USER-SUPPLIER INTEGRATION THROUGHOUT THE DIFFERENT LIFECYCLE STAGES OF THE PRODUCTION EQUIPMENT

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Abstract: As production equipment is often designed and built by equipment suppliers rather than made in-house, a collaborative buyer-supplier-relationship could be utilized in order to create robust solutions and enhance innovative ideas. The purpose with this paper is to explore critical user-supplier collaboration activities throughout the different lifecycle stages of the production equipment development. The purpose is accomplished by a literature review and a case study including more than 30 semi-structured interviews at four companies. The challenges vary depending on equipment life cycle phase and user/supplier perspective. A life cycle model with eight stages is proposed including critical interconnected activities for each stage.

Keywords: Production equipment development, User-Equipment supplier integration, Life cycle, Manufacturing industry.

1. INTRODUCTION

In today's competitive manufacturing environment, it becomes clear that to stay competitive, the design and implementation of production equipment needs to be thoroughly thought out, as it has become an economic and strategic imperative. To succeed, dedication is required as well as a shift in attention from the operations phase to the under-utilized potential of the design of production systems (Bellgran and Säfsten, 2010). The potential of gaining a competitive edge by improving both the way the production system is designed and the way it is operated is often ignored, although it is a well-known fact that it is during the design phase where the most important decisions are made. Consequently, if the production system is not designed in a proper way, this will eventually end up with disturbances during both start-up and serial production. The result is evidently low capacity utilization, high production cost and hence low profitability. Also, when the process of designing the production system is recognized in industry as a means of achieving the best possible production system, the next step for industry is to actually utilize this design process in order to create new production systems and technology caracterized by innovation and differentiation that supports the need for increased sustainability.

One critical part of the design of the production system is the design of new production equipment since changes in the technology allow for larger changes to the production process (Pisano, 1997) leading to enhanced operational performance. Utilizing the production equipment development process in an effective and efficient way proves a great potential for innovation and differentiation by the creation of new and unique production processes and technologies and thus contribute to a company's success. However, the development of production equipment is characterized by high complexity due to the large number of interdependent activities and functions involved. A change or modification in the production equipment will also affect the other subsystems within the overall production system. Further, successful production equipment development projects are facilitated by a strong integration between the user/buyer and the equipment supplier. As production equipment is often designed and built by equipment suppliers rather than made in-house by the manufacturing company, a collaborative buyer-supplier-relationship could be utilized as a competitive means in order to create robust

solutions as well as enhance and implement innovative ideas. Previous research points out the importance to study the interconnected activities during the lifecycle of the production equipment since technical problems, information needs and managerial challenges will be different. At present, research has mainly focused the user perspective ignoring the fact that the input of the equipment supplier is critical (e.g. Wu, 1994; Bellgran and Säfsten, 2010). In addition, a majority of the prior studies are performed in the process industry or within the context of new product development projects (e.g. Rönnberg Sjödin, 2013). Accordingly, research emphasizing the user-supplier relationships with a lifecycle approach and applied within the manufacturing industry is limited thus offering the opportunity of further scientific investigations. The purpose of this paper is therefore to explore critical user-supplier collaboration activities throughout the different lifecycle stages of the production equipment development. The purpose will be accomplished by a litterature review and a comprehensive case study.

2. FRAME OF REFERENCE

2.1. Opportunities and challenges in successful user-supplier collaboration

Since the technical subsystem of the production system is often designed and built by machine/production equipment suppliers rather than made in-house by the manufacturing company (Hutcheson, Pearson *et al*., 1996; Reichstein and Salter, 2006) collaborating with the equipment suppliers is of utmost importance for manufacturing companies. Focusing on the process of designing production equipment in cooperation with the equipment suppliers proves a great potential for the generation of new innovative ideas that could be realized in the new equipment. Earlier research points out that to have a good network and strong collaboration with equipment suppliers is critical in both radical and incremental production process development (Lager and Hörte, 2005).

