Improving coordination in an engineer-to-order supply chain using a soft systems approach

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Abstract

An empirical study in the ship-building sector has been undertaken to understand the problems associated with the coordination of engineer-to-order (ETO) supply chains and to reveal insights into opportunities for improvements based on the application of soft systems methodology (SSM). A number of alternatives to improve coordination of supply chain have been proposed based on the comparison between a soft systems model and actual practice. These alternatives were summarized into seven general principles that help define the role of individual companies' in coordinating ETO supply chains, highlighting the company's structures and interdependencies that lead to project tardiness. Due to the specific nature of a project which changes according to the context, it is difficult to generalize the soft system model. Nevertheless, future research can further explore some of the principles proposed to deal with coordination problems experienced in other types of ETO project operations, such as construction and oil and gas.

1. Introduction

There is little literature on the problems faced by engineer-to-order (ETO) supply chains and there is still a considerable gap between theory and practice (Gosling and Naim 2009, Mello and Strandhagen 2011). The development of supply chain management theory and practice in ETO supply chains is still relatively immature when compared with other types of supply chains that produce high-volume products (Hicks et al. 2000, Gosling and Naim 2009, Zirpoli and Becker 2011, Shishank and Dekkers 2013, Gosling et al. 2014). Engineering, or product development, which encompasses concept, basic design and detailed engineering, is an integral element of the ETO supply chain that typically is a separate business process in other types of supply chains (Hicks et al. 2000). Furthermore, many ETO companies have been outsourcing production to low-labour cost countries, and retained engineering as a core expertise (Stavrulaki and Davis 2010). This decision has created a barrier between engineering and production that has resulted in the occurrence of protracted delays leading to poor on time delivery performance.

In ETO supply chains there is typically no stock of finished products to immediately satisfy a specific customer need, hence the customer is exposed to the total product lead time (McGovern et al. 1999). The high degree of product customization required by individual customers has a direct impact on the delivery lead-time (Konijnendijk 1994). The greater the degree of customization the longer the lead time, since more activities are performed after receiving the order (Amaro et al. 1999). To remain competitive in this context, companies need to understand customer needs and fulfil customer demands through short lead times. Therefore, lead time reduction is considered one of the most important factors for improving the performance of ETO supply chains (Hicks et al. 2001, McGovern et al. 1999, Konijnendijk 1994).

According to Caron and Fiore (1995), delays happen because of the lack of inter-functional coordination which increases both project lead times and costs. In particular, there is a need for better coordination of engineering and its interface with production activities in an ETO supply chain (Gosling and Naim 2009). Hence, coordinating engineering and production has considerable scope to improve supply chain performance (Hicks et al. 2001). Although the problems related to coordination of engineering-production interface have also appeared in MTS supply chains (Hoek and Chapman 2007, Hoek and Chapman 2006, Pero et al. 2010), the complexity of the product structure and the need to deal with specific customer needs make them more relevant to ETO supply chains (Pandit and Zhu 2007).

To outline the opportunities for improving coordination, this study explores the use of soft systems methodology (SSM). SSM was initially proposed by Checkland (1981) as a way to deal with real-world problem situations involving complex systems which lack a formal definition. This approach enables improving the perceptions about problems through the learning experience gained working with a soft systems model (Checkland and Scholes 1990). This model is used to guide an inquiry process which helps to address meaningful changes for improving coordination. Although SSM has demonstrated its applicability to tackle complex problems, applications of SSM in project-based operations, such as ETO supply chains, are still scarce (Winter et al. 2006).

Therefore, the formal aim of this paper is: *to understand how to coordinate an engineer-to-order supply chain in order to avoid delays and reduce the lead time, and to outline opportunities for improvements based on the application of the soft systems methodology*. To achieve this aim, the following research questions have been proposed:

(i) What are the coordination needs in an ETO supply chain?

(ii) How can SSM be applied to fulfil those needs?

(iii) Based on the application of SSM, what are the alternatives to improve coordination in an ETO supply chain?

The next section provides an overview of the literature that covers the coordination of ETO supply chains and the applicability of SSM in a project context. After that, the research approach is explained and the empirical setting is described. Next, the application of SSM is reported and the current management practices are analyzed. Finally, the conclusions summarize the main findings and address the opportunities for further research.

2. Background

2.1 Project and production management

The emphasis on type of management control often depends on the type of operations. According to Hayes and Wheelwright (1984), volume and variety are two important variables to characterize the different types of operations. In the case of customer-specific products, characterized by low volume and high variety, operations can be managed through project-based processes (Hayes and Wheelwright 1984). A project usually comprises a high level of uncertainty because project activities typically involve unique attributes with a high degree of human judgment with little opportunity for process standardization. The body of knowledge for managing projects, related to 'one-of-a-kind' products, is typically associated within the 'project management' literature, while jobbing, batch, mass and continuous operations are related to 'production management'. While the purpose of a project is to accomplish its objective and then complete, hence temporary in nature, production has the objective of sustaining on-going business and is therefore repetitive (PMI 2013). The 'uniqueness' of each project is an essential characteristic that distinguishes project management from production management (Gosling et al. 2014). According to the Project Management Body of Knowledge (PMBOK):

> "Every project creates a unique product, service, or result. The outcome of the project may be tangible or intangible. Although repetitive elements may be present in some project deliverables and activities, this repetition does not change the fundamental, unique characteristics of the project work. For example, office buildings can be constructed with the same or similar materials and by the same or different teams.

> However, each building project remains unique with a different location, different design, different circumstances and situations, different stakeholders, and so on..” (PMI 2013: p.3)

In general, operations in project-oriented companies are characterized as engineer-to-order (ETO). In ETO companies value is created mainly by developing customer-specific solutions and integrating sophisticated systems (Wortmann et al. 1997). More recently, the emergence of a new paradigm has changed the perception of how companies compete. The main premise is that companies are no longer competing individually but as supply chains (Cooper et al. 1997, Lambert and Cooper 2000). Project organizations have realized that the inter-functional coordination of companies carrying out different activities has the potential of reducing project schedule and cost overruns and the chances of project failure systems (Asbjørnslett 2002, Venkataraman 2007). But while there has been much research on ‘production management’ supply chains there is little work on project-based supply chains that are managed as ETO systems (Asbjørnslett 2002, Venkataraman 2007).

2.2 The engineer-to-order supply chain

Supply chains consist of multiple companies which together satisfy customer needs through products and/or services. As defined by Christopher (1992: p.15): *“A supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer”.* In practice, there are several types of supply chains and different ways to classify them. The customer order decoupling point (CODP) enables differentiation of four principal types of supply chains: make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO), and engineer-to-order (ETO) (Olhager 2003). In ETO supply chains, the CODP is located at the design stage, so each customer order penetrates to the design phase of a product (Gosling and Naim 2009). This means that each product is designed according to specific customer needs.

In general, ETO companies create value in understanding customer requirements, translating them into specifications at product and component level, and integrating components and subsystems into products (McGovern et al. 1999). Shipbuilding, heavy equipment, offshore oil and gas, and construction are typical examples of sectors with ETO operations. Some main characteristics of ETO include: low volume, high demand oscillations, specific customer requirements, various engineering disciplines, high number of customized items, long lead times, contractual relationships, and high capital investment. In general, such characteristics lead to increasing costs. Consequently, ETO companies have pursued different strategies in order to increase cost efficiency, and outsourcing has being a major trend for most of them (Hicks et al. 2000). In most cases design and engineering capabilities are retained at the headquarters while manufacturing activities have been preferentially outsourced, except from the case where manufacturing capability is necessary due to a lack of potential suppliers (Hicks et al. 2000). The result is an ETO supply chain involving multiple companies worldwide to develop and produce high-value products (McGovern et al. 1999, Hicks et al. 2000, Gosling and Naim 2009).

In ETO supply chains there are basically two main flows: physical material flows and non-physical information flows (Bertrand and Muntslag 1993). According to Bertrand and Muntslag (1993), the non-physical stage concerns planning, design, engineering and procurement and the physical stage relates to manufacturing, assembly, and installation. The interdependency between information and material flow gradually increases as products move from development to production. Consequently any changes at the latter stages of product development have a higher impact on the efficiency of production (Simchi-Levi et al. 2008). Managing information and material flows requires a systems approach to identify, analyze, and coordinate the interactions among the entities (Shin and Robinson 2002). Such an approach can help to understand the relationship between various activities across companies, and how the behaviour of a single company can damage the performance of the supply chain as a whole (Forrester 1961).

Many of the difficulties in ETO supply chains arise from managing the customization requirements in the new product development process (Rahman et al. 2003). The importance of effectively managing the interface between engineering and supply chains has been noted by a number of researchers (Dekkers et al. 2013, Pero et al. 2010, Hoek and Chapman 2007). The issue of the 'regularity' of demand becomes particularly relevant in ETO supply chains, whereby demand patterns are inconsistent (Ireland 2004). Competitive bidding within project situations have been found to be an important source of delays and problems (Elfving et al. 2005), and, more generally, project situations have been found to introduce unpredictability in what would normally be regarded as stable supply situations (Sanderson and Cox 2008). Potential responses to such problems include the use of flexible supply chains (Gosling et al. 2013), better information flow through IT (Information Technology) solutions (Pero and Rossi 2013), and business process improvement (McGovern et al 1999). In this paper we focus on the need for a system-based view of co-ordination strategies.

