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Comparing the quality of documentation used in production equipment acquisitions and the impact on the performance of the acquired equipment – a pre study

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Abstract

There are often problems with design documentation, such as incomplete or missing and quality of input. A pre study within an engineering department for advanced machinery investigates the quality of production equipment acquisition documents used with the performance of the acquired equipment in terms of maintenance costs. The study shows indications that incomplete or missing input as well as the quality of the input could have an impact on the performance of the acquired machines and the project performance.

Keywords: documentation management, design activities, performance indicators, equipment acquisition

1 Introduction

Efficient production systems are necessary for the realisation of products that fulfil customer needs and delivery requirements (Bellgran, 2003). Bellgran states; “Designing a production system is a unique and complex task where many parameters should be taken into account during the process of creating, evaluating and selecting the proper alternative”. The importance of design, in particular as an industrial activity and the increasingly complex and dynamic context in which it takes place, has led to the wish to improve the effectiveness and efficiency of design practice (Blessing & Chakrabati, 2009). This applies to the design of production equipment as well. The paper describes a case study in an advanced engineering environment, investigating engineering design methods within the design of production equipment, with the focus on maintenance. To investigate the effectiveness and efficiency of production equipment design, a comparative case study from powertrain manufacturing engineering in a large heavy truck company has been performed. The focus is the quality of the documentation of the equipment acquisition process and its impact on the performance of the purchased equipment in terms of breakdown cost due to design weakness. The research questions are stated below:

RQ1: Which types of documentation are used in production equipment acquisition in the case company?

RQ2: Does the quality of the documentation used by the case company in production equipment acquisitions impact the performance of the acquired equipment?

2 Frame of reference

The "product" for this study is the production equipment; the focus is on development and design of production equipment. Blanchard and Fabrycky (1998) mention the equipment acquisition as an important activity and describe the equipment acquisition process as an innovation activity that refers to "goods specifically purchased for use in product and process innovation activities of the firm. This includes the acquisition of land and buildings (including major improvements, modifications and repairs); machinery, instruments and equipment (including computer hardware); and computer software.

There are various reasons why a company would like to invest in new machines; it could be to increase capacity, replacement or introduction of new products that the current equipment is not capable of producing. Equipment acquisition in this definition concerns machines that are not bought off the shelf but are instead designed to order, leading to longer lead times and higher procurement cost (Yeo & Ning, 2006). Equipment investments are usually conducted in projects, which entails project metrics as time and cost (Jha & Iyer, 2007). However, it is not only about the investment but also to procure the best possible equipment for production and maintenance by using existing knowledge and experience. To be more resource efficient, front-loading information gathering and knowledge transfer in a project is preferred. The later problems arise in a project, the more expensive they are to handle, as the cost of design changes increase rapidly when made late in the development process (Folkestad & Johnson, 2001). To make sure the adequate knowledge is available for ongoing projects, several activities need to take place outside of the project environment (Stenholm, 2018). Knowledge should be collected from several parts of the organisation and be fed into the procurement process to ensure the best equipment is purchased from several angles of operations.

Maintenance has been found to be a major contributor to achieve equipment stability and is one of the success factors in equipment acquisitions (R Gulati, 2013). Several production disturbances are often experienced after implementing a new machine; difficulties in maintainability, complex equipment, safety issues and difficulties to achieve high efficiency from start of production.

2.1 Equipment breakdowns and the link to equipment acquisitions

Equipment breakdowns are normally described in the field of maintenance. The Swedish Standards Institute describes maintenance as "the combination of technical and administrative actions, including monitoring, intended to maintain or restore a device to such a state that it can perform a required function" (SIS, 2000). Further on, Gulati (2013) describes maintenance "as the work of keeping the condition of the production equipment so that it can achieve its intended production efficiency". Events that disturb the intended production condition can be regarded as disturbances and losses for production. The activities in maintenance are both activities that prevent failures of the equipment but also activities that restores the condition into the original condition. All maintenance activities have the target of maximizing production capacity and reducing overall costs of the production (Bellgran & Säfsten, 2009) . The maintenance cost increases nearly exponentially closer to the end of the equipment's life cycle and it is in the

design stage that it is possible to prevent many of the causes for production disturbances in a cost efficient way (Bellgran & Säfsten, 2009) (R. Gulati, 2013). Despite the potential in cost savings, studies show that the awareness of the cost implied with breakdowns and maintenance losses is low among respondents in Swedish industry (Salonen & Tabikh, 2016). Other studies show that even though the importance of maintenance have been acknowledged, industry under performs due to under investments in the maintenance organisations (Lundgren, 2019). Lundgren further mentions that it is important to link the maintenance cost and potential production disturbances already in the procurement process. This is also supported by Salonen (2018) who showed that 65% of recorded data from eight automotive sites in Sweden registered design weakness of the machine as the root cause of the breakdowns. In addition, 23% of the breakdowns was related to poor professional maintenance performed. The article also mentions that there is a missing area of research on how to manage the procurement and/or design of dependable production equipment, which further highlights the research gap this article is covering.

