or improper preventive risk management practices can cause a lot of trouble and make conclusion on schedule unfeasible, which has led to the development of the following finding (see Table 9 for more references):

Positive preventive risk management is associated with project conclusion in the required time, while negative preventive risk management is associated with project conclusion delay.

Finding	Codes	Projects
Positive preventive risk management is associated with project conclusion in the required time, while negative preventive risk management is associated with project conclusion delay.	Risk prevention through contract regulations about construction period, payment conditions and contract infractions	EE
	Risk prevention through analysis of project construction period and cost	EE
	Construction period divergence due to vague contract terms of rainy days calculation	EE
	Risk prevention through contract regulations about construction period, payment conditions and contract infractions	SS
	Risk prevention through analysis of project construction period and cost	SS
	A lack of professional technician delays the construction period	SS

Table 9 Relationship between preventive risk management and construction period

Source: proposed by the author

4.3.2 Corrective risk management and project efficiency

In the case of EE, the dryer and furnace were transferred to another subcontractor because it could not meet the contracted capacity requirement. It was a move for the better. In the case of SS, BB demanded SS to rectify the pipe dimension, as otherwise it would influence the equipment installation.

The above cases demonstrate that timely equipment correction - equipment capacity correction and equipment adjustment and repair can guarantee the required normal function of project equipment, which has led to the development of the following finding (see Table 10 for more references):

Positive corrective risk management is associated with high project functionality.

Finding	Codes	Projects
Positive corrective risk management is associated with high project functionality.	Change equipment position for design optimization and process rationality	EE
	Change equipment to attend the contracted processing capability	EE
	Subcontracting risk correction by changing subcontractors to meet the capacity requirement	EE
	Material specified in the contract change for better project functionality	EE
	Design risk correction depends on whether it influences the project functionality	SS
	Rectification of pipe dimensions by the drawings, otherwise it would influence the equipment installation	SS

Table 10 Relationship between corrective risk management and project functionality

Source: proposed by the author

BB had to accept the cultural difference of prohibition of overtime work in Brazil, which occurs quite often and is normal in China. More investment of time and untimely correction mean more cost.

In the case of EE, it saved money by selecting a cheaper supplier that provided the equipment capacity. SS implemented the rectification of pipe dimensions according to the drawings, otherwise it would incur additional construction cost in the future.

The above cases indicate that timely proper correction can reduce extra effort and cost to some degree, while otherwise it would lead to the contrary. This has led to the development of the following finding (see Table 11 for more references):

Positive corrective risk management is associated with low project cost.

Finding	Codes	Projects
Positive corrective risk management is associated with low project cost.	Extra cost and negotiation for equipment maintenance due to different cultural views	EE
	Without risk prevention on changing subcontractors, it suffered a big economic loss	EE
	Without financial risk budget for contract administration risk prevention, it suffered an economic loss	EE
	Economic loss and construction period delay due to cultural difference of prohibition of extra working hours	EE
	Financial payment process difference results in economic loss	EE
	Design optimization beneficial to contractor, saving the cost	EE
	Construction cost increased because of equipment subcontractors' substitution and cooperation	EE
	Rework due to bad construction quality results in extra cost	EE
	Rectification of pipe dimensions by the drawings, otherwise it would extend construction period and increase construction cost	SS
	Economic loss and construction period delay due to cultural difference of prohibition of extra working hours	SS
	Financial payment process difference results in economic loss	SS

Table 11 Relationship between corrective risk management and project cost

Source: proposed by the author

In the case of EE, there was only one site manager, and, as mentioned in the citation below, he was incapable of managing and co-ordinating so many subcontractors, as can be verified below by the BB senior engineer. However, until the end of the project, EE did not send another site manager. It was a kind of negative risk correction, and it took more work and time for him to blend in.

"The EE site manager asked us to co-ordinate and solve many things, but he couldn't fully control the project." (translated version)

Also, in the case of SS, during the transformer installation, the manufacturer sent a 30-ton crane, and later discovered that it was unable to lift the transformer. Then a 50-ton

crane was brought to the site, but this did not succeed either. After a recalculation, an 80-ton machine managed to perform the lift. Altogether, it took more than 3 days, and involved preparation of the team several times (source from the author's observation).

Both cases show that negative treatment of risk correction can cause more rework. This has led to the development of the following finding (see Table 12 for more references):

Negative corrective risk management is associated with complex project construction.

Finding	Codes	Projects
Negative corrective risk management is associated with complex project construction.	Project construction complicated by a lack of overall coordination management capability	EE
	Purchase process complicated by credit risk of reputation (EE)	EE
	Construction quality risk correction complicated project construction (EE)	EE
	Correction of uncoordinated design risk complicated the project construction (SS)	SS
	Incomplete drawings influence project quality control (SS)	SS

Table 12 Relationship between corrective risk management and project construction

Source: proposed by the author

Timely correction can be helpful to conclusion on time, while negative treatment can cause delay. In the case of SS, if it had not corrected the pipe dimension in a timely manner, it would have been unable to cross the cables later, which would possibly delay the project construction. On the other hand, in the case of EE, due to the fact that the site manager was incapable of co-ordinating the subcontractors and controlling the project, it took more time for the blend-in-process, which delayed the project delivery.