2.3 The role of coordination and systems thinking in ETO supply chains

Malone and Crowston (1994) defined supply chain coordination as *"the act of managing dependencies between entities and the joint effort of entities working together towards mutually defined goals".* In this sense coordination is a relevant aspect of the decision-making process that maintain the order and stability of a system. To be fully coordinated, a supply chain requires that all decisions are aligned to accomplish a global system objective (Shin and Robinson 2002). A system view is essential to highlight individual behaviours that may damage overall performance. This means that coordination is enacted on decisions, communications and interactions between supply chain members and supports companies in managing information and material flows associated with key business processes (Romano 2003).

In an ETO context, poor coordination among project participants to deal with specific customer requirements and product changes generates delays which increase the lead time (Pandit and Zhu 2007). Delays often result in difficulties in defining accurate lead-times. According to Hicks et al. (2001) improving delivery in an ETO context is dependent on both reducing lead times and increasing the reliability of lead time estimates. The three major phases that require coordination are: marketing (tendering), engineering (product development), and production (product realization) (Hicks et al. 2000). Coordination of these processes requires specific coordination mechanisms , such as: mutual adjustments or teams, which can be used in a situation of limited standardization and rarely any repeat orders (Konijnendijk 1994). Konijnendijk (1994) argues that in ETO the use of rules for coordination in the form of design standards is very limited.

In general, supply chain coordination has been addressed mainly from a logistics perspective (Romano 2003), and there has been little effort made to develop a holistic view of coordination (Arshinder and Deshmukh 2008). The requirements of coordination may change according to the nature of activities performed in the supply chain. In some types of supply chains, especially those requiring a high degree of manual work, performance is highly dependent on the people who execute the processes and interact with the technologies. One of the most difficult issues in coordinating supply chain members is to manage people, and more case studies are required to explore qualitative issues related to human-based systems in order to achieve coordination (Arshinder and Deshmukh 2008, Christopher and Towill 2000, Stank et al. 2011).

The operations in ETO companies are project-oriented. Given the number of daily problems that managers have to deal with, a project can be viewed as a problem-solving situation in itself. Indeed, a project is a typical example of human-activity system which involves different parties with conflicting objectives. To prevent poor functional performance, each part may act on behalf of its own interests even though this behaviour can deteriorate the overall performance of the project. Methodologies commonly adopted to tackle problems related to coordination include: analytical, mathematical and optimization tools which are based on the positivism paradigm (Arshinder and Deshmukh 2008). Such approaches, however, usually fail to adequately present complex problems because they tend to focus on one specific element of the system or oversimplifying a problem situation (Jackson 2003). In this sense SSM can provide a holistic view of coordination which may help to understand the roles of each company and the interdependence between its activities.

Previous systems-based research, using predominantly System Dynamics, in project management (which is also relevant to ETO) has elaborated on many of the aspects presented in the paper. For instance, Chapman (1998) emphasized that people issues can have an impact on project performance as great as technical issues. According to Chapman (1998), changing project personnel during the design stage erodes the productivity, and this is something considerable difficulty for recovering. In this paper, we came across a similar finding. While Chapman (1998) has focused on the design stage, we emphasized the importance of people skills, knowledge and experience during the production stage. As we pointed out, developing and maintaining the production capability has a great importance for avoiding delays delivery, particularly when designs are innovative.

The Ingalls case, described by Sterman (2000), sheds lights in some of challenges to manage design changes in innovative and technically sophisticated projects. During the 70s, Ingalls Shipbuilding won a contract to build a fleet of 30 new destroyers for the US Navy, but, as the project progressed, cost overruns projected to exceed $500 million and the case ended up in the court (Sterman 2000). A systems dynamics model was used to help both Ingalls and the Navy set up a common framework for discussion of the causes of the delays and cost overrun. Sterman (2000) points out that the learning from this experience was that the better the understanding of the model, the more likely it will be influential in the resolution of the dispute. More details on the applicability of hard (system dynamics) and soft (soft system methodology) methods in project management are discussed in detail by Crawford and Pollack (2004).

2.4 Soft systems methodology

SSM helps to deal with messy problem situations in the real world which lack a proper definition (Checkland 1981). Such types of problems are common in 'human-activity systems'. According to Checkland (1981), humans are able to attribute meaning to what they experience and observe, hence a transformation process, for example, can assume several meanings according to different points of view. Consequently, each person may pursue their own objectives instead of the objectives set by an organization. Such behaviour may result in conflicting interests which are surrounded by a higher level of subjectivity. SSM aims to accommodate different interests, something that is facilitated by the use of systems thinking.

Checkland and Scholes (1990) highlight that the goal of SSM is not simply consensus-seeking, but preparing the different parties to 'go along with' purposeful actions. The goal is to capture the real-life richness of details and impressions to build SSM models which are used for comparison and debate. Checkland and Scholes argue that SSM is a wider concept than just a 'seven-step' problem solving. SSM is an enquiring process in which a system is developed to organize a debate about purposeful changes (Checkland and Scholes 1990). SSM requires the involvement of people, which may find themselves in the problem situation to collaboratively develop models. Such models help to make sense of a complex situation and to take purposeful actions to change the situation constructively.

Relevant successful applications of SSM include: organizational structuring, performance evaluation, policy assessment and information systems redesign (Mingers and Taylor 1992, Zhou et al. 2007, Liu et al. 2012). In particular the case of larger engineering projects performed by several companies is considered a very complex setting where a system perspective can provide useful insights. Project management practice has been mainly influenced by a 'hard' systems approach, which derives from systems engineering; however, SSM has a growing acceptance in developing understanding of, and tackling, complex problem situations (Pollack 2007).

Conventional project management practices do not address the fundamental sources of uncertainty, which may be present in the conception and post delivery stages of the project life cycle (Atkinson et al. 2006). According to Atkinson (2006), while projects with low uncertainty and ambiguity can be managed using quantitative success measures such as time and cost performance, projects with high uncertainty and ambiguity require a different approach based on the validity of different perspectives and worldviews. Although SSM has been pointed out as a relevant approach to address the complexity of projects (Atkinson et al. 2006), a number of authors (i.e. Winter et al. 2006, and upheld by White and Fortune 2009, Staadt 2012) emphasizes that most studies have been largely theoretical lacking examples of practical application. Therefore, more practical examples of the use of SSM in real project situations are needed to fulfil this gap.

3. Method

3.1 *Overview*

A field study has been undertaken to understand the problem situation and to reveal insights into possible changes. The motivation for carrying out the SSM was to tackle the coordination problems which cause project delays and longer delivery time in shipbuilding projects. Field studies are characterized by the detailed understanding of the practice in a particular company, business or industry (DeHoratius and Rabinovich 2011). The main appeal for conducting a field study is the need to understand empirical phenomena through the use of observation and participation over an extended time period (Karlsson 2009). It gives rich insights into the investigation of complex and dynamic processes by allowing the researcher to collect new data, revisit the site of previous data collection and/or develop the methods used in data analysis (Karlsson 2009). According to Karlsson (2009), the presence of the researcher in the company helps to observe behaviours and patterns of human activity, and become part of the situation being studied to feel what it is like for the people in a specific context.

The research study presented was undertaken in the shipbuilding industry, which is a setting to represent the ETO context. Two companies were selected, a ship designer and a shipyard. These companies are responsible for developing (ship designer) and producing (shipyard) sophisticated and customized vessels that operate in offshore oil and gas platforms. The main unit of analysis is the interdependences between activities carried by these companies in a shipbuilding project, and embedded units correspond to the departments inside each company.

While the study incorporated extensive data from interviews, facilitated workshops and documentation review (see the following section). The core modelling/stakeholder team guiding the SSM application were 4 academics and 3 practitioners. This included the co-authors, the Managing Director of the design company, the Supply Chain Manager and the Engineering Manager. This core team discussed the project as the study progressed.

3.2 Data collection

Data was collected through semi-structured interviews, facilitated workshops, field observation, press material, and access to companies' procedures, flowcharts and project documentation over a period of approximately one and a half years. Engineering and production activities have the greatest lead times. The data was collected with the intention to cover the completion of engineering (data collection phase 1) and production (data collection phase 2) activities. Data collection phase 1 was carried out from October 2010 to May 2011, and data collection phase 2 from October 2011 to July 2012 (Figure 1). Following Kotiadis et al. (2013) the workshop and SSM stages have also been mapped onto the timeline. Reflection and analysis were performed after each data collection period and the preliminary results presented in two workshops. This created a series of iterations between the evidence (via case notes in the form of digitally recorded interviews and meeting), the existing body of knowledge from the literature, and discussions between the research team, as well as with practitioners. This is in line with Dubois and Gadde (2002) and Naim et al. (2002). The latter was particularly influential as the research team had previously tested and applied the iterative data collection approach using the method described therein, including post-data collection brainstorming activities and data triangulation.

To mitigate the bias from interviews and facilitated workshops, triangulation was performed based on additional sources of information including procedures, flowcharts and project documentation. Contracts, schedules, drawings, specifications, standards, and reports were the main types of project documentation used. Data from media press were collected from newspapers, technical magazines and company's public documentation. Such material was organized to highlight facts and events during the development of each project. Due to commercial sensitivity, data on costs were not available.