2.2 The importance of quality in the project documentation on the success of the end product

Design and development are a highly knowledge-intensive activities (Blessing & Chakrabati, 2009). A distinction regarding knowledge usually made is the one between data, information and knowledge. Data is raw numbers and text that can exist in for example a database of some sort, information is this data processed somehow to put in some context and knowledge is this information processed by a mind and put into relation to everything this mind knows (Dretske, 1981) (Vance, 1997). A supporting knowledge management infrastructure together with a well-working process is what creates knowledge value for businesses, which is important for their competitiveness in today's market (Lee, 2016). For engineering, the organisational knowledge is often manifested in the documentation during the engineering project. Documentation of design decisions in complex projects is of significance as it increases the ability to trace decisions, provides insight in which decisions that were critical, and improves efficiency of development by eliminating meetings and phone calls. Engineering projects often have a long duration and are dynamic in nature. Documentation is of importance as it is the main means to transfer information from party to party and from phase to phase in projects (Kinneging et al., 2020). Kinneging et.al state further that there are often problems with design decision documentation, such as incomplete or missing and quality of input. Consequently, teams might not be able to perform tasks depending on documentation from previous phases and might make incorrect assumptions. A supporting knowledge management infrastructure together with a well-working process is what creates knowledge value for businesses, which is important for their competitiveness in today's market (Lee, 2016). For engineering, the organisational knowledge is often manifested in the documentation during the engineering project.

3 Case study

The case company comprises of ten business areas and 100.000 employees across the world, with factories in 18 countries. Their portfolio consists of several brands and vehicles, from excavators to buses and trucks. The study was performed within the Powertrain engineering organisation and focusing on one plant when evaluating the performance of the acquired equipment. The engineering community consists of around 400 engineers with the main objective of designing production systems of the future, from tomorrow until decades ahead.

The study is investigating the acquisition of advanced subtractive manufacturing equipment. For the case company equipment design and equipment acquisition means the same thing as the equipment bought are standard solutions offered by the suppliers with minor modifications specified by the case company.

4 Research approach and data collection

Several authors have discussed the need for design research to be scientific (Blessing & Chakrabati, 2009) and how to achieve a sufficiently scientific level in this type of research. Research in the engineering design field is not only understood as a pursuit of scientific knowledge; it also pursues the goal of practically improving engineering design and practice (Eckert et al., 2003). Ullman (2003) states that an estimated 85% of product development projects encounters problems in cost, time management or by simply not functioning as intended which means the design process is worth studying to identify improvement areas.

For RQ1, a study was designed to interview project managers and engineers in the case company whit the purpose to consolidate which types of documentations were used in the production equipment acquisition process and what the purpose of each document type was.

For RQ2, the research approach consists of two parts: a) the data collection of the quality of the documentation and b) the production equipment performance.

a) The quality of the equipment acquisition documentation the ambition was to investigate number of identified issued in the Acceptance Records, delays in the project and the equipment acquisition documentation quality. The quality of the equipment acquisition documentation was evaluated qualitatively by observing the depth, range and detail of the documentation. The data were collected from internal share-points within the company. The variables were ranked from lower to higher based on the level of detail in the documentation.

b) to collect the data on the performance of the acquired production equipment, a longitudinal retrospective case study was performed in a large, high-volume plant with more than 1000 multiple-operation machines in subtractive manufacturing. The breakdown maintenance cost for a selection of machines has been compared to the quality of the equipment acquisition documentation from the acquisition of those specific machines, acquired between 2014 and 2019. The breakdown maintenance costs represent the cost of missed time in production, the hourly cost of a technician plus the cost of any spare parts needed. The breakdown data are captured in real time or on the same day and are collected to a large extent automatically, as well as manually. The breakdowns are then categorised into root causes. The attributes are maintenance costs but also the years the machine was bought and age of the machine. The variables for maintenance costs include the costs for downtime, technician time and spare-part costs, which are categorised as ratio and dependent variables. The variables for the year the machine was bought, and the age of the machine are categorised as interval and dependent variables. The data are categorised as raw, field, financial, empirical, objective, quantitative and secondary data, and is captured through the company's automatic maintenance system.