Both cases demonstrate that positive risk management can be helpful to ensure project conclusion, while negative management can be harmful. This has led to the development of the following finding (see Table 13 for more references):

Positive corrective risk management is associated with project conclusion in the required time, while negative corrective risk management is associated with delay.

Finding	Codes	Projects
Positive corrective risk management is associated with project conclusion in the required time, while negative corrective risk management is associated with delay.	Equipment quality risk correction influences project construction period and project functionality	EE
	Economic loss and construction period delay due to cultural difference of prohibition of extra working hours	EE
	Cultural difference risk of working days extends construction period	EE
	Cultural difference of efficiency results in longer construction period	EE
	Rectification of pipe dimensions by the drawings, otherwise it would extend construction period	SS
	Economic loss and construction period delay due to cultural difference of prohibition of extra working hours	SS
	Cultural difference risk of working days extends construction period	SS
	Cultural difference of efficiency results in longer construction period	SS
	Design risk correction delays the construction period	SS

Table 13 Relationship between corrective risk management and construction period

Source: proposed by the author

4.3.3 Preventive risk management and corrective risk management

As mentioned above, in both EE and SS cases, there was a lack of communication between designers that caused some construction obstacles, eventually solved by modification and revision.

A lack of proper preventive risk practices often accompanies necessary risk correction. Risk considerations should be taken into account and avoid unnecessary correction.

In the case of SS, due to the supervision and approval of general drawings, no big drawing risks happened. Also, in the case of EE, due to the preparation of workers from other states, there were no personnel turnover risks as happened to SS.

Both cases show that positive risk management can be helpful to risk correction management, leading to the development of the following finding (see Table 14 for more references):

Positive preventive risk management is associated with less risk correction management.

Finding	Codes	Projects
Positive preventive risk management is associated with less risk correction management.	It didn't consider the risk of delaying the project conclusion but exists	EE
	Without consideration of contract administration risk, it suffered a big economic loss from risk correction	EE
	Safety risks correction due to a lack of preventive measures	EE
	A lack of design coordination results in unachievable construction	EE
	Without design risk prevention, it results in a big economic loss by risk correction	EE
	Without an in-depth and detailed investigation of the contractor, the company had to change another capable contractor when the original bankrupted	SS
	A lack of design coordination results in unachievable construction	SS

Table 14 Relationship from preventive risk management to corrective risk management

Source: proposed by the author

When some risks were corrected, they could possibly have led to positive risk prevention. For example, there was a frequent employee absence in the case of SS that caused big trouble to construction, but they could have developed and established a reliable workforce, and have taken them wherever they were needed to act in prevention, as suggested below by the BB construction supervisor:

"And now finishing this work, he already has some people who can already join his work group to take to another site. He can't take 100%, but he can take 20. He takes 30%. You know, it's easier for him to assemble his work team." (translated version)

The EE project was suspended for almost two months because they replaced the equipment without prior communication and approval of BB, which can be verified by the BB senior engineer and the author's observation.

"The contractor changed the direction of the hot blast stove at will. It turned out to be in a north-south direction, but now it is completely changed, that is to an east-west direction without our consent" (translated version)

It is often after learning from mistakes that some corrective risk practices, corresponding to preventive risk practices, are considered. The above argument has led to the development of the following finding (see Table 15 for more references):

Positive correction management is associated with positive risk prevention management.

Finding	Codes	Projects
Positive correction management is associated with positive risk prevention management.	Design risk correction by signing additional contract	EE
	Divergence risk correction by signing additional contract	EE
	Safety risk correction&prevention by analyzing and taking preventive measures	EE
	Safety risk correction&prevention by communicating to the labor ministry to be wary	EE
	Safety risk correction&prevention by verifying the causes and learning to prevent	EE
	Design risk correction&prevention by communication ahead	EE
	Design risk correction&prevention by asking for consent of client	SS
	Quality risk correction&prevention by asking for prior approval	SS
	Shortage of qualified staff risk correction&prevention by developing and establish reliable staff team	SS
	Prevent construction quality risk through previous construction experience	SS

Table 15 Relationship from corrective risk management to preventive risk management

Source: proposed by the author

5. DISCUSSION AND CONCLUSION

5.1 Discussion

In this work, a within-case and a cross-case analysis with two ETO cases were performed to explore the research theme, namely, how preventive risk management and corrective risk management influence project efficiency respectively, and how preventive risk management and corrective risk management influence each other in the context of ETO projects.

Through coding and interpretation of interview transcripts, a full image of risk classification, project efficiency, risk prevention and risk correction is explicitly expanded, which allows a clear understanding in the context of ETO projects. It shows that risks can be classified into 11 groups - design risk, contract administration risk, personnel administration risk, safety risk, cultural difference risk, subcontracting risk, quality risk, credit&financial risk, archive&process risk, communication risk and divergence risk based on data analysis and previous literature. It also indicates four principal indexes of project efficiency - project functionality, project cost, project construction and construction period.