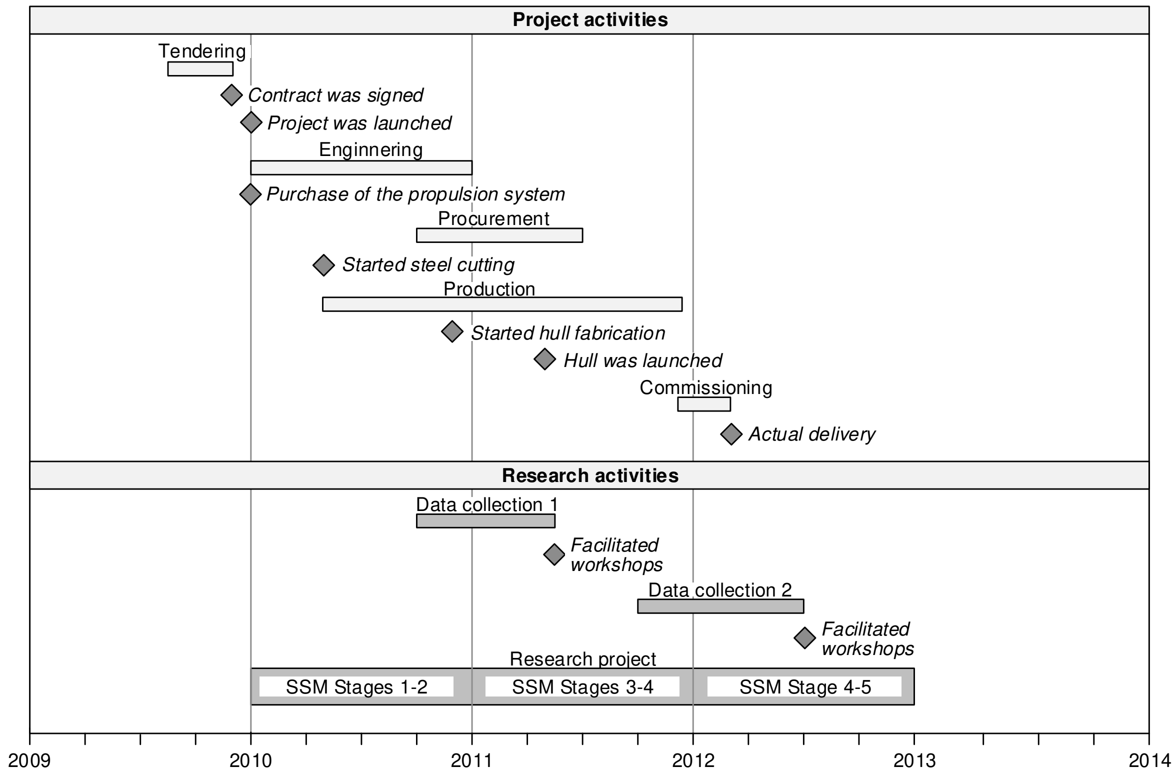

Figure 1. Data collection in relation to the project life cycle

In total, a period of five weeks was spent in companies' sites to perform interviews and facilitated workshops. Sixteen interviews were conducted with the ship designer's staff and twelve with the shipyard's staff. Interviewees from the ship designer included the managing director and the underlining organization: sales manager, design manager, engineering manager, project engineers (4), supply chain manager, procurement coordinator, project manager, production advisor, site engineer. In the shipyard, interviews were carried out with the administrative manager and the respective line organization: engineering manager and design engineer, supply and logistics manager, procurement coordinator, planning and production manager, project coordinator (2) and project planners (2).

Most of these interviews took approximately one hour, and were audio recorded and field notes were used to summarize key points of discussions and to record events and impressions. A semi-structured questionnaire was used to guide the interviews. Due to the nature of soft systems study which deals with ill-defined problem situations, the questions used in the research protocol were 'open questions'. Some examples of questions used were: What are the major problems in this project? How often do these problems happen? How can these problems affect the lead time? Why are these problems happening? How could these problems be mitigated or avoided? More specific questions were made according to the answer from interviewees, such as: What activities will be affected by doing this change? How will they be affected? Asking the same questions across various departments and companies helped us to compare the different views of delays. E-mails and phone calls were used after the interviews to clarify and validate the information gathered from interviewees. On-site observation helped to contextualize the problems described and make sense of their criticality. Drafts of the rich picture were developed through meetings, and were presented at the facilitated workshops, as well as feedback gathered through email exchange between people participating in the study.

Facilitated workshops helped to further discuss problems identified during interviews and to bring insights about possible changes. A mix of insider-outsider viewpoints helped to develop a deep understanding of both organizational and technical issues affecting coordination, and helped to generate a number of alternatives to improve coordination. Three facilitated workshops were carried out, two with the ship designer and one with the shipyard. These facilitated workshops were structured as a debate in which participants were invited to contribute with their opinions about various alternatives to improve coordination, which also helped the team to model the situation (Franco and Montibeller 2010). The number of participants in facilitated workshops varied from 4 to 6 people. The target group was managers from engineering, supply chain, production and project management departments**.** The first workshop, at ship designer, company has focused on discussing critical problems which may delay the project, identifying sources of conflicts between project partners and highlighting potential alternative solutions. The second workshop, at the shipyard, gave us the opportunity to discuss more in depth the problems previously highlighted in the first workshop and to assess which solutions would be feasible to implement. The third workshop, at the ship designer, was dedicated to build consensus around solutions which would make sense from both ship designer and shipyard perspectives. An overview of participants in each of the facilitated workshops is given in Table I.

[Table I. Around here]

3.3 Analysis using soft systems methods

All the data were collected and analyzed by applying the soft systems methods proposed by Checkland and Scholes (1990), namely Customer, Actors, Transformation, Owner, Weltanschauung (worldview), and Environmental constraints (CATWOE), root definition, rich picture and soft systems model as shown in Table II. A more detailed description of these methods is given in the next section. The Figure 2 provides a comprehensible representation of how the soft systems methods are combined with one another. CATWOE, and root definition, supported by a rich picture, has helped to create a soft systems model.

[Table II. Around here]

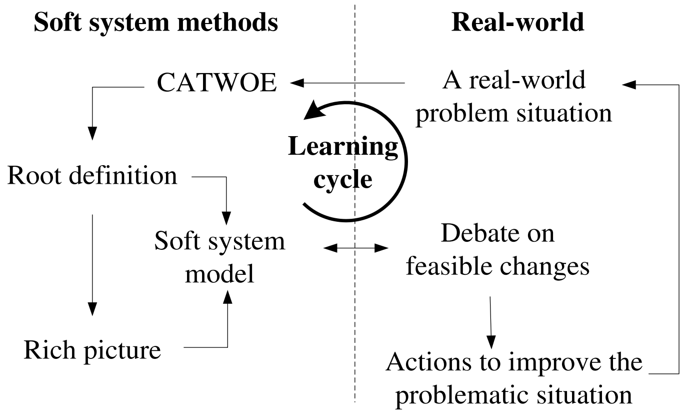

Figure 2. The SSM roadmap, adapted from Checkland and Scholes (1990).

CATWOE

CATWOE summarizes relevant elements of a problem situation. Checkland and Scholes (1990) point out that for any transformation process (T) there will be always different interpretations (W), someone undertaking it (A), someone that can stop it (O), someone who will be affected (C), as well as environmental constraints (E) which are taken as given.

Root definition

The elements of the CATWOE are used for developing a root definition which expresses a formal system definition. A root definition is derived from the worldview and the transformation process. A simple schema "a system to do X by Y in order to achieve Z" has show to be useful to develop a root definition (Checkland and Scholes 1990). Although sometimes a root definition seems trivial, it helps to bring together diverse views about what the system really is.

Rich picture

Other subjective (also called soft) elements of a system can be represented using a rich picture. A rich picture is a visual representation of the problem situation that enables to show behaviours which are important in the problem situation analyzed. There is no formal technique to generate these pictures. Judgments, mindsets, concerns, and other issues concerning human affairs are relevant to represent (Checkland and Scholes 1990). The rich picture was drawn mainly from impressions of on-site observations. These impressions were later on confirmed either by interviews, facilitated workshops, procedures, flowcharts, or press material.

Soft systems model

The modelling process consists of using verbs to structure the minimum number of activities needed to carry out the transformation process (Checkland and Scholes 1990). The model provides a basis for comparison with the perceived reality, and makes the thinking process coherent and capable of being shared. The soft systems approach does not offer pre-conceived answers for a problematic situation. This means that potential changes are addressed comparing the soft systems model and the perceived reality through a debate. In fact, the new perceptions generated during this debate are more important than the model itself. According to Checkland and Scholes (1990) such interpretations do not deserve the status of being universal, new interpretations of the problem are continually generated throughout the debate.

4. Soft system study

The goal of the soft system study was to understand how the functional structure of each company and its interdependence can generate problems which delay the overall project execution. The analysis is carried out considering that the boundary of the system comprises the project activities accomplished by the ship designer and shipyard.

4.1 Rich picture - Representing the project behaviour

To highlight the behaviour of the ship designer and the shipyard during a shipbuilding project, a pictorial representation was developed using a rich picture as given in Figure 3. It shows the perspectives of different actors, both in ship design processes and at the shipyard. It is possible to see from this representation the complex interplay between the actors, and potential tension points as the project progresses. The rich picture illustrates a typical project situation where each function, while attempting to perform in a better manner, ultimately leads to a problematic situation for the system as a whole, as evidenced by protracted delays.