The method to compare the quality of the design documentation to the production equipment performance was performed in two steps: a) classifying the raw maintenance cost data to high- and low performing equipment and b) classifying the quality of design documentation into high- and low quality.

4.1 Classifying the performance of the production equipment based on their maintenance cost to high- and low performing equipment

To find suitable machines to compare, data from multiple data sources were used. These sources include a register of all machines in use with their acquisition value, data from all breakdowns (called emergency work orders, EWO) on these machines and the corresponding maintenance costs. The data was compiled and the total maintenance cost and total number of EWO's for each machine was calculated. The machines in question were installed between 2014 and 2019. This data was then used to filter the machines, omitting outliers in terms of acquisition value, as conclusions from an abnormally costly, or an abnormally cheap, project most likely cannot be applied to an arbitrary project. Another filter was applied; namely the function it is belonging to. In the plant in question, there are three main functions, two of which were deemed inappropriate, the first function due to being too simplistic and the second due to the complexity and large intervals between purchases of new machines. Lastly, the remaining machines were compared in terms of maintenance cost and number of EWO's, to identify relevant projects to investigate further.

Machine 2.1 and Machine 2.2 are identical machines, as is Machine 11.1 and Machine 11.2. Further, all four are supplied by the same supplier but the performance varies significantly. The more costly pair, Machine 2.1 and 2.2, are costing the company seven times more in maintenance than Machine 11.1 and 11.2. Another note was how Machine 2.1 and 2.2 varied significantly as well, with Machine 2.2 causing twice as many EWO's as its counterpart. Therefore, these four machines were selected to analyse further, along with Machine 5 which have a high number of EWO's considering it has only been in use since 2019. Lastly, Machine 10 was chosen for further analysis since it had relatively low maintenance as well as number of EWO's. The reason to disregard Machine 9 although it had the best record of the machines was due to it being a robot cell, a type of machine which overall was relatively unproblematic. This resulted in six selected machines, three on the low end of the spectra in terms of performance and three on the high end. These machines were purchased in four equipment acquisitions projects.

4.2 Classifying the quality of the documentation used by the case company in production equipment acquisitions for the selected projects

The quality of the documentation used by the case company in production equipment acquisitions in the identified four projects (Project A, B, C and D) were analysed qualitatively. The identified projects were similar in nature; their acquisition cost was approximately the same and about the same amount of time to complete. The case company also acquired two of each of these machines and while one set of machines has caused a significant amount of maintenance cost, the other set did not cause a higher cost than average. Both these projects have several equipment acquisition documents connected to them, about 40. A review of these documents was performed with the aim to identify any major differences in the projects and in the documentation. The documents were analysed in terms of incomplete or missing input and the quality of input, based on the proposed approach from Kinneging et al (2020). The variables were categorised as the more relative terms of "higher" and "lower", rather than absolute terms

as “high” and “low”. Project performance indicators were selected namely number of identified issues in acceptance records, delays in the project and warranty claims after production start.

5 Results

RQ1: Which types of documentation are used in production equipment acquisition in the case company?

There are 46 different types of documents that can be found for the equipment acquisition projects at the case company, not counting technical documents, such as CAD-drawings which are connected to the machine itself rather than the project. The main project documentation types that were used in the equipment acquisition projects are described below in Table 1:

Table 1: Overview of the main project documentation types that were used in the equipment acquisition projects

Document name	Document content
Scope of Supply	A list of requirements specific to each machine. The Scope of Supply, together with the Technical Specification, consolidates the requirements for the machinery. The document consists of around 400 specification points.
Technical Specification	General requirements that are updated once a year to with input from the plant needs on new machinery.
Acceptance Record	Documents that follow along the process of acquiring new machines. Acceptance Record (AR) are used by supplier and purchaser to monitor the progress of the purchase through-out the gates of the acquisition process. The documents are used to high-light any aspects of the machine not fulfilling the requirements to be addressed by the supplier.
Handover Record	This document has the same content as AR but is used to manage the handover between the acquisition project team and the Production organisation.
Meeting Minutes	Meeting minutes are protocols from meetings between buyer and supplier to document agreements that differ from the Technical Specification and the Scope of Supply. For example, changes to the design/demands of the machine or changes to the time-plan are logged here.
White book	Everyone involved in a project should contribute with lessons learned, good and bad, from each project. This is used to improve the next project. The white book is either stored as a single document continuously updated after each project, thus consisting of multiple projects, or as individual white books for each project with lessons learned from that specific project.