For the equipment supplier a successful collaboration increases the possibilities to learn and improve their own development capabilities. A functioning collaboration is necessary to gain knowledge and expertise about experiences, process data and optimizations done with the production equipment in the operation phase (Rönnberg Sjödin, 2013). In addition, the equipment suppliers are strongly dependent on collaborating with manufacturing companies to enhance their innovative activities. Hutcheson *et al*. (1995) point out that by collaboration with the manufacturing company the equipment suppliers can get access to operation expertise that often is missing internally.

For the user, many of the problems that arise from not having a structured early equipment management program such as: start-up period repairs, inspection, adjustments, and initial lubrication and cleaning (Nakajima, 1984), can be mitigated if having a horizontal communication with the equipment supplier. The ability to achieve higher installation performance is also increased when users and equipment suppliers develop stronger relationships in the earlier phases of the development project (Abd Rahman, Brooks *et al*., 2009).

If a functional user-supplier collaboration is enhanced, the possibility to get a holistic view increases. The design of production equipment is an iterative process requiring input from members of various functions with different backgrounds and roles. Holden and Konishi (1996) conclude that the old model of technology transfer, i.e. import of technology, has to be replaced by more reciprocal collaboration including a more dynamic and interactive process of balancing internal R&D with that of strategic partners around the world. This is in line with Malik (2002), who argues that technology transfer should be a reciprocal iterative process. Consequently, it is of utmost importance to have good contacts and strong collaboration with equipment suppliers in order to explore new process development opportunities (Lager and Hörte, 2005).

A successful user-supplier collaboration however implies additional challenges. Integrative design work can be considered as a type of open innovation. Henry Chesbrough defines open innovation as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively” (Chesbrough and Crowther, 2006, p.1) and the implication of this definition is that companies could and should use both internal and external knowledge, ideas and paths to market, when they seek to maximize returns from the development activities. However, the study of Enkel, Gassmann et al (2009) shows that loss of knowledge, higher coordination costs and loss of control and higher complexity are mentioned as frequent risks connected to open innovation activities. Thus, by working together with an equipment supplier, a manufacturing company face the risk that knowledge about core production processes is transferred to competitors via the equipment suppliers (Lager and Frishammar, 2010). Companies that integrate equipment suppliers in the design of the production equipment become dependent on the equipment suppliers’ efforts to

provide reliable equipment and to secure or improve the operating performance of the equipment (Lager and Frishammar, 2010).

Another challenge is that the manufacturing company and the equipment supplier may have different perspectives on the project, i.e. the generation of production equipment may be considered as either product development or production process development depending on the parties concerned (Hutcheson, Pearson *et al*., 1995; Lager and Frishammar, 2010). From the manufacturing company's perspective this kind of development is normally considered as process innovation, while the equipment supplier regards this as product innovation activities. Therefore, a critical aspect in ensuring successful collaboration between user and supplier when generating ideas is to develop a common objective to be accomplished in the production system design project, i.e. there needs to be a common understanding about the application of the production equipment (Bruch and Bellgran, 2012). The findings of Bruch and Bellgran (2012) highlight that a clear integration success factor for the design and acquisition process concerns the manufacturing company's appointment of a skilled and engaged contact person that bridges the exchange of relevant information between the buyer/user and the supplier. This poses a great challenge for the manufacturing company to possess the required in-house ordering competence. The integrated user-supplier equipment design process to have an increasingly important effect in terms of generating innovative and sustainable production process ideas that can be easily ramped-up to high volume production and are unique, i.e. difficult to imitate by competitors. To conclude, a successful user-supplier collaboration is accordingly vital and implies additonal opportunities and challenges. It claims a continous dialogue and a balanced collaboration through the whole lifecycle of the production equipment.