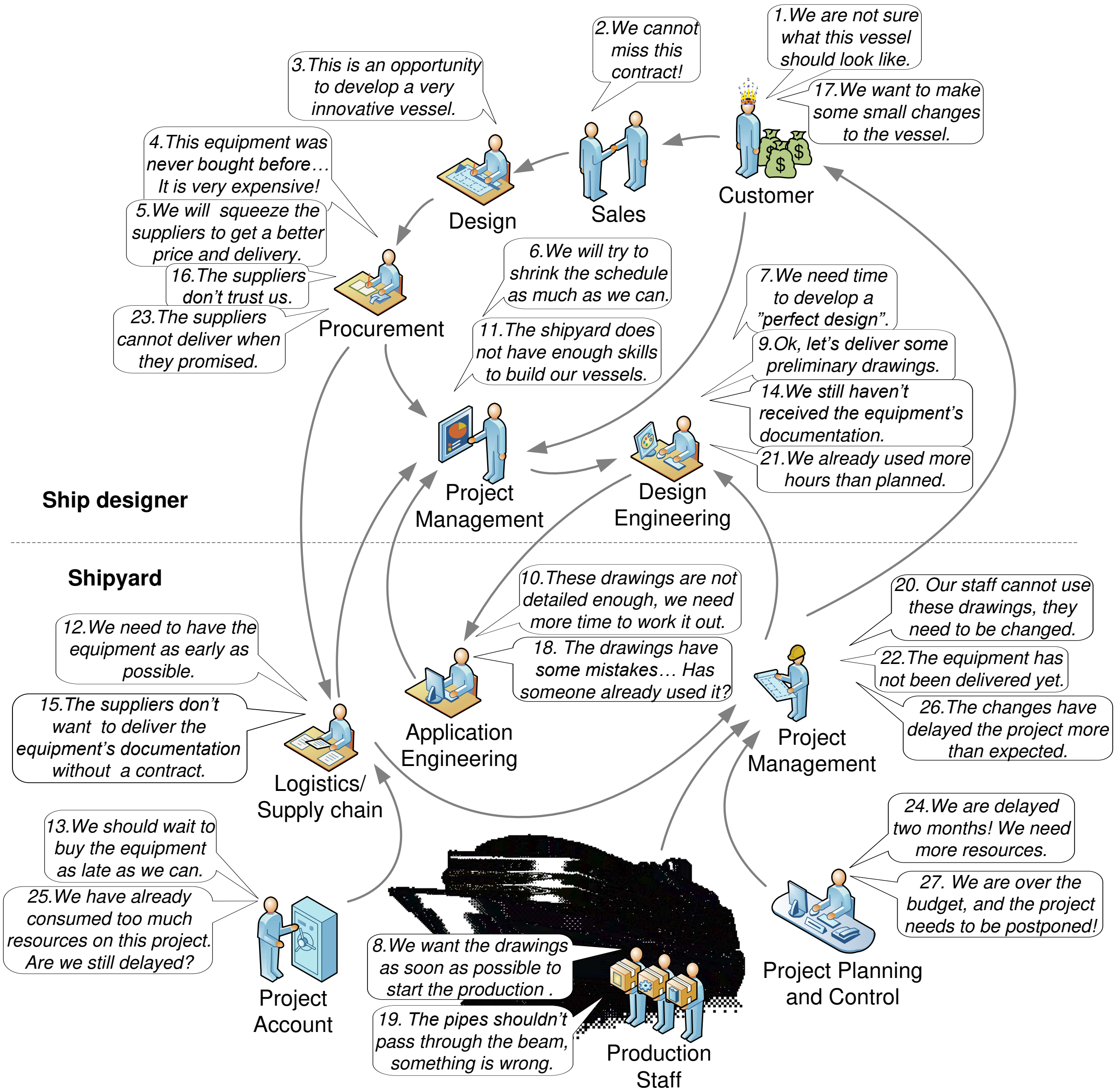

Figure 3. Rich picture of the project behaviour

4.2 Describing the problem situation

This study is based on a project carried out to develop and produce an offshore supply vessel. The project involved several companies including a shipowner, a ship designer, a shipyard, dozens of main equipment suppliers and hundreds of minor other suppliers. The shipowner is the customer, and each offshore vessel needs to be customized according to its specific needs and preferences. The ship designer led the tendering process which is carried out to understand the shipowner's needs and, through an interactive process, define a design that best satisfies those needs. During the tendering, main equipment suppliers and shipyards are contacted by the ship designer to evaluate the technical capability, delivery schedule and cost.

To win a contract, the shipbuilding supply chain needs to demonstrate its ability to deliver a vessel that provides maximum operational performance while minimizing both total costs and contractual risks. Although the ship designer led the negotiation with the shipowner, contractually, it is the shipyard that has the obligation to deliver the vessel to the shipowner. The shipyard has signed a contract with the ship designer only to deliver the drawings and specifications. The ship designer was also contracted to procure main equipment, such as main engines, generators, tunnel thrusters, propellers, cargo systems, electrical and communication systems. In this case, the ship designer established a contract with several main equipment suppliers to deliver the equipment according to the specifications provided. Other minor suppliers, for accommodation, windows, electrical cables, pipes, steels plates and HVAC (heating, ventilation and air condition) had a contract with the shipyard.

Once the contract was signed the project was formally launched. The main project processes include tendering, engineering, procurement, production and commissioning. The description of these processes, companies involved and their main roles are presented in the Table III.

[Table III. Around here]

In the shipbuilding project each company had its main deliveries defined in the contract. Although the contract influences the behaviour of companies setting penalties and incentives, the contract itself does not assure that coordination is achieved. Examples of this lack of coordination appear in a number of quotations from interviews with managers, and evidence problems which occurred throughout the project as shown in Table IV. In summary, the project involves a significant level of interdependence between activities which are difficult to streamline because these activities are not performed at the same company. Consequently, a problem in one company also affected other companies, and negotiations across companies were often needed and joint effort was required to overcome conflicts. Most of the time problems were discovered later during production, when it becomes more difficult to solve. For example, engineering errors seem difficult to avoid, and it has a significant impact in the progress of production activities. When problems were not solved quickly, they propagated to activities performed in other companies producing a 'snow ball effect' that increased the delay of the project even more.

[Table IV. Around here]

4.3 CATWOE - Identifying essential elements of the system

The CATWOE is applied to structure the elements of a shipbuilding project as it is shown in Table V. Interviews were the main data sources to develop the CATWOE. Facilitated workshops, procedures, flow charts, and project documentation were used to collect complementary information.

[Table V. Around here]

The CATWOE shows that the shipowner is the customer (C) of a shipbuilding project. Although the ship designer and the shipyard are the leading companies in delivering a project to satisfy shipowner needs, there are other companies involved including main equipment suppliers, other suppliers and financial institutions (A). Three sub-processes (T) are essential to accomplish the transformation from understanding a customer need through to the delivery of a ship to the customer: engineering (including tendering), procurement and production (including commissioning). The main reason (W) why several companies accept the risks of performing a shipbuilding project is because they each expect to make a profit. The worldview of the ship designer is the primary lens for analysis in this study. This is justified on a number of grounds. Firstly, the ship designer is the hub for co-ordination, bringing together information from the main equipment suppliers, the shipyard, the client and other stakeholders for the needs of the project. Secondly, it is a large global company (employing over 4000 people), playing a substantive role in the establishment of the supply chain, project and industry more generally. The common mindset is that all companies can mutually benefit from using their expertise to satisfy the needs of a shipowner.

Although contractually the shipyard is primary responsible to deliver the vessel to the shipowner, both the ship designer and the shipyard (O) share the authority over the project. The ship designer coordinates the engineering and procurement of main equipment while the shipyard coordinates the procurement of materials and production. The ship designer has a contract with the shipyard, but if delays occur the shipyard will be the most affected actor since the latter allocates more resources and contractually takes the responsibility for delivering the vessel. That is the reason trust plays an important role in this type of project. A shipbuilding project is usually dependent of the approval of classification societies and local authorities (E) which restrict the scope of project decisions. For example, classification societies such as DNV and Lloyd's play an important role in approving drawings and calculations made in the engineering.

4.4 *Root definition - Formally defining the system*

Based on the CATWOE, a root definition is proposed as:

A project, instigated by a shipowner and co-managed by a ship designer and ship yard, that efficiently delivers shipbuilding projects, consisting of engineering, procurement and production, also involving suppliers and financiers, who make profits by satisfying shipowner needs, in terms of delivery, price and vessel performance subject to the regulations imposed by local authorities and classification societies.

This root definition was primarily set up based on data from interviews, observations and project documentation. The perception of company members towards the root definition was captured during the facilitated workshops. Except for a few adjustments, there were not substant changes to the root definition initially proposed

4.5 A soft systems model - Supporting the improvement process

A soft systems model is developed, as shown in Figure 4, in order to structure a debate about possible changes to mitigate the occurrence of problems that delay the project. To develop the model, information about core project activities was listed and cross-checked against data from interviews, procedures, flow charts, and project documentation. Interaction with company members by phone and e-mail was necessary to endorse the model before starting to use it in facilitated workshops to debate feasible changes.