On the other hand, a comparison between the two ETO project cases was conducted. Some features are found to be in common among preventive risk management, corrective risk management and project efficiency (see Figure 8).

Main Findings	Discussion
Positive preventive risk management is associated with high project functionality.	**Proposition 1** Positive preventive risk management improves project efficiency.
Positive preventive risk management is associated with smooth project construction, and negative preventive risk management is associated with complicated project construction.	
Positive preventive risk management is associated with project conclusion in the required time, while negative preventive risk management is associated with project conclusion delay.	
Positive corrective risk management is associated with high project functionality.	**Proposition 2** Positive corrective risk management improves project efficiency.
Positive corrective risk management is associated with low project cost.	
Negative corrective risk management is associated with complex project construction.	
Positive corrective risk management is associated with project conclusion in the required time, while negative corrective risk management is associated with delay.	
Positive preventive risk management is associated with less risk correction management.	**Proposition 3** Positive preventive risk management and positive corrective risk management benefit each other.
Positive correction management is associated with positive risk prevention management.	

Figure 8: Proposition discussion

Source: proposed by the author

Based on the EE and SS project data, the adoption of a specific process to discuss the design of projects by EE and safety tests by SS helped improve the equipment functionality. The successful adoption of communication measures by BB and failure of the previous communication by EE and SS proved the importance of positive preventive risk practices to project construction. The adoption of detailed contract terms for all the projects helped avoid many disputes and trouble in project conclusion. It is inferred that the adoption of positive preventive risk practices improves the project functionality, project construction and project conclusion, leading to the development of the following finding:

Proposition 1 **Positive preventive risk management improves project efficiency.**

Based on the EE and SS project data, the alteration of the furnace and the dryer by EE and the pipe dimension correction by SS helped guarantee the normal function of the equipment. The passive acceptance of cultural difference standards brought extra cost to the company, while the alteration to a cheaper electricity subcontractor saved EE a lot money, which proved that the adoption of positive corrective practices is associated with less project cost and vice versa. The passive correction of EE by sending only one

site manager and of SS by recalculating the exact precision of crane capacity several times resulted in more time cost and constitute part of the project delay factors. Therefore, it is inferred that the adoption of positive corrective risk practices improves the project functionality, project cost and project conclusion, which leads to the development of the following finding:

Proposition 2 **Positive corrective risk management improves project efficiency.**

Based on the EE and SS project data, a lack of previous communication between designers caused construction impossibility requiring correction. A prior supervision and approval of general drawings and equipment by an authoritative institution guaranteed less material quality risks and design risks. The preparation of skilled workers helped EE reduce the quantity of rework and improved the construction quality. Those corrective measures that EE and SS took could help improve the risk prevention management. Therefore, it is inferred that the adoption of positive preventive risk practices improves the corrective risk management, and the adoption of positive corrective risk practices improves the preventive risk management, which leads to the development of the following finding:

Proposition 3 **Positive preventive risk management and positive corrective risk management benefit each other.**

5.2 Theoretical implications

A thorough analysis of supply chain risk management literature reveals its formation circle. The preventive risk management can be divided into risk measurement (including risk identification, risk classification, risk quantification, risk analysis and risk assessment) and preventive mitigation strategies, while the corrective risk management can be divided into corrective mitigation strategies and subsequent preparation.

A comparison between supply chain risk management and project risk management was conducted, which showed that supply chain risk management is part of project risk management, here indicating ETO project risk management in particular.

As mentioned in the Introduction, originally few researchers explored corrective risk management, let alone a combination of supply chain risk management and ETO project risk management. However, this work compensates for some of this dearth by combining the two together and exploring the relation among preventive risk management, corrective risk management and project efficiency.

It helps the understanding of how preventive risk management contributes to project efficiency in terms of project period, project cost, project functionality and project construction respectively, as well as how corrective risk management contributes to project efficiency in terms of project period, project cost, project functionality and project construction respectively. In addition, it helps further explore how preventive risk management influences corrective risk management.

5.3 Managerial implications

Through the research of the two ETO cases, it is indicated that the positive preventive risk management is quite important to the success of the whole project. Considerations in terms of contract and technical delivery in this phase can help avoid unnecessary rework, save extra cost and guarantee timely project delivery and equipment functioning perfectly, and vice versa.

Also, it demonstrates that the positive corrective risk management plays an important role in the project development. Timely and proper correction can help terminate the deviation, reduce future cost and shorten the construction period and eliminate operation problems and vice versa.

Further, it shows that managers can learn from corrective risk management and make better decisions in subsequent risk prevention.

5.4 Research suggestions and limitations

As this research is qualitative and exploratory, it has its own limit. It needs further quantitative verification for the relations proposed. In addition, it is based on two cases in spite of the effort to ensure the validity of the qualitative investigation. It needs to be tested if it can be generalized to a broader level. Moreover, all the interviews were conducted by the author, causing certain limitation. Furthermore, the two companies were the Type II ETO companies. It would be interesting if researches could study other types of ETO companies to further validate the conclusions.