RQ2: Does the quality of the documentation used by the case company in production equipment acquisitions impact the performance of the acquired equipment?

Comparing and analysing project documentation to performance of the equipment in terms of maintenance costs highlighted that:

- The low performing machinery had 140 entries of action in their acceptance records and the high performing set of machines had 100 entries, meaning a 40% factor of more issues logged in the design phase.
- The projects tied to the low performing machinery had more significant delays during the project for various reasons, such as waiting for documentation from the supplier and pushing installation dates as the equipment was not ready in time.

- A slightly higher number of warranty issues on the low performing set of machines, meaning issues that are identified already in the first year of use, and considered to be the responsibility of the supplier.
- The high performing machinery demonstrated a more thorough documentation on the testing.
- The documentation quality was evaluated qualitatively in two factors; richness of entries and quantity of rows filled in.

The comparison is described in Table 2.

Table 2: Comparing the quality of the documentation used in production equipment acquisition projects with the performance of the acquired equipment and the project performance

Type	Factor	Project A	Project B	Project C	Project D
Production equipment performance	Performance of the machine in terms of maintenance cost	High	High	Low	Low
Project performance	Identified issues in the acceptance records	Not able to track due to low updating of documents	Not able to track due to low updating of documents	Not able to track due to low updating of documents	Not able to track due to low updating of documents
	Delays in the project	Low	Low	High	High
	Warranty issues after production	Low	Low	High	High
Equipment acquisition documentation quality	Richness of entries and quantity of rows filled in	Higher	Higher	Lower	Lower

6 Conclusions

Regarding RQ1 the study demonstrates that there are 46 different types of documents for the equipment acquisition projects at the case company, not counting technical documents.

Regarding RQ2 the study showed indications that incomplete or missing input as well as the quality of the input could have an impact on the performance of the acquired machines and the project performance. As this is a pre-study to investigate the relevance to study further, the findings suggest that this is the case and further studies are recommended. Of course, there could also be many other factors than the quality of the documentation influencing the equipment performance, such as the production environment, the maintenance approach and production management. Even so, the quality of the documentations could also have an impact.

7 Discussion

During the research the authors aimed to evaluate the document quality without further analysis of the different type of documents. It turned out to be more difficult than expected as the documents were not filled in according to expected level. This is a finding in itself which was

supported by literature but made the analysis of the study more difficult as the data was not as robust as expected. This is something that should be highlighted to management as there might be an *impression* that the documents are well populated and that the acquisition process is more stable than in reality. The findings from the pre-study gives indications that there could be a relation between document quality and performance of equipment, but the authors now aim to sample a larger quantity of documents and acquisitions to get a fuller picture of the relations. The indications of project performance were not investigated further in this pre-study but the relation between the documentation quality and the project performance would be interesting to study deeper.

Other findings collected during the research was that 46 document types are used by the case company in production equipment acquisition seems like a high number to the authors. This combined with the finding that the quality of the input in the documents varied a lot triggers the thought that perhaps the number of document types is too high. The notion that engineers have so many documents to fill in and a multitude of parallel ongoing projects, perhaps this documentation approach is not the most efficient one.

As stated in the introduction, earlier studies have identified problems with engineering documentations, such as incomplete or missing and quality of input (Kinneging et al., 2020). This study is confirming that statement, however with a small number of machines and projects analysed and further studies are recommended.

8 Limitations and further research

This research has limitations that should be pointed out. First, the analysis of the documentation quality was performed qualitatively and is hence of subjective nature. Consequently, the variables were categorised as the more relative terms of “higher” and “lower”, rather than absolute terms as “high” and “low”. Second, this was a limited study of only six machine acquisitions. Also, the pre-study did not in depth analyse the different document types and did instead evaluate each of the main document types equally important.

The project documentation is the manifestation of the output of the engineering work, and it is also currently the way the case company documents knowledge from a project. The results from this limited case study suggest that it is vital to understand deeper the coupling between this manifestation of output and the performance of the acquired project. This is crucial to be able to understand further the important factors in an acquisition project to be able to deliver a successful project. To increase the significance of the findings a deeper analysis of breakdowns related to document quality should be performed.

From the analysis of the documents, it was not evident how knowledge from earlier projects was reused to improve studied projects. For the authors, the information collected in the documents could potentially be very beneficial for coming projects. Also, the documents used are not supporting the possibility to track performance of the project; the connection between the project and the performance of the delivered equipment was missing, which this study aimed to address.

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