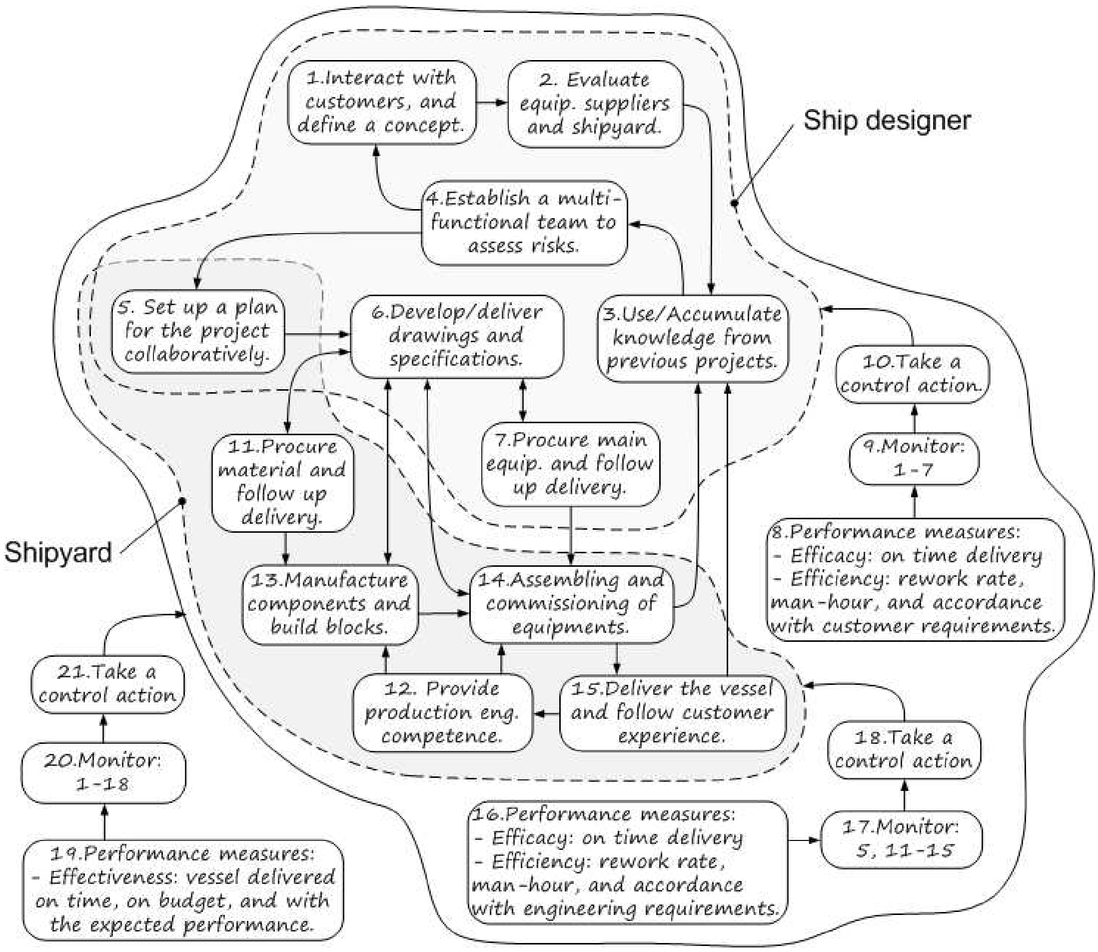

Figure 4. Soft systems model of the ETO supply chain under study

The model is generated to identify the minimum number of activities required to successfully perform the project. The basic activities for developing the soft systems model are activities: (1) Tendering - covers the concept design and systems engineering; (6) Engineering - relates to development of drawings and specifications which are delivered to main equipment suppliers and shipyard as per project schedule; (7, 11) Procurement - the ship designer procures the main equipment while the shipyard procures standard components and commodities; (13) Manufacturing - fabrication of frames and blocks at the shipyard; (14) Assembling and commissioning – the shipyard is responsible for outfitting and commissioning the equipment prior to sea testing; (15) Testing – the performance of the vessel can be continually evaluated to feed back engineering and production. This soft systems model also includes the following support activities: (9, 10, 17, 18) Project management - responsible for monitoring and controlling the execution of project activities within the ship designer and shipyard; (5) Planning and control - plans and schedules are defined collaboratively, and both ship designer and shipyard needs to be committed to achieve the delivery time; (2) Quality assurance - assessment of project partners' capabilities (skills, competence and resources) in order to avoid quality problems later on during the project execution; (4) Risk management - use of knowledge from previous projects in order to assess both technical and management risks; (3) Lessons learned - the knowledge obtained from post-project appraisals need to feed back quality assurance and risk management in order to avoid previous problems; (8, 16, 19) Performance measurement - the performance is measured based on efficacy (the extent the system accomplish its objectives) and efficiency (how well the resources are used), while the performance of project is measured based on effectiveness (the extent the system meets its long term goals); (12) Continuous improvement - production engineering team provides the necessary skills in order to avoid errors and accidents while optimizing the productivity; (20, 21) Managing the whole project – consist of monitoring all activities from 1 to 18 from both ship designer and shipyard in order to ensure the effectiveness of the project.

4.6 Debate on feasible changes

As Checkland and Scholes (1990) suggest, the compassion between soft system model and the perceived reality was organized as a debate. Such debate was structured in four steps. Initially participants received explanations about the soft system model (step 1). So, participants who had not been involved in the early phases had the opportunity to understand what the model is. Then, the participants were exposed to the problems illustrated in the rich picture (step 2). This enabled illustration, for example, of how solutions adopted in one department may create problems in another one. Actions to improve the problem situation were discussed comparing whether each activity in the system model exists in practice (step 3).

A list of potential changes was previously organized based on a literature review (see Appendix A). Such a list was distributed among the participants, and it helped to trigger the debate where participants were asked to give opinions on the feasibility of potential changes. To enrich the debate about the alternatives to improve coordination participants used the list to develop new insights. At the end of the debate, the changes that achieved more empathy among the participants were summarized (step 4). Indeed, the debate serves to 'accommodate' meaningful improvement actions which different people having different worldviews can still live with (Checkland and Winter 2006). It does not mean that all participants agreed with all alternatives. As Checkland and Scholes (1990: p.30) states *"It is wrong to see SSM simply as ... consensus-seeking... the conflicts endemic in human affairs are still there, but are subsumed in an accommodation which different parties are prepared to 'go along with'".* Throughout the debate, the researcher's role was mainly mediating the discussion and stimulating the involvement of participants. Such participants were also taking part in developing knowledge as co-researchers since the practice of dealing with the problem provides tacit knowledge which was essential (Shani et al. 2008). Therefore, this approach has shown useful for conducting research in a complex setting which involves a considerable number of variables and uncertainties, and a lack of reliable quantitative data (Mingers and Rosenhead 2001). In such context, problem solving is not simply an intervention but a continuous learning cycle (Senge 1990).

4.7 Analysis of the current practices and outcomes

The debate, comparing the system model of Figure 4 and the perceived reality, highlighted potential actions for improving coordination as given in Table VI. The left-hand column corresponds to the activities derived from the model. The next two columns question whether such activity exists in practice and who does it respectively. The right-hand column addresses the feasible alternatives to change an activity in order to improve coordination. Even the activities that already exist in practice may offer opportunities for improvements. We have considered five possibilities to categorize whether or not an activity exists. In some case, simply stating 'Yes' or 'No' was not enough to categorize an activity. In some cases an activity does not exist yet, but is 'Being implemented'. The use of 'To some extent' refers to the fact that a particular activity does exist but its scope is rather limited. For example, the ship designer and shipyard have performance measures however the application of such measures in only limited to monitor schedule progress, rework rate and quality problems are not recorded. 'Not formally' indicates that the activity does exist but is not rigorously or routinely undertaken in practice. For instance, a lesson learned is not carried out a process throughout the project by the ship designer, but only as a 'close out' meeting in the end of the project. More than simply highlighting changes SSM helped to structure a debate that increased the knowledge of the problem situation. As Jackson (2003: p.188) states *"Problem resolving should be seen as a never-ending process in which participants' attitudes and perceptions are continually explored, tested and changed, and they come to entertain new conceptions of desirability and feasibility".*

[Table VI. Around here]

5. Discussion

Via the application of soft systems methods, this paper has investigated the role of coordination in an ETO supply chain. At the beginning of the paper three research questions were posed. We now revisit and discuss each question in turn.

The first research question was *'what are the coordination needs in an ETO supply chain?'*. An ETO supply chain consists of multiple companies engaged to perform complex projects. Coordinating these companies and their interrelated activities is regarded as a critical issue for mitigating delays and reducing the total lead time. The main coordination needs in an ETO supply chain are related to design / engineering, procurement, and production / testing. In practice the interdependence between these processes is substantive, and that increases the complexity of coordination.

The second research question was *'how can SSM be applied to fulfil those needs?'*. To deploy effective coordination mechanisms, a system view is necessary. In this study, a number of soft systems methods have been applied, namely: CATWOE, root definition, rich picture and system model. The CATWOE has helped to clarify the structure of the system and the roles of each company as given in Table V. In large projects involving several companies, a holistic view of the project is missing. In this sense, the root definition set a common view about what the system is. Functional silos, inadequate contractual rules, and non-aligned performance measures are attributed to engineering and production not being undertaken within the boundaries of a single company.

The rich picture of Figure 3 enabled the implications of the relationship between two companies to be drawn. The adoption of a systemic perspective to analyse the interdependence between these companies has resulted in a system model. The model shown as Figure 4 indicates a higher number of linkages across the boundaries of each company, and suggests that managing this interface is critical for delivering the project on-time. The comparison between the model and actual practice has guided an inquiry process to tackle the problem situation. The 'system view' provided by SSM was very useful in presenting the complexity in an ETO supply chain. Rather than a recipe for guaranteed achievements, SSM has provided a learning experience to explore a complex problem situation. In SSM, a structured, coherent and shared vision has motivated the improvement process. Therefore the role of SSM is twofold. First, it has enhanced the knowledge about the problem in order to address meaningful changes, and second it contributed to engage people which may support the process of change.

The application of SSM was very effective to involve practitioners in discussing alternatives to improve coordination. Such alternatives were developed together with the people that do the job. The soft system study was undertaken to highlight meaningful alternatives, which make sense to people in that particular problem situation. As Checkland and Schole (1990: p.58) emphasize: *"SSM will always emerge in use in a form which its users find comfortable in the particular situation they are in"*. Hence the alternatives generated are assumed to be feasible from the perspective of the participants in the soft system study.