2.2. Life cycle perspective

Collaboration with the equipment supplier is usually carried out over several stages of the lifecycle of the production equipment, where different stages imply different challenges and opportunities (Rönnberg Sjödin, 2013). Lager and Frishammar (2010) describe the life cycle of process equipment in five phases including (1) Concept study, (2) Development, (3) Installation, (4) Start-up, and (5) Operation. *Concept study* is described as the period between idea and when a firm decides to proceed to formal development (Kim and Wilemon, 2002). Both user and equipment supplier need to engage in a number of important activities including e.g. articulate needs, product concept, preliminary experimental tests and simulations (Cooper, 1988; Lager and Frishammar, 2010). Since the activities in this phase to high extent affect future equipment performance and cost in the following phases, it is vital that the user and the equipment supplier have discussed and agreed upon equipment specifications and costs for such equipment (Cooper, 1988). The *development phase* involves both the technical development and marketing of new products to external customers as well as to enable the process from input and output by means of new tools, devices and knowledge in throughput technology (Gopalakrishnan and Damanpour, 1997). Process development for the manufacturing company is typically considered to be product development for the equipment supplier (Hutcheson, Pearson *et al*., 1995). In *installation* a strong collaboration between user and equipment supplier accelerates effective use of the process equipment (Athaide and Klink, 2009). This phase is followed by *start-up* where a complete transfer of the technology and the equipment know-how, from the suppliers to the users, is crucial for effective utilization (Lee, Wang *et al*., 2010). In the *operation phase* the collaboration between equipment supplier and user might imply additional benefits. The users can provide suppliers with vital information of their operating environment which can be re-used in future projects in concept studies (Rönnberg Sjödin, Eriksson *et al*., 2011).

A life cycle based procurement perspective is required in order to address the interconnections both among different procurement procedures but also among different lifecycle stages of process equipment (Rönnberg Sjödin and Eriksson, 2010). As a result, collaboration between the user and the equipment supplier is required over a considerable amount of time and the strategies that facilitate collaboration need to be adjusted according to the distinct challenges of each phase.

3. METHODOLOGY

The empirical data presented has been collected as part of a research project which aims at developing an integrated production equipment design methodology to be used by users and equipment suppliers in order to increase creativity and innovation resulting in new solutions for sustainable and competitive production equipment. A multiple case study was conducted with two equipment suppliers and two manufacturing companies in Sweden, i.e. the users of the production technology. Both the equipment suppliers and the manufacturing companies were large international companies. The manufacturing companies did not develop any production technology internally, which made collaboration with the equipment supplier critical. The case setting is particularly interesting as it includes both manufacturing companies and equipment suppliers, which

provided the possibility to explore not only the perspective of the users, but also how equipment suppliers experience collaboration with their customers. The majority of earlier research has been on the user perspective, while the perspective of the equipment supplier in production equipment development has received less attention among academics.

Given the lack of studies focusing on collaboration challenges in production equipment development projects the case study approach was considered the most suitable method. The case study method provides the possibility to gather a rich set of data from actual practice in order to facilitate the understanding of the phenomenon studied (Voss, Tsikriktsis *et al*., 2002). Thus, the cases allowed for a more holistic and contextual assessment of the complex activities that constitute collaborative development of production equipment. Furthermore, a case study strategy contributes to new insights of the phenomenon studied.

Data for the study were collected primarily through in-depth interviews at the four case companies. Interviews are essential sources of case study evidence and can be focused directly on the research topic (Yin, 2009). The interviews were semi-structured and guided by a list of questions covering different issues in joint development projects of production equipment. Conducting semi-structured interviews allowed follow up questions to be asked in order to clarify understanding and discussion of critical issues. In total, 30 semi-structured interviews with 33 respondents were undertaken ranging in duration between 60-120 minutes. Two thirds of the interviews were conducted at the manufacturing companies, which was partly motivated by the fact that at the customer side usually more people are involved in this kind of projects. The respondents were selected both from the operational and strategic levels to avoid bias in the data collection as well as to include diverse perspectives. All respondents had been continuously involved in production equipment development projects and they were carefully selected together with key informants at the case study companies. The respondents had different roles in production equipment development projects and came from a range of functions within the companies. As such, there were differences in their background and knowledge, years of training, experience, etc. and thus contributed with diverse perspectives. The aim was to gain a two company perspective of collaboration and the experience made.