In addition, in this work, due to the limited time of research, there are also some other research directions, for example: What is the role of personnel administration risk in each phase of supply chain risk management and ETO project risk management as it was handled in different ways in two cases?; How to make the most of its advantages and avoid its disadvantages?; What kind of strategies can be implemented in the preventive risk management and corrective risk management to reach this goal?

6. REFERENCES:

Amaro, G., Hendry, L., & Kingsman, B. (1999). Competitive advantage, customisation and a new taxonomy for non make-to-stock companies. ***International Journal of Operations & Production Management***, 19(4), 349–371. doi:10.1108/01443579910254213

Aqlan, F., & Lam, S. S. (2015). Supply chain risk modelling and mitigation. ***International Journal of Production Research***, 53(18), 5640–5656. doi:10.1080/00207543.2015.1047975

Atkinson, A.A., Waterhouse, J.H. and Wells, R.B. (1997), "A stakeholder approach to strategic performance measurement", ***Sloan Management Review***, Vol. 38 No. 3, pp. 25-37.

Atkinson, R. (1999), "Project management: cost time and quality two best guesses and a phenomenon, it's time to accept other success criteria", ***International Journal of Project Management***, Vol. 17, No. 6, pp. 337-342.

Baroud, H., Ramirez-Marquez, J. E., Barker, K., & Rocco, C. M. (2014). Stochastic Measures of Network Resilience: Applications to Waterway Commodity Flows. ***Risk Analysis***, 34(7), 1317–1335. doi:10.1111/risa.12175

BEA (2014)〈 http://www.bea.gov/industry/gdpbyind_data.htm〉.

Bertrand, J. W. M., & Muntslag, D. R. (1993). Production control in engineer-to-order firms. ***International Journal of Production Economics***, 30-31, 3–22. doi:10.1016/0925-5273(93)90077-x

Birkie, S. E., Trucco, P., & Kaulio, M. (2017). Sustaining performance under operational turbulence. ***International Journal of Lean Six Sigma***, 8(4), 457–481. doi:10.1108/ijlss-12-2016-0077

Blackhurst, J., Wu, T., & O'Grady, P. (2004). Network-based approach to modelling uncertainty in a supply chain. ***International Journal of Production Research***, 42(8), 1639–1658. doi:10.1080/00207540303600016460

Blome, C., & Schoenherr, T. (2011). Supply chain risk management in financial crises—A multiple case-study approach. ***International Journal of Production Economics***, 134(1), 43–57. doi:10.1016/j.ijpe.2011.01.002

Blos, M. F., da Silva, R. M., & Wee, H.-M. (2018). A framework for designing supply chain disruptions management considering productive systems and carrier viewpoints. ***International Journal of Production Research***, 1–17. doi:10.1080/00207543.2018.1442943

Cabral, I., Grilo, A., & Cruz-Machado, V. (2012). A decision-making model for Lean, Agile, Resilient and Green supply chain management. ***International Journal of Production Research***, 50(17), 4830–4845. doi:10.1080/00207543.2012.657970

Cameron, N. S., & Braiden, P. M. (2004). Using business process re-engineering for the development of production efficiency in companies making engineered to order products. ***International Journal of Production Economics***, 89(3), 261–273. doi:10.1016/s0925-5273(02)00448-6

Carvalho, A. N., Oliveira, F., & Scavarda, L. F. (2015). Tactical capacity planning in a real-world ETO industry case: An action research. ***International Journal of Production Economics***, 167, 187–203. doi:10.1016/j.ijpe.2015.05.032

Carvalho, H. and Machado, V.C. (2009). Lean, agile, resilient and green supply chain: a review. ***Proceedings of the 3rd international conference on management science and engineering management***, 2-4 November, Bangkok, Thailand. World Academic Press, World Academic Union, 66-76.

Charu, C. and Sameer, K. (2001). Enterprise architectural framework for supply-chain integration. ***Industrial Management + Data Systems***, 101 (5-6), 290-304.

Chen, C.-S. (2006). Concurrent engineer-to-order operation in the manufacturing engineering contracting industries, ***International Journal of Industrial and Systems Engineering.***Vol. 1 Nos 1/2, pp. 37-58.

Cho, S.-H., & Eppinger, S. D. (2005). A Simulation-Based Process Model for Managing Complex Design Projects. ***IEEE Transactions on Engineering Management***, 52(3), 316–328. doi:10.1109/tem.2005.850722

Christian A. Rudolf, Stefan Spinler, (2018) "Key risks in the supply chain of large scale engineering and construction projects", ***Supply Chain Management: An International Journal***, https://doi.org/10.1108/SCM-09-2017-0292

Cox, I., Morris, J., Rogerson, J. and Jared, G. (1999) 'A quantitative study of post contract award design changes in construction', ***Construction Management and Economics***, Vol. 17, No. 4, pp.427–439.