It is important to note that, due to the focus of the study, and the experience of the academic and practitioner teams, the improvements and alternatives generated were from an operational stand point. Further relational approaches at a strategic level to improve coordination among supply chain members could also be considered. Contracts and incentive structures might be re-thought to encourage collaborative working (Broome, 2002), risk sharing arrangements could help with appropriate allocation of risks (Barnes, 1981) and 3rd party consultants could act as liaisons to facilitate synergies among partners.

Indeed, it was a 'bottom-up' rather than a 'top-down' approach. Although most of the alternatives proposed have not been implemented yet, we expect that managers involved in interviews and facilitated workshops will be engaged in the change process. Further attention is required for ensuring that such changes can be accepted at higher hierarchical levels. From that perspective, the use of a soft system approach which includes tables, diagrams and illustrations can facilitate the communication with top management.

The main weakness of SSM in terms of implementation can be the lack of reliable quantitative data to compare the potential gains adopting the different alternatives to improve coordination. This would be particularly helpful to prioritize the implementation of alternatives that give better results. Additionally, the use of SSM was relatively time consuming in terms of collecting and analysing data as well as organizing facilitate workshops. There was a need to continuously interact with company members, which might be easier when SSM is led by the practitioners themselves, as Checkland and Scholes (1990) suggest.

In terms of learning, the feedback from participants indicates that the soft system approach was useful for improving the perceptions about delays. It was clear in the initial interviews that in the mindset of managers of the ship designer the reason for delays was lack of competence in the shipyard. It was common to hear that delays were a problem of the shipyard rather than of the ship designer. In contrast, on the shipyard side, it was argued that delays occurred because the ship designer had not delivered drawings on-time and several drawings had to be revised after being released. It was quite surprising to realize how the soft system methods helped many participants to change their mindset. By changing their mindset, we expect that companies will be more willing to collaborate with other as they realize the mutual benefits of avoiding delays. A statement from the supply chain manager (ship designer) during one of the facilitated workshops highlights this change of perception: *"I think this approach [SSM] helps us from different departments to understand a bit more about needs and difficulties of other departments. It is not that we have clashes between departments but sometimes one argue in this way [right] and another one in this way [left], two different approaches. Here, we see the whole picture."*

After the SSM study was conducted, a number of the recommendations were taken forward in relation to the alternatives envisaged in Table VI. For activity 2, a new supplier assessment processed was designed and trialled. For activity 3, an improved risk management system was developed which pooled knowledge from previous projects to feedforward into a risk mitigation plan. In considering activity 5, collaborative planning initiatives were trialled, which encourage more pro-active sharing of information. This also helped to shape activity 6, where production plans at the shipyard were considered at a much earlier phase by the engineering teams. A common issue identified at activity 7 was delays at customs due to incorrect paperwork. A new structured approach to document control was developed based on this acknowledgement.

The final research question was *'based on the application of SSM, what are the alternatives to improve coordination in an ETO supply chain?'*.

Based on the specific alternatives generated in Table VI, the generic learning outcomes of the soft systems model can be summarized into seven principles for improving coordination in ETO: systematize requirements and reuse solutions, develop/ maintain the production capability, collaborate with suppliers, integrate engineering and production, structure a 'lessons-learnt' process, enable joint project management and extend use of IT systems. Some of the practical and theoretical implications regarding these principles are described as follows.

Systematize requirements and reuse solutions

In practice, shipbuilding deals with a considerable amount of customer requirements. Accurately translating customer requirements into feasible engineering specifications is one of the most relevant aspects of engineering activity. Customer requirements have several implications which are important to understand as early as possible in order to avoid delays. The use of quality function development (QFD) can help to systematize requirements and to reduce the level of uncertainty during the project (Akao 1990). One of the main advantages of the QDF is to reduce the product development lead times and to enhance customer satisfaction (Youssef 1994, King 1989, Clausing 1994). Although the QFD was originally developed by Japanese shipbuilders (Nishimura 1972), it seems that, outside of Japan, the QFD has not been extensively applied in shipbuilding. The formalization of requirements is the first step towards increasing the adoption of standards components and modular systems in ETO, and this is something essential to reduce late rework and mitigate delays (Jansson et al. 2013). From a manufacturability perspective, both standardization and modularization is highly desirable, and they can provide a smooth transition from engineering to production (Pero et al. 2010).

Develop / maintain production capability

Innovative ship designs have two direct implications for the occurrence of delays. First, it generates a number of errors which leads to a large amount of rework during production, a phenomenon often seen in the construction industry (Barker et al. 2004). Thus, the production capability, which involves staff's skills, knowledge, experience and autonomy, is important to identify and solve such design errors as quickly as possible. Previous literature has shown that the maturity of the design influences the downstream coordination effort (Adler 1995). Valle and Vázquez-Bustelo (2009) has shown that innovative design increases uncertainty and makes it difficult to specify all the project details and diagnose problems. Second, manufacturing operations in a shipbuilding yard often lacks routine and repetition. Streamlining the workflow and creating one-piece flow can enable to shorter the production lead time and improve resource utilization compared to batch processing in shipbuilding (Liker and Lamb 2002) The material flow in ETO is often complex since several different projects are executed at the same time (Ballard and Howell 1998). While in high-volume manufacturing (make-to-stock) the challenge is high efficiency (productivity) without compromising quality (Naylor et al. 1999), in low-volume manufacturing it is high quality without compromising efficiency.

Collaborate with suppliers

Multi-sourced adversarial trading is widespread in ETO companies (Hicks et al. 2000). Particularly in shipbuilding, lack of collaboration is one of the major issues concerning quality and efficiency (Held 2010). Held (2010: p.372) points out that *"Joint cost reducing programmes with suppliers are only at the beginning in the shipbuilding industry, even though they would make it possible to avoid time consuming and capacity binding concept competitions and RfQs [request for quotations]"*. Suppliers have little commitment with the shipbuilding project because the purchase for a single project is relatively small compared to suppliers' total sales volume. In terms of delivery performance, most suppliers are not delivering equipment on time but this is not seen as a major problem because the project is frequently delayed as well. In fact, when a supplier is delayed this opens up an opportunity to project partners to blame someone for their own delays (Ford and Sterman 2003). To overcome this situation, shipbuilding companies may have to give more importance to on time delivery as the criteria to select suppliers. In addition to that, suppliers may also have to start focusing on improving the overall project performance rather than obtaining individual advantages through opportunistic behaviour. The experience of the construction industry shows that collaboration has evolved when not constrained by contractually-defined partnering relationships (Briscoe and Dainty 2005).

Integrate engineering and production

Integration is necessary to manage engineering changes more effectively and ensure a seamless information flow. Integration in shipbuilding depends on several aspects, such as: co-located teams, integrated IT, common goals, direct communication and similar organisational culture (Held 2010). According to Held (2010), the interdependence between activities performed by the ship designer and shipyard is massive, thus it is important that the ship designer can interact directly with the shipyard in order to handle changes quickly and then prevent generation of delays in other downstream activities. The importance of integrating engineering and production is more evident when production is outsourced (Ulrich and Ellison 2005, Novak and Eppinger 2001, Treville and Trigeorgis 2010). For example, Treville and Trigeorgis (2010) argue that the synergy between engineering and production is a critical factor to deliver customised products on time and to directly manage problems. According to Treville and Trigeorgis (2010), having engineering and production located at the same site enables companies to better exploit the innovation capability and to achieve customisation and responsiveness. Outsourcing production of complex products, when companies do not maintain high levels of dominance over the activities that are performed, creates coordination challenges which lead to poor project performance (Hui et al. 2008, Dekkers et al. 2013).

Structure a lessons-learnt process

In shipbuilding, effective decisions rely on experience dealing with similar problem situations (the learning curve). "*When it comes to the adaptation to change and adoption of new business concepts and work procedures, incremental advances typically prevail. Radical change among maritime firms is not so frequently experienced"* (Ulstein and Brett 2012). This situation indicates the need to engage project participants in a more systemic learning process (Senge 1990) which can be used to support the early project phase in mitigating potential problems. For example, post-project appraisal can be an additional mechanism for helping companies to cope with uncertainty, interdependence and change which characterize projects in an ETO supply chain (Twigg 2002). Hence, the learning obtained by the project team can increase the effectiveness of coordination and progressively reduce the need for interaction. Indeed, the learning developed carrying out complex projects is essential for avoiding excessive adaptation in later phases which can delay the project. To address the root cause of problems in a complex situation, companies need to implement a more effective learning process (Parnaby and Towill 2012). This is particularly the case in the ETO environment, since learning and innovation must be captured in such a way that it may inform future one off projects (Gosling et al. 2014). We believe that soft systems methods can contribute to this learning process.

Enable joint project management

Shipbuilding projects involve multiple companies, and each company has to take into account how their decisions can impact on the project as a whole. For example, if the shipyard does comply with the payment milestones for main equipment suppliers, such suppliers will not deliver product data sheets to the ship designer. If the ship designer does not receive the data sheets as planned, the ship designer may have to reallocate resources to another project and it may take several weeks until the same resources are available again. If the ship designer has not allocated enough resources to work in the project, the shipyard may have production delays due to unavailability of drawings and specifications. As projects become more fragmented, the risk of having conflicts also increases considerably. In shipbuilding projects, joint project management it is an alternative to support problem resolution and to solve conflicts (Held 2010). Joint project management, or partnering (Cowan et al. 1992), means that a team or committee involving members of various companies is set up to coordinate the decisions among project partners. Since most of project members are geographically distributed, virtual project teams may have to be adopted. According to the PMBOK (PMI 2013), virtual teams coordinate their activities and exchange project information based on collaborative tools, such as: shared online workspaces and video conferences. Similar concepts have been discussed within the literature on virtual organizations and enterprises (Goldman et al. 1995), as well as virtual projects (Pokharel 2011).