When collecting case data, the focus was on identifying and analysing challenges and opportunities with user-supplier collaboration during production equipment development projects. The data set was validated by asking several persons at both the manufacturing companies and the equipment suppliers. In cases when differences were found in the answers of the respondents, these were followed up by discussions with several people. Most of the interviews were conducted by two of the authors in order to facilitate investigator triangulation. The data collected by interviews were complemented by document studies of projects documents and processes of the companies as well as five workshops at the case study companies were the interview results were presented and discussed. The workshops were thus also a way to validate the collected interview data and the conclusions drawn from it.

4. EMPIRICAL FINDINGS

Integration activities are critical, but at the same time challenging both for the supplier of the equipment and the users. The challenges vary depending on equipment life cycle phase and user/supplier perspective. The manufacturing companies and equipment suppliers demonstrate different collaboration approaches during the lifecycle stages; in concept study before formal purchasing decision, in the development phase, in the installation and start up phase and during operation.

4.1. Collaboration in the concept study

The concept study, or the pre-study phase, is a critical phase from a user perspective since it is the point where the investment decision should be made as well as the extent of the investment and the request note should be created. The pre-study could either be made in-house or be bought by the equipment supplier. It was shown in the case study that the pre-studies mainly were made in-house even if there was a lack of competence within manufacturing companies. According to the equipment suppliers, this resulted in deficient scopes of supply. The equipment suppliers were especially missing the emphasis on what parts that were important for the specific order for the customer (user) and what to focus on. In the cases when a customer (user) had bought the pre-study the equipment suppliers mainly had positive experiences. In those cases the pre-studies had been carefully carried out since the equipment supplier could afford to put effort and resources to do the work.

An insufficient pre-study made by the customer (user) created extra work later on for the equipment supplier who needed to visit the customer to create their own picture of the scope. However, it was hard for the

equipment supplier to comprehend risks and problems and it would be valuable if the costumer (user) could have helped identifying the most critical risks and problems since their product knowledge as well as their production system knowledge is better. In the case study, a large amount of effort and thus resources was demended by the equipment suppliers without being paid meanwhile there was a large risks that ideas would be spread to competitors.

4.2. Collaboration in the development phase

The procurement is a critical activity for the user in terms of choosing the equipment supplier. The case study showed that in several cases equipment suppliers had accepted orders but later on in the process they got difficulties to complete the job. When procuring the production equipment it is therefore important to check that the equipment supplier really could meet the specified requirements. It must be made clear that the equipment supplier has correctly understood the customer need.

In order to succeed, the user and the equipment supplier must have an equal relation. An example of difficultiees in equality which was indicated by the case studies conserned the matter of time tables and project planning. In order to accomplish the project in time a realistic time table is crucial. The time table must be shared and both the equipment supplier and the customer (user) must agree upon the time table. One must however remember that it is not only the customer (user) that is dependent on that equipment supplier finishing their activities in time but also the equipment supplier is dependent on the customer. It was shown in the case studies that the equipment supplier was always obliged to deliver according to the time table even if the customner had not delivered their tasks in time to the equipment supplier. A number of design reviews were appreciated, from general design reviews to more detailed. In order to succeed in the equipment design the customer (user) should be engaged and involve several resources with differing competences and backgrounds.

4.3. Collaboration in the installation and start up phase

The installation phase is a good opportunity for the customer (user) to learn and get trained in the equipment. Both the equipment supplier and the custumer (user) should see this as a phase to train and hand over the equipment to the user and put effort and resources to get the full potential of this. The customer (user) must be prepared to regularily send resources to the equipment supplier and the equipment supplier should be prepared to train the customer (user), be aware of and, as far as possible, avoid the barriers of differences in languge and culture.