Cutler, T. R. 2005. "Are You Eto? The Increasing Importance of Custom (Engineer-to-order) Manufacturers." ***InMFG*** 1–3.

Das, K., & Lashkari, R. S. (2015). Risk readiness and resiliency planning for a supply chain. ***International Journal of Production Research***, 53(22), 6752–6771. doi:10.1080/00207543.2015.1057624

Davis, T. (1993). Effective supply chain management. ***Sloan Management Review***, 34 (4), 35-46.

De Graaf, R. S., & Loonen, M. L. A. (2018). Exploring Team Effectiveness in Systems Engineering Construction Projects: Explanations Why Some SE Teams Are More Effective than Others. Systems Research and Behavioral Science. doi:10.1002/sres.2512

DENICOL, Juliano (2014). ***Sistemática para seleção de fornecedores na indústria da construção civil***. 2014. 115 f. Dissertação (Mestrado em Engenharia de Produção) - Univeraidade Federal do Rio Grande do Sul, Porto Alegre, Brasil.

Dennis R. Muntslag (1994). Profit and risk evaluation in customer driven engineering and manufacturing. ***Int. J. Production Economics***, 36, 97-107.

Dietrich, D. M., & Cudney, E. A. (2011). Methods and considerations for the development of emerging manufacturing technologies into a global aerospace supply chain. ***International Journal of Production Research***, 49(10), 2819–2831. doi:10.1080/00207541003801275

Dillon, R. L., Pate-Cornell, M. E., & Guikema, S. D. (2005). Optimal Use of Budget Reserves to Minimize Technical and Management Failure Risks During Complex Project Development. ***IEEE Transactions on Engineering Management***, 52(3), 382–395. doi:10.1109/tem.2005.850733

DiMase, D., Collier, Z. A., Carlson, J., Gray, R. B., & Linkov, I. (2016). Traceability and Risk Analysis Strategies for Addressing Counterfeit Electronics in Supply Chains for Complex Systems. ***Risk Analysis***, 36(10), 1834–1843. doi:10.1111/risa.12536

Djalma Araújo Rangel, Taiane Kamel de Oliveira & Maria Silene Alexandre Leite (2015). Supply chain risk classification: discussion and proposal. International Journal of Production Research, 53:22, 6868-6887, DOI: 10.1080/00207543.2014.910620

Éder Suzarte Donda Veiga, Eliciane Maria da Silva (2018). ***A systematic review of management risks in the projects management*** (translation). In SIMPOI (XXI SIMPÓSIO DE ADMINISTRAÇÃO DA PRODUÇÃO, LOGÍSTICA E OPERAÇÕES INTERNACIONAIS) 2018.

Eisenhardt, K. M. (1989). Building theory from case study research. ***Acad. Management Rev***. 14(4) 532–550.7.

Fisher, M.L. (1997). What is the right supply chain for your product? ***Harvard Business Review***, 75 (2), 105-116.

Flyvbjerg, B. (2011), "***Over budget, over time, over and over again: managing major projects***", in Morris, P.W.G., Pinto, J.K. and Söderlund, J. (Eds), The Oxford Handbook of Project Management, Oxford University Press, Oxford, pp. 321-344.

Garber, R., & Paté-Cornell, E. (2011). Shortcuts in Complex Engineering Systems: A Principal-Agent Approach to Risk Management. ***Risk Analysis***, 32(5), 836–854. doi:10.1111/j.1539-6924.2011.01736.x

Geary, S., Childerhouse, P., and Towill, D.R. (2002). Uncertainty and the seamless supply chain. ***Supply Chain Management Review***, 6 (4), 52-61.

Gerwin, D. (1993). Manufacturing flexibility: a strategic perspective. ***Management Science***, 39 (4), 395-410.

Godoi, C.K et al. (2012). Sustainability discourse analysis in a company of the electric energy sector. ***Management and Connections Journal***, Vitória (ES), v.1, n.1.

Gosling, J., Hewlett, B., & Naim, M. M. (2017). Extending customer order penetration concepts to engineering designs. ***International Journal of Operations & Production Management***, 37(4), 402–422. doi:10.1108/ijopm-07-2015-0453

Gosling, J., Naim, M., 2009. Engineer-to-order supply chain management: a literature review and research agenda. ***Int. J. Prod. Econ***. 122, 741–754.

Gosling, J., Purvis, L. and Naim, M.M. (2010), Supply chain flexibility as a determinant of supplier selection. ***International Journal of Production Economics.*** 128 (1), 11-21.

Grabenstetter, D, & Usher, J. 2014. "Developing due dates in an engineer-to-order engineering environment." ***International Journal of Production Research*** 52 (21): 6349-6361

Gupta, A. and Maranas, C.D. (2003). Managing demand uncertainty in supply chain planning. ***Computers and Chemical Engineering***, 27 (8-9), 1219-1227.

Helms, M.M., Ettkin, L.P., and Chapman, S. (2000). Supply chain forecasting - collaborative forecasting supports supply chain management. ***Business Process Management Journal***, 6 (5), 392-407.