Extend use of IT systems

The shipbuilding project is carried out in a dynamic environment where project managers are not able to effectively coordinate cross-business activities without the support IT systems. Nevertheless, the use of IT system in shipbuilding is rather limited, except to design and engineering activities (i.e. Solesvik 2007). One of the challenges is to integrate project management data from several partners into a single database. Due to the complexity of the project, a large amount of data and information have to be exchanged between the project partners. The considerable number of companies participating in the project causes numerous different IT systems which are challenging to integrate. Integration of these system means that data can be easily transferred from one system to another (Gronau and Kern 2004). The information that flows through the shipbuilding supply chain can be accurate and available by integrating the existent IT systems (Bolton 2001). In addition to that, more functionalities are necessary to enhance the collaboration with project partners, to communicate across multiple companies, to integrate logistic and production information, etc. IT developments in project oriented companies such as ETO are apparently less developed compared to serialized production.

6. **Conclusion**

The paper provides relevant contributions in a number of ways. First, it gives a better understanding of coordination in ETO supply chains and highlights alternatives to improve coordination based on the application of SSM. Most of the discussion on coordination has been carried out at a conceptual level, and there is still a lack of guidance about how companies can improve coordination (Fugate et al. 2006). From that perspective, this study helps to shorten the gap between theory and practice on coordination. Secondly, the paper helps in indicating potential improvements in the coordination of the engineering-production interface by showing how the functional structure of each company and its interference generate problems that delay the project. Thirdly, the paper enhances our knowledge of problem solving approaches in a complex setting, such as ETO supply chains, providing a detailed application of SSM. As the literature has shown (i.e. Jackson 2003, Atkinson et al. 2006), other methodologies based on a positivism paradigm (i.e. analytical, mathematical and optimization tools) usually fail to analyse and document complex problems by focusing on one specific element of the system or oversimplifying a problem situation. Therefore, SSM provides a holistic view of coordination in a context with considerable number of variables and uncertainties, and lack of reliable quantitative data. SSM was found to be a useful approach for outlining opportunities for improvement in this challenging sector. Due to the specific nature of a project which changes according to the context, it is difficult to generalize the model itself. Thus, the authors encourage further research effort to explore some of the general principles proposed to deal with coordination problems experienced in other types of ETO project operations, such as construction and oil and gas, as well as to adopt a broader perspective which also includes other ETO supply chain members i.e. equipment supplier and customers. Finally, it might be interesting to adopt few quantitative measures in order to perform analysis on cost efficiency, lead-time reduction and quality improvement.

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Group meeting ___ / ____ / ________

Name: .... Position: ....

Activity in the model	Does it exist?	Who does it?	What are the alternatives to improve it?	Applied? (yes / no)	Feasible? (x)	Unfeasible? (x)
1. Interact with customers, and define a concept.	Yes	Design dept. (Ship designer)	• *Involve suppliers into development*			
			• *Formalize customer requirements (QFD)*			
			• *Use of design rules based on previous projects*			
			• *Use of multifunctional teams during the design*			
2. Evaluate equipment suppliers and shipyard.	Being implemented	Project management dept. (Ship designer)	• *Establish a committee to plan and develop capabilities*			
			• *Proceed supplier/shipyard quality certification - TQM*			
3. Use/Accumulate knowledge from previous projects.	Not formally		• *Deploy a system to manage the knowledge developed in projects*			
			• *Conduct post-project appraisal based on project performance*			
4. Establish a multifunctional team to assess risks.	To some extent		• *Develop a culture of trust (sharing risks and rewards)*			
			• *Perform total cost analysis to assess hidden costs*			
			• *Analyze the critical modes of failure (FMEA – product/process)*			
5. Set up a plan for the project collaboratively.	Being implemented	Project management dept. (Ship designer/ Shipyard)	• *Implement a cooperative production planning approach*			
			• *Use flexible/adaptable scheduling (i.e. critical chain, last planner)*			
			• *Critical analysis of overlapping project activities*			
			• *The design work need to be approved by manufacturing*			
			• *Plan for resolving producibility issues after design is released*			
			• *Manage product changes (design spiral)*			
6. Develop/deliver drawings and specifications.	Yes	Design dept. and engineering dept. (Ship designer)	• *Integrate product information systems (PLM)*			
			• *Adopt modular design/standard items*			
			• *Involve procurement/manufacturing in the specification*			
7. Procure main equipment and follow up delivery	Yes	SCM dept. (Ship designer)	• *Develop strategic partnerships*			
			• *Collaborate with suppliers (supplier development)*			
			• *Use of turnkey suppliers/systems suppliers*			
			• *Consolidate purchasing*			
			• *Develop new suppliers*			
			• *Ensure on-time payments to suppliers*			

			• *Use check lists before shipping equipments*			
8. Performance measures: Efficacy / Efficiency	To some extent	Project management dept. (Ship designer)	• *Have similar values/Common performance measures*			
			• *Joint project management (visibility of project status)*			
9. Monitor 1-7	To some extent		• *Integrate management information systems (communication)*			
10. Take a control action	To some extent		• *Joint solving problem teams*			
			• *Use a protocol for dealing with problems and disputes*			
			• *Stimulate face-to-face communication*			

11. Procure material and follow up delivery	Yes	SCM dept. (Shipyard)	• *Collaborate with suppliers (supplier development)*			
			• *Use electronic Data Exchange (EDI)/E-procurement*			
			• *Adopt frame agreements*			
			• *Implement vendor managed inventory (VMI)*			
			• *Use online inventory management/inventory control*			
			• *Adopt kanban / JIT deliveries*			
			• *Joint container systems*			
			• *Consolidated purchasing*			
			• *Develop new suppliers*			
			• *Ensure on-time payments to suppliers*			
12. Provide production engineering competence	No	Production dept. (Shipyard)	• *Streamline the workflow / Process orientation (visibility)*			
			• *Adopt process standardization*			
			• *Time compression (eliminate NVA time)*			
			• *Shift production from ETO to ATO*			
			• *Exchange of design and production information*			
			• *Generate detailed manufacturing/assembling instructions*			
13. Manufacture components and build blocks	Yes	Production dept. (Shipyard)	• *Integrate logistics and production information*			
14. Assembling and commissioning equipments	Yes	Production dept. (Shipyard) / Equip. suppliers	• *Increase the autonomy (semi-autonomous groups)*			
			• *Improve the manufacturing flexibility (multifunctional workers)*			
15. Delivery the vessel and follow customer experience	To some extent	Quality management (Shipyard/Ship designer)	• *Follow up the customer/crew experience (social media)*			
16. Performance measures: Efficacy / Efficiency	To some extent	Project management dept. (Shipyard)	• *Have similar values/Common performance measures*			
			• *Joint project management (visibility of project status)*			
17. Monitor 5, 11-15	To some extent		• *Integrate management information systems (communication)*			
			• *Adopt shop floor coordination using RFID, real time data, ...*			
18. Take a control action	No		• *Joint solving problem teams*			
			• *Use a protocol for dealing with problems and disputes*			
			• *Stimulate face-to-face communication*			

19. Performance measures: - Effectiveness	No	Project management team (Ship designer/ Shipyard)	• *Have similar values/Common performance measures*			
			• *Joint project management (visibility of project status)*			
20. Monitor 1-18	No		• *Integrate management information systems (communication)*			
21. Take a control action	No		• *Coordinate inter-firm teams*			

Comments?

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Table I - Overview of participants in group meetings

	Participants	Group meeting #1	Group meeting #2	Group meeting #3
Ship designer	Design Manager	✓		
	Engineering Manager	✓		✓
	Supply Chain Manager	✓		✓
	Project Manager	✓		✓
	Site Engineer		✓	✓
	Production Advisor			✓
	Project Engineer			✓
Shipyard	Engineering Manager		✓	
	Application Engineer		✓	
	Planning and Production Manager		✓	
	Supply and Logistics Manager		✓	
	Project Coordinator		✓	

Table II. Summary of data collection procedure and its correspondent method of analysis

Methods / **Data**	**CATWOE**	**Root definition**	**Rich picture**	**Soft systems model**
Interviews	✓	✓	✓	✓
Group meetings	✓	✓	✓	✓
Observation			✓	
Procedures	✓	✓		✓
Flow charts	✓		✓	✓
Project documentation	✓	✓		✓
Press material			✓	

Table III. Overview of processes, actors and roles

Shipbuilding processes	Companies involved	Main role
1. Tendering: translate shipowner needs into product requirements.	Shipowner	Externalize aspirations, desires, and expectations, provide information needed and discuss concepts.
	Ship designer	Define requirements considering a broad range of aspects (efficiency, safety, cost, etc.) and develop general specifications.
2. Engineering: develop technical specifications based on product requirements.	Ship designer	Develop technical specifications and detailed drawings according to schedule.
	Main equipment suppliers	Provide technical information about main equipments when it is required.
	Shipyard	Provide technical information from other suppliers about equipments when it is required.
3. Procurement: purchase equipments and materials based on technical specifications.	Ship designer	Negotiate contractual terms and conditions, purchase main equipments and follow up delivery.
	Main equipment suppliers	Make quotations, provide technical specifications, and answer inquiries.
	Shipyard	Negotiate contractual terms and conditions, purchase materials and equipments and follow up delivery.
	Other suppliers	Make quotations, provide technical specifications, and answer inquiries.
4. Production: manufacture and assembly the vessel following the technical specifications.	Ship designer	Deliver technical specifications and drawings, and answer inquiries.
	Shipyard	Manufacture blocks, build the hull, and assemble the equipments according to schedule.
	Main equipment suppliers	Deliver equipments according to the specifications received from engineering.
	Other suppliers	Deliver equipments according to the specifications received from shipyard.
	Shipowner	Follow up the realization of quality checks and monitor the progress of the project execution.
5. Commissioning: assure that the vessel is ready to operate and evaluate the adherence to contractual specifications.	Main equipment suppliers	Inspection and test equipments, generate reports, and provide technical support.
	Shipyard	Perform sea trials, make adjustments, and support suppliers.
	Shipowner	Supervise tests, provide feedback, and involve crew members.

