MODEL BASED DEFINITION WITHIN RELOCATION OF AIRCRAFT PRODUCTION

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Abstract

The purpose of the paper is to discuss how relocation of production can be affected when MBD is applied. The research is performed from a view point of production relocation; the focus is not on MBD as a method. The paper is based on a literature review combined with empirical data from an industrial study at the Swedish enterprise Saab Aeronautics. It was hard to find gaps in the literature since no literature covering the aim of the research was found. Important subject of discussion was that update or creation of MBD production documentation can decrease the amount of tacit knowledge at the sender and help the possibility to differentiate off-line learning from on-line learning, which can save both time and cost.

1 Introduction and research objective

Technical drawings have been important for the development for decades, they were used even back when the ancient pyramids were built [1]. In more modern times, has drawings traditionally been used for communication within the industry, it is an engineering way to communicate what to make and how to make it [2]. The purpose of a drawing is to carry, control and maintain a product's definition, to decrease the risk of misinterpretation [3]. Creating instructions is also important for the technology and knowledge transfer [4] and to adapt the production process to a new environment [5].

Today, companies have to introduce new products into market on time and on budget, and often sharing risks with partners and suppliers. These challenges may introduce a new way of working, based on innovation and global collaboration [6]. Adopting Model Based Definition (MBD) can be a logical move in order to continue reducing time-to-market and improve product quality [7]. MBD is a way of managing engineering and business processes using 3D models as sources of information for design, production, distribution, technical documentation, services and the overall product lifecycle. Most of the data is stored in a 3D CAD model; the model becomes the reference document for the main engineering and manufacturing phases [6]. In times of rapid economic growth and globalization, an increasing number of companies relocate production over the national borders. Global workplaces include various geographic locations and span numerous cultures. According to Johnson [8], relocation of production can involve difficulties such as material supply, assembly instructions, way-of-working, competence differences and so forth. Most of these difficulties within relocation of production are related to failure in the communication between the two sites [8].

The purpose of the research within this paper is to discuss how relocation of production can be affected when MBD is applied. At first were risks that can appear within production relocation identified, then were risks connected to the interface between design and production that MBD can affect chosen. Note that MBD already was implemented on the products at the sender before the production was relocated to the receiver.

The research is performed from a view point of production relocation; the main focus is not on MBD as a method.

The paper is based on a literature review combined with empirical data from an industrial study, including a risk analysis. The study was performed at the Swedish enterprise Saab Aeronautics (later referred to as Aeronautics). Saab is one name but two independent companies: Saab Group and Saab Automobile. Aeronautics, with about 3,000 employees, is one of five business units in the Saab Group, an aerospace and Defence Company. The business portfolio for Aeronautics involves for example Gripen (fighter aircraft), unmanned aerial systems (UAS) and commercial aeronautics. The Gripen fighter aircraft is a product with low purchase volume, advanced logistics, complicated manufacturing, high change rate, long qualification and validation time. This complexity within the product makes it difficult to perform relocation of production. Aeronautics is a small company with long experience and holistic knowledge of manufacturing aircrafts; they have developed, introduced and produced aircrafts since 1940. Aeronautics started to be influenced by MBD somewhere around 1990. However, since 2003, when the cooperation with Boeing started within commercial aircraft (Boeing 787, Dreamliner) has the work been more focused. Aeronautics is now implementing MBD within Neuron (UAS) and Gripen Next Generation (fighter).

2 Method

Method applied for this paper was an industry study combined with a risk analysis and a literature study. Multiple sources of evidence have been used; data collection techniques were interviews, observations, company documentations and literature. The author of this article is employed as an industrial PhD student at Aeronautics. As an employee at the company with a pre-existing contact net, was the access to interview persons good. It was also easier to get access to needed company information, to attend to company meetings and to perform observations. A challenge with being an industrial PhD student and with using qualitative methods is the risk to influence the data collection and analysis process. This can increase the risk for bias, the researcher's way of evaluating and reacting to the environment. A way to decrease this risk is for the author to keep this risk in mind when performing and analyzing the data.

The literature study provided a background and context for the study and it will point out gaps in the literature [9]. Semi-structured interviews were used; the interviewer was quite free to allow deviations from the original questions. A lower scale of structure can give the interviewee more space to express their knowledge within the subject. One risk is that the interview will take a longer time, and be indistinct; it can be difficult to extract results [10]. On various occasions from October 2011 to May 2012 were interviews conducted with employees at Aeronautics. The interviewees were selected based upon their knowledge within the related areas, such as MBD (Model Based Definition), production engineering and technology transfer. The interviews were not recorded; though notes were taken during and after the interviews. The length of the interviews varied from 30 minutes to 3 hours. When performing interviews, there is always some uncertainty in the empirical data. In this study, the empirical data is used rather freely, as input to generating new ideas and adjustment of existing reasoning [10]. Observations have been performed from fall 2011 to spring 2012 by attending to weekly meetings in relocation of production projects.