Hicks, C. and McGovern, T. (2009) 'Product life cycle management in engineer-to-order industries', ***Int. J. Technology Management***, Vol. 48, No. 2, pp.153–167.

Hicks, C., Earl, C.F. and McGovern, T. (1999) 'Modelling supply chain management processes in engineer-to-order companies', ***International Journal of Logistics: Research and Applications***, Vol. 2, No. 2, p.147.

Hicks, C., Earl, C.F. and McGovern, T. (2000a) 'An analysis of company structure and business processes in the capital goods industry in the U.K', ***IEEE Transactions on Engineering Management***, Vol. 47, No. 4, pp.414–423.

Hicks, Christian & Mcgovern, Tom & Earl, Christopher. (2001). A Typology of UK Engineer-to-Order Companies. ***International Journal of Logistics Research and Applications***. 4. 10.1080/13675560110038068.

Hicks, C., McGovern, T. and Earl, C.F. (2000b) 'Supply chain management: a strategic issue in engineer to order manufacturing', ***International Journal of Production Economics***, Vol. 65, No. 2, pp.179–190.

Hillson, D. (2015). ***Managing risk in projects: New concepts***. In the proceeding of the 15th International PM Conference of the PMI Arabian Gulf Chapter, 2015.

Hill, T. (1993), ***Manufacturing Strategy: The Strategic Management of the Manufacturing Function***, The Macmillan Press, BBrasingstoke and New York, NY.

Inman, R. R., & Blumenfeld, D. E. (2013). Product complexity and supply chain design. ***International Journal of Production Research***, 52(7), 1956–1969. doi:10.1080/00207543.2013.787495

Ivanov, D., Das, A., & Choi, T.-M. (2018). New flexibility drivers for manufacturing, supply chain and service operations. ***International Journal of Production Research***, 56(10), 3359–3368. doi:10.1080/00207543.2018.1457813

Ivanov, D., Dolgui, A., Sokolov, B., & Ivanova, M. (2017). Literature review on disruption recovery in the supply chain. ***International Journal of Production Research***, 55(20), 6158–6174. doi:10.1080/00207543.2017.1330572

James G. March, Zur Shapira, (1987) Managerial Perspectives on Risk and Risk Taking. ***Management Science*** 33(11):1404-1418. http://dx.doi.org/10.1287/mnsc.33.11.1404

Jan Olhager (2003). Strategic positioning of the order penetration point. ***Int. J. Production Economics***, 85, 319–329.

Kamil J. Mizgier (2017). Global sensitivity analysis and aggregation of risk in multi-product supply chain networks. ***International Journal of Production Research***. Vol. 55 Issue 1, p130-144.

Kozjek, D., Vrabič, R., Rihtaršič, B., & Butala, P. (2018). Big data analytics for operations management in engineer-to-order manufacturing. ***Procedia CIRP***, 72, 209 - 214

Krishnan, K. K., Jithavech, I., & Liao, H. (2009). Mitigation of risk in facility layout design for single and multi-period problems. ***International Journal of Production Research***, 47(21), 5911–5940. doi:10.1080/00207540802175337

Lecoeuvre, Laurence. (2017). ***The performance of projects and Project Management. Sustainable Delivery in Project Intensive Companies***. PROJECT MANAGER (IL). 44-46. 10.3280/PM2017-031012.

Lee, C. K. M., Lv, Y., & Hong, Z. (2013). Risk modelling and assessment for distributed manufacturing system. ***International Journal of Production Research***, 51(9), 2652–2666. doi:10.1080/00207543.2012.738943

Lee, H.L., Padmanabhan, V., and Whang, S. (1997). Information distortion in a supply chain: the bullwhip effect. ***Management Science***, 43 (4), 546-558.

Lee, H.L. and Billington, C. (1995). The evolution of supply-chain-management models and practice at Hewlett-Packard. ***Interfaces.*** 25 (5), 42-63.

Loutchkina, I., Jain, L.C., Nguyen, T., & Nesterov, S.V. (2014). Systems' Integration Technical Risks' Assessment Model (SITRAM). ***IEEE Transactions on Systems, Man, and Cybernetics: Systems***, 44, 342-352.

Marle, F., Vidal, L.-A., & Bocquet, J.-C. (2013). Interactions-based risk clustering methodologies and algorithms for complex project management. ***International Journal of Production Economics***, 142(2), 225–234. doi:10.1016/j.ijpe.2010.11.022

Mason-Jones, R. and Towill, D.R. (1998). Shrinking the supply chain uncertainty circle. ***IOM Control***, 24 (7), 17-22.

Mcgovern, T., Hicks, C. and Earl, C.F. (1999), "Modelling supply chain management processes in engineer-to-order companies", ***International Journal of Logistics Research and Applications***, Vol. 2 No. 2, pp. 147-159.