Table IV. Example of problems evidencing the lack of coordination

Problem	Consequence	Quotation
Poor quality of documentation	The quality of the documentation affects the performance of the engineering work generating delays and reworks. In addition, poor technical documentation requires more interaction with equipment suppliers and shipyard.	*"Many of these shipyards are not making drawings themselves, and they do not have a good understanding of what is really needed for the engineering department to do good drawings. They don't understand at all our need for documentation".* Project Manager (Ship designer)
Delay to deliver drawings	It directly impacts the work of the shipyard by delaying the project. In most cases the shipyard assumes the risks of buying material before receiving the specification in order to avoid such delays.	*"Deliver the drawings in the right time is the most difficult thing for us because we are missing information [from equipment suppliers]".* Project Manager (Ship designer)
Product changes after production starts	Late product changes delay the whole project. After the design freezes, any change will certainly impact the performance of the shipyard. The effect of changes on other components already built tends to be underestimated.	*"Drawings from all the blocks were updated. I start to build, and then they [ship design & engineering] start to replace the drawings for updated versions. For example, they [ship design & engineering] say that 'the inspection door cannot be placed there anymore, close it and open a new one in another place'".* Planning and Production Manager (Shipyard)
Long time to find and correct errors	If an error is found and not communicated quickly to all other project partners, more errors will continue to be generated consequently increasing delays. Companies tend to hide their errors assuming that communicating them will give a bad reputation.	*"So the big killer for us is HVAC (Heating, Ventilation and Air Condition) system that is the area where we do the biggest mistakes and it cost the biggest money and we don't find out about the mistakes until very late in the project. That is the major problem."* Engineer Manager (Ship designer)
High number of quality problems	All in all, quality problems end up affecting the shipyard most. When discovered during the production, errors demand more time to solve and therefore increase delays.	*"There is a well-know standard defining that the maximum capacity of transportation for certain products is 800 m^3. But, they [ship design and engineering] sent us a design where the total capacity of the tanks was 900 m^3. I realized the mistake and informed my team, but the tank was already built".* Application Engineer (Shipyard)
Information flow is not integrated	The lack integration between engineering and production can generate reworks/delays and redundant work demanding more staff. Furthermore, the lack of integration affects the time to find and correct errors.	*"Sometimes we make a notification to someone of the structure design, but this information does not go through other disciplines such as accommodation. And now we [at the shipyard] are struggling because there is a beam crossing a furnished compartment".* Application Engineer (Shipyard)
Little visibility of processes	In order to plan activities it is necessary to have a good visibility of the progress of the work. Allocating resources to activities when it is not needed increase costs and buying material/ equipment very early affects the cash flow.	*"I need to assembly an engine that comes from a supplier abroad, and I don't know anything about this engine. I will give you an example, we assembled the thruster, and now we have to remove this thruster to change its base because the base was 70 millimeters larger than it should be".* Planning and Production Manager (Shipyard)
Partners may over evaluate their own skills	It is difficult to precisely measure the capabilities needed to perform a project. Also project partners deny admitting lack of capability in order to avoid being blamed for all the mistakes throughout the project.	*"If people at shipyard have not made this type of vessel before, then, of course, they will realize that there are new solutions which they have never used. They may think that this is a very easy vessel because the hull is a small one. And, often, an offshore vessel is small, but it has a lot of equipments in a small area."* Procurement Coordinator (Ship designer)
Delays to deliver equipments	It has a significant impact in the occurrence of delays during the production. Having the equipment very early, however, demands more area for storage and increases the risks of accidental damage.	*The equipment arrives there [harbor], then it goes to the customs. If any information is missing…, then all the documentation needs to be corrected …. The equipment will not be released …, and it'll take from two to three weeks. During this time the equipment stays at the harbor and the company has to pay a storage fee, moreover this delay will have impact on the production".* Supply and Logistics Manager (Shipyard)
Processes are difficult to follow up	The number of project activities is very high and consequently it is difficult to follow them up. This lack of visibility increase delays due to false impression of the project being on-time.	*"The link with the ship design & engineering demands more attention and needs to be followed up frequently. Because it may happen that information is stuck in the middle of the process waiting for someone to make a decision. For example, the list of electrical cables that we are struggling to have here [shipyard] was already available there [at the ship design & engineering], but nobody sent it because of the size of the file".* Project Coordinator (Shipyard)

Table V. CATWOE of a shipbuilding project

C	*Who will be affected by the project?*	Shipowner
A	*Who is performing the project?*	• Ship design & engineering • Main equipment suppliers • Other suppliers • Shipyard
T	*What are the main processes in the project?*	Three sub-processes (T) are essential to accomplish the transformation from understanding a customer need through to the delivery of a ship to the customer: engineering (including tendering), procurement and production (including commissioning).
W*	*What is the meaning of performing the project?*	Companies can mutually benefits from performing shipbuilding projects that satisfy a specific shipowner's needs.
O	*Who is the responsible for the project?*	Ship designer (indirectly) and shipyard (directly).
E	*What are the environmental constraints?*	• Classification societies (certification) • Authorities (regulations) • Financial institutions (banks, brokers, etc.) • Healthy, Safety, Environmental norms

* From view point of ship designer (mainly) and shipyard.

Table VI. Comparison system model and perceived reality

Activity in the model	Does it exist?	Who does it?	What are the alternatives to change it?
1. Interact with shipowner, and define a concept.	Yes	Design department (Ship designer)	Implement a systematic analysis of customer requirements applying quality function development (QFD). Incentivise the early involvement of production to improve manufacturability.
2. Evaluate equipment suppliers and shipyard.	Being implemented	Project management department (Ship designer)	Assess main equipment suppliers and shipyards (quality certification). Set up plans for developing equipment suppliers' and shipyards' capabilities in order to reduce potential risks.
3. Use/Accumulate knowledge from previous projects.	Not formally		Conduct post-project appraisal and use a database to manage the knowledge developed in previous projects.
4. Establish a multifunctional team to assess risks.	To some extent		Perform total cost analysis that includes indirect costs (i.e. coordination costs, supplier/shipyard development costs).
5. Set up a plan for the project collaboratively.	Being implemented	Project management department (Ship designer, Shipyard)	Make plans collaboratively and provide more flexibility to adjust plans to new project situations (manage product changes). Integrate ship designer and shipyard plans.
6. Develop/deliver drawings and specifications.	Yes	Design department and engineering department (Ship designer)	Incentive the adoption of modular systems and standard components. Integrate design teams using product information systems and project-oriented office layout. Involve main equipment suppliers/shipyard in development of specifications.
7. Procure main equipment and follow up delivery	Yes	SCM department (Ship designer)	Collaborate with main equipment suppliers to assure that all documentation, equipment and assembling instructions are delivered on-time.
8. Performance measures: Efficacy / Efficiency	To some extent	Project management department (Ship designer)	Establish common performance measures and use a system to monitor the progress of projects and highlight problems in different phases.
9. Monitor 1-7	To some extent		
10. Take a control action	To some extent		Use joint problem-solving team and project management team to solve conflicts.
11. Procure material and follow up delivery	Yes	SCM department (Shipyard)	Develop a culture of trust with suppliers to receive the technical documentation and equipment on-time. To build trust it is necessary to adopt a procurement approach focusing not only price but also other aspects such as on-time deliveries, number of quality problems, level of service, and so on.
12. Provide production engineering competence	No	Production department (Shipyard)	Streamline the workflow, stimulate process standardization and provide instructions for manufacturing/ assembling critical components.
13. Manufacture components and build blocks	Yes	Production department (Shipyard)	Integrate logistics (delivery of drawings and equip) and production information. Improve the flexibility using more multifunctional workers and semi-autonomous teams.
14. Assembling and commissioning equipment	Yes	Production department (Shipyard and Main equipment suppliers)	
15. Deliver the vessel and follow shipowner experience	To some extent	Quality management (Shipyard and Ship designer)	Implement an approach to follow up the crew experience onboard the vessel. This can be facilitated through use of social media (i.e. Facebook and Twitter).
16. Performance measures: Efficacy/ Efficiency	To some extent	Project management department (Shipyard)	Establish common performance measures and use a system to monitor the progress of projects and highlight problems in different phases.
17. Monitor 5, 11-15	To some extent		
18. Take a control action	No		Use joint problem-solving team and project management team to solve conflicts.
19. Performance measures: - Effectiveness	No	Project management team (Ship designer, Shipyard, and Shipowner)	Monitor the performance measures to assure that the system reach its goal (see 'root definition' section 5.1). Due to geographical distribution of project partners, more IT systems are needed to support this activity and facilitate collaboration.
20. Monitor 1-18	No		
21. Take a control action	No		Coordinate inter-firm teams and communication across multiple companies in order to enable joint project management.

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