To enable a smooth tranfer of the equipment from the equipment supplier to the customer (user) carefull preparations are required. The equipment supplier should consider to build an equipment easy to pack, transport and unpack and preferably have the same resources during building as in installation. It would help if the test protocol i.e. what is going to be tested ,is sent by the customer (user) to the equipment supplier in advance.

Another challenge seen in the case study was the fact that the equipment supplier had not finished installation before the Factory acceptance test (FAT). From both an equipment supplier and a user perspective a common plan for installation was demanded including that the customer had made all necessary prepations, that necessary resources and equipment were available, and that the customer clearly understood how to take advantage of the equipment supplier knowledge during start-up.

4.4. Collaboration in the operation phase and recycling

It was shown in the case studies that there were almost no collaboration after warrenty time had past. In some cases a small amount of collaboration existed conserning updates when the equipment suppliers were responsible for reprogramming. Finally, when recycling the production equipment the equipment suppliers were not involved in any of the cases studied.

5. ANALYSIS AND DISCUSSION

A good collaboration between user and equipment supplier increases the potential to succed and to create new innovative ideas for the production equipment (Lager and Hörte, 2005). In the case study the collaboration varied through the different phases. In the beginning and in the end the level of collaboration was low. The pre-studies which were mainly made internally resulted in problems such as deficient scopes of supply and extra work for the equipment suppliers. The companies did not have a structured program or process when designing

and building the equipment. Due to this the prerequisites for communication and an equal relation were low (Abd Rahman, Brooks *et al*., 2009). Issues like that the pre-studies often were made internally and that probable problems and risks seldom were identified in the early phases could have been easier to handle if a common structured process were used. Also the dilemma of having an common time table and project planning could be simplified by structured process.

The different perspectives on the project, i.e. that the generation of production equipment could be considered as either product development or production process development depending on the parties concerned (Hutcheson, Pearson *et al*., 1995; Lager and Frishammar, 2010) might also be a reason for the difficulties identified in the case study. In the case study time was seldom spent to get a common understanding of the project in previous phases. A skilled contact person (Bruch and Bellgran, 2012) would have simplified for the companies to get a common view of the project which could e.g. helped to develop better pre-studies and scopes of supply adapted to both perspectives.

Due to the trend of outsourcing both the selection, design and building of the equipment, the suppliers become important designers of essential parts of the production system and consequently need to be involved to a larger extent and in an earlier stage compared to today if the quality is in focus. By synthesizing the findings of the case studies and the literature review a life cycle model with eight stages is proposed, Fig. 1. For each of the stages critical interconnected activities are identified that need to be efficiently managed in order to facilitate the ability to obtain superior production equipment capabilities. The identified activities should facilitate managers to understand and apply appropriate collaboration strategies for each stage of the lifecycle of the production equipment development process, and in doing so ensure less rework and problems, improved planning and more reliable and innovate production equipment. Literature has highlighted the need for further guidance on how to facilitate collaboration between equipment suppliers and user.

As been pictured in previous research and shown in the case study a life cycle perspective is crucial since different types of collaboration are required in the different life cycle phases and each of the phases imples different challenges for both the user and the equipment supplier. The type of collaboration, and who is leading the collaboration varies between the life cycle phases.