Mello, M. H., Strandhagen, J. O., & Alfnes, E. (2015). The role of coordination in avoiding project delays in an engineer-to-order supply chain. ***Journal of Manufacturing Technology Management***, 26(3), 429–454. doi:10.1108/jmtm-03-2013-0021

Meredith, Jack (1998). "Building Operations Management Theory through Case and Field Research," ***Journal of Operations Management***, 16 (4), 441-454.

Miles, M. B., & Huberman, A. M. (1994). ***Qualitative Data Analysis: An Expanded Sourcebook***. Thousand Oaks, CA Sage Publications.

Nogueira, Marcelo, and Ricardo J. Machado (2014). "Importance of Risk Process in Management Software Projects in Small Companies." Ifip ***Advances in Information and Communication Technology***, Vol. 439, No. 2, pp. 358–365. Web.

Nunzia Carbonara & Roberta Pellegrino (2018) Real options approach to evaluate postponement as supply chain disruptions mitigation strategy, ***International Journal of Production Research***, 56:15, 5249-5271, DOI: 10.1080/00207543.2017.1403663

Ojha, R., Ghadge, A., Tiwari, M. K., & Bititci, U. S. (2018). Bayesian network modelling for supply chain risk propagation. ***International Journal of Production Research***, 1–25. doi:10.1080/00207543.2018.1467059

Olivier Lavastre, Angappa Gunasekaran & Alain Spalanzani (2014) Effect of firm characteristics, supplier relationships and techniques used on Supply Chain Risk Management (SCRM): an empirical investigation on French industrial firms, ***International Journal of Production Research***, 52:11, 3381-3403, DOI: 10.1080/00207543.2013.878057

Paul A. Konijnendijk (1994). Coordinating marketing and manufacturing in ETO companies. ***Int. J. Production Economics***, 37, 19-26.

Prater, E., Biehl, M., and Smith, M.A. (2001). International supply chain agility: tradeoffs between flexibility and uncertainty. ***International Journal of Operations and Production Management***, 21 (5-6), 823-839.

Project Management Institute (2013). **A guide to the project management body of knowledge (PMBOK guide)**. Newtown Square, Pa: Project Management Institute.

Rahman Abdul Rahim, A., & Shariff Nabi Baksh, M. (2003). Case study method for new product development in engineer-to-order organizations. ***Work Study***, 52(1), 25–36. doi:10.1108/00438020310458705

Rajesh, R., Ravi, V., & Venkata Rao, R. (2014). Selection of risk mitigation strategy in electronic supply chains using grey theory and digraph-matrix approaches. ***International Journal of Production Research***, 53(1), 238–257. doi:10.1080/00207543.2014.948579

Ritchie, B., & Brindley, C. (2007). Supply chain risk management and performance. ***International Journal of Operations & Production Management***, 27(3), 303–322.

Sanderson, J., & Cox, A. (2008). The challenges of supply strategy selection in a project environment: evidence from UK naval shipbuilding. ***Supply Chain Management: An International Journal***, 13(1), 16–25. doi:10.1108/13598540810850283

Sawhney, R. (2006). Interplay between uncertainty and flexibility across the value-chain: towards a transformation model of manufacturing flexibility. ***Journal of Operations Management***, 24 (5), 476-493.

Simangunsong, E., Hendry, L. C., & Stevenson, M. (2012). Supply-chain uncertainty: a review and theoretical foundation for future research. ***International Journal of Production Research***, 50(16), 4493–4523. doi:10.1080/00207543.2011.613864

Singhal, Piyush & Agarwal, G & Mittal, M.L.. (2011). Supply chain risk management: Review, classification and future research directions. ***Int J Bus Sci Appl Manag***. 6.

Snell, P. (2010). Beware of the risks, and snap up the opportunities in 2010. ***IFPSM ezine Highlights***, January 11, 2010, /http://www.ifpsm-ezine.org/S (retrieved January 11, 2010).

Stavrulaki, E. and Davis, M. (2010), “Aligning products with supply chain processes and strategy”, ***International Journal of Logistics Management.*** Vol. 21 No. 1, pp. 127-151.

Timothy Ch.U. Kalu (1999). Capital budgeting under uncertainty: An extended goal programming approach. ***International Journal of Production Economics***. Vol. 58 Issue 3, p235-251.

Van der Vorst, J.G.A.J. and Beulens, A.J.M. (2002). Identifying sources of uncertainty to generate supply chain redesign strategies. ***International Journal of Physical Distribution and Logistics Management***, 32 (6), 409-430.

Van Donk, D. P., & van Doorne, R. (2015). The impact of the customer order decoupling point on type and level of supply chain integration. ***International Journal of Production Research***, 54(9), 2572–2584. doi:10.1080/00207543.2015.1101176

Van Marrewijk, A., Clegg, S. R., Pitsis, T. S., & Veenswijk, M. (2008). Managing public–private megaprojects: Paradoxes, complexity, and project design. International ***Journal of Project Management***, 26(6), 591–600. doi:10.1016/j.ijproman.2007.09.007

Voordijk, H., de Haan, J., & Joosten, G.-J. (2000). Changing governance of supply chains in the building industry: a multiple case study. ***European Journal of Purchasing & Supply Management***, 6(3-4), 217–225. doi:10.1016/s0969-7012(00)00017-4

Wikner, J., & Rudberg, M. (2005). Integrating production and engineering perspectives on the customer order decoupling point. International Journal of Operations & Production Management, 25(7), 623–641. doi:10.1108/01443570510605072

Wilding, R. (1998). The supply chain complexity triangle. International Journal of ***Physical Distribution and Logistics Management***, 28 (8), 599-616.

Willner, O., Powell, D., Gerschberger, M., & Schönsleben, P. (2016). Exploring the archetypes of engineer-to-order: an empirical analysis. ***International Journal of Operations & Production Management***, 36(3), 242–264. doi:10.1108/ijopm-07-2014-0339

Wright, J. N., & Fergusson, W. (2009). Benefits of the NEC ECC form of contract: A New Zealand case study. ***International Journal of Project Management***, 27(3), 243–249. doi:10.1016/j.ijproman.2008.03.005

Yang, B. and Yang, Y. (2010). Postponement in supply chain risk management: a complexity perspective. ***International Journal of Production Research***, 48 (7), 1901-1912.

Yang, B., Burns, N.D., and Backhouse, C.J. (2004). Management of uncertainty through postponement. ***International Journal of Production Research***, 42 (6), 1049-1064.

Yang, L. (2013). Key practices, manufacturing capability and attainment of manufacturing goals: the perspective of project/engineer-to-order manufacturing. ***Int. J. Proj. Manag***. 31, 109–125.

Yin, Robert K. (2003), ***Case Study Research: Design and Methods***. Thousand Oaks, CA: Sage

Yin, Robert K. (2018), ***Case study research and applications : design and methods***. COSMOS Corporation, LA: Sage

Yudi Fernando, Tim Walters, Mohamad Norris Ismail, Yong Won Seo, Masatoshi Kaimasu, (2018) "Managing project success using project risk and green supply chain management: A survey of automotive industry", ***International Journal of Managing Projects in Business***, https://doi.org/10.1108/IJMPB-01-2017-0007

Zhang, Q., Vonderembse, M. A., & Lim, J.-S. (2002). Value chain flexibility: A dichotomy of competence and capability. ***International Journal of Production Research***, 40(3), 561–583. doi:10.1080/00207540110091695

Zhang, X., Luo, L., Yang, Y., Li, Y., Schlick, C. M., & Grandt, M. (2009). A simulation approach for evaluation and improvement of organisational planning in collaborative product development projects. ***International Journal of Production Research***, 47(13), 3471–3501. doi:10.1080/00207540802356770

Zsidisin, G.A. (2003) 'Managerial perceptions of supply risk', Journal of Supply Chain Management, Vol. 39, No. 1, pp.14–26.

Zsidisin, G. A., & Ritchie, B. (Eds.) (2008). ***Supply chain risk: a handbook of assessment, management, and performance*** (Vol. 124). Springer Science & Business Media.

Appendix A - Interview protocols

1) Since when have you participated in the project? At that time, what was the company doing? What do you do daily in this work? Can you explain your daily activities to me?

If the interviewee is involved in the preventive part, follow the questions below:

2) At the beginning, before execution (contract signature, design, etc.), had the company already considered some possible risks that may arise? Can you give some examples?

Technical risks (work safety, quality risk, design / project risk)

3) In the area of work safety, what type of strategy / practices has the company adopted to prevent risks? Can you give some examples? What kind of skills do you think are necessary to prevent risks? As these preventive strategies influence the execution of the work, can you give some examples? How do these strategies influence the work's efficiency?

Project management risks (documentation or process management, risk due to inadequate communication, risk due to management change, risk due to company reputation, risk due to different culture, risk due to conflicts, risk due to contract and technical proposal disputes, risk in supplier management)

4) In the area of documentation or process management, what type of strategy / practices has the company adopted to prevent risk. Can you give some examples? What kind of skills do you think are necessary to prevent risks? As these preventive strategies influence the execution of the work, can you give some examples? How do these strategies influence the work's efficiency?

If the interviewee is involved in the corrective part, follow the questions below:

2) There were some risks during the execution of the work. Can you give some examples?

Technical risks (work safety, quality risk, design / project risk)

3) In the area of work safety, what type of strategy / practices has the company adopted to correct risks? Can you give some examples? What kind of skills do you think are necessary to correct the risks? As these corrective strategies influence the execution of the work, can you give some examples? How do these strategies influence the work's efficiency?

Project management risks (documentation or process management, risk due to inadequate communication, risk due to change management, risk due to company reputation, risk due to different culture , risk due to conflicts, risk due to contract dispute and technical proposal, risk existing in supplier management)

4) In the area of documentation or process management, what type of strategy / practices has the company adopted to correct the risk? Can you give some examples? What kind of skills do you think are necessary to correct the risks? As these preventive strategies influence the execution of the work, can you give some examples? How do these strategies influence the work's efficiency?

Note: If the interviewee participates in both the preventive and corrective phases, he/she needs to answer all the questions above.