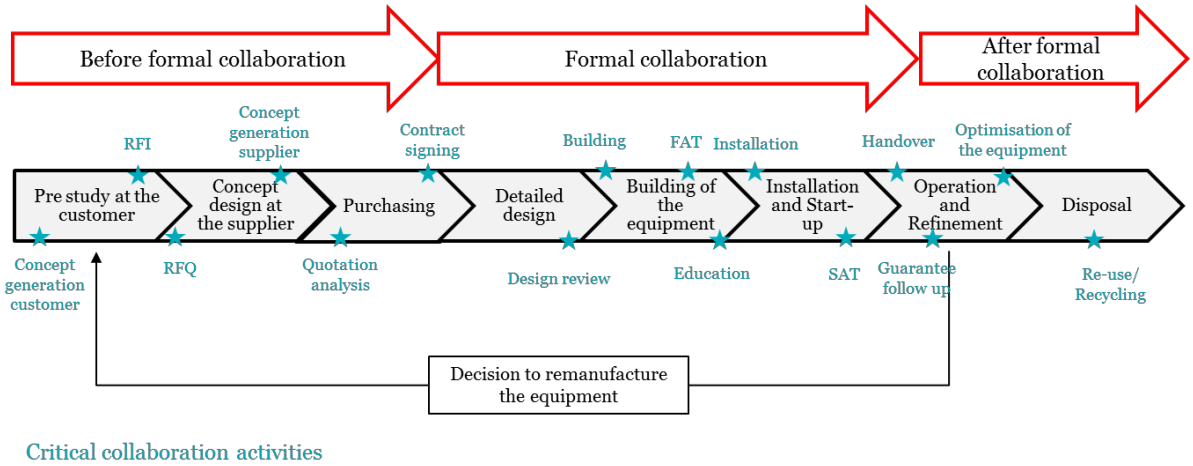

Fig. 1. Life cycle model exploring critical user-supplier collaboration activities.

The process including eight stages explores critical user-equipment supplier collaboration activities (marked by blue stars). Within these activities it is of major importance to communicate and picture both the user and the equipment supplier perspective. Moreover, three overall phases could be distinguished that strongly affect the character of the user-supplier collaboration through the life cycle of the technical equipment. These phases are marked be red arrows and includes (1) Before formal collaboration, (2) Formal collaboration, and (3) After formal collaboration. The case studies showed that the first of these phases was the most critical concerning collaboration between user and equipment supplier. During this phase the equipment supplier is obliged to perform a great amount of work without getting paid. This phase includes both pre-study, concept design and purchasing which are three crucial stages where a great amount of effort should be laid in order to succeed in the following stages. In general, it is a common desire in industry to front-load development projects with attention put on the preparation and concept generation activities. However, the case studies have demonstrated the

difficulty to realize these thoughts. The same is true as regards the difficulty to include equipment suppliers early in the design process. Including the equipment suppliers after the scope of supply is determined and sent out by the manufacturing company is rather late and affects not only the quality of the equipment solutions, but also lead times.

During the formal collaboration phase the collaboration is more structured and often more successful. The installation and start-up were found most problematic in this formal collaboration phase. It was shown that neither the user or the equipment supplier were prepared enough for the learning and training that should be made. Also, neither the user or equipment supplier were prepared for a smooth move of the equipment which requires preparations.

In contrast to previous research on user-equipment supplier collaboration in the process industry (Rönnberg Sjödin, 2013) the case studies showed no collaboration after warranty time has past. From the equipment supplier perspective this implies that they are missing the opportunity to learn about how the equipment works in operation and from a customer (user) perspective it implies that expert competencies are not seized.

One of the drawbacks often from case studies is the limited possibilities of generalizing. In this study the ability to generalize is enabled through cross-case analysis in multiple-case studies (Yin 2009). Still, it must be kept in mind that the conclusions are only valid for the cases that were studied. Further research is thus needed to testing and verifying the the model.

6. CONCLUSION

Drawing upon empirical studies at equipment suppliers and users, this paper contributes with new knowledge by adopting a lifecycle perspective on joint production equipment development projects as well as including the perspective of the equipment supplier and the user. Collaboration between the user and the equipment supplier is required over the whole production equipment life cycle and the strategies that facilitate collaboration need to be adjusted according to the distinct challenges of each phase. A life cycle model is described exploring critical activities to be performed by the user and the equipment supplier in collaboration.

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