Empirical data also consisted of results from a risk analysis conducted with people from the engineering and management side. The risk analysis was performed with a qualitative method (mini risk), it is a method used to handle risks in projects. The risk analysis includes the probability that a risk will occur in combination with the consequence if the risk actually do occur. The people involved with the risk analysis have experience of working with relocation of fighter aircraft and experience of design and manufacturing with MBD. The result from the risk analysis set the base for which risks that could be investigated. The discussion at the end is based upon the result from the risk analysis, the empirical data and the literature study.

3 Theoretical Framework

The theoretical chapter will involve an introduction to the study's main areas: Production relocation and MBD.

3.1 Production Relocation

Transfer of production is a growing phenomenon, and it will become even more important to increase the awareness and decrease the risks of transferring production. One of the largest risks with product transfer is that full-scale production is not reached as planned, which can lead to a lack of needed materials and extra costs [11]. Earlier research has shown that it can take years to reach full scale production in relation to product transfer [12]. Production transfer often includes questions both on the strategy level and the tactical level. The strategic time period focus on general questions, such as: Why? Where? What? And When? The tactical period consists mainly of the answer to the question: How? Research within production transfer usually focuses on the strategic level and more seldom on the tactical issues [13], such as relocation of production.

Engineers often have the ambitions to standardize, formalize and generalize their work into categorizations and "languages". Not many engineers focus their work on the non formalized part of engineering. This is interesting, because many requirements can not be expressed in an explicit way, not even obvious requirement such as good usability and easy maintenance. A lot of engineering knowledge will remain unspoken and the engineers have to use their experience, intuition and professional judgment [14]. Knowledge can be roughly divided into two different categories; explicit and tacit, it is not a distinct line between the two terms. They act more like guidelines how to describe knowledge. Explicit knowledge can be defined by "know-what" and "know-why" [15], it refers to knowledge about facts and can often be divided into smaller pieces and be documented. Access to this type of knowledge often will increase the speed of technology development and decrease the frequency of errors in a manufacturing environment [16]. Tacit knowledge can be defined by "know-how" and "know-who" [15]. Tacit knowledge is something that is difficult to identify in an industrial context. Quoted from Polanyi [17], the statement "we know more than we can tell" gives some education about the concept of tacit knowledge. Experiences perceived by individuals are often difficult to explain to other individuals – and so often remain tacit [17]. However, in many industries it is important to transfer tacit knowledge between employees. A company that fails to keep track of components needed in a manufacturing process will probably not function. The same is true for companies that do not keep track of their knowledge components [18].

To make a smooth knowledge transfer in connection with a transfer of manufacturing facilities, it is important to consider the level of absorptive capacity at the receiving unit i.e., the supplier's ability to learn [19], [20], [21]. The absorptive capacity depends on the recipient's knowledge prior to transfer, i.e., its capability [20], [4], [21] and the experience of transfers on the part of both the sender and recipient [22], [23], [21]. Furthermore, the context of the supplier and buyer, such as legal, political, financial and cultural differences, creates challenges [24].

3.2 MBD

The globalization and the increasing competition urge companies to constant launch new high-technological products on their markets [25]. Shorter product life cycles, faster change rates of technologies reinforce the importance of successful new product development [26]. Product development is defined by Ulrich and Eppinger [27] as: “the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product.” [27].

Managers often make one set of decisions prior to the development, and others after finalizing of physical development. Decisions prior to the development are in Hultinks [26] article defined as the strategic decisions. Later decisions are in the tactical launch period [26]. MBD is in relocation involved in both strategic and tactic decisions, since the 3D model is used both in development and production.

MBD has for a long time been underestimated. It has been viewed as a tool to suppress 2D drawings and get a paper reduced product [6]. The chase of the paperless airplane started years ago. Computer Aided Design (CAD) was a significant step in that direction. Next Computer Aided Manufacturing (CAM) allowed use of the CAD model for programming, for example Computer Numeric Control (CNC) machining. Manufacturer saw numerous challenges caused by using both digital and non-digital means, it often ended up to have definitions in disagreement. Organizations struggled hard to find solutions to each deviation, the solution often ended up in switching to fully digital definition. That was one way in for MBD [28]. The Boeing B-777 was one of the first in the aircraft industry to have 100% digital definition. Digital data were used to drive the manufacturing processes; the entire aircraft assembly was simulated using digital techniques [7].

Historically, the use of 2D drawings has been required to “see” details. Thanks to unified data structure and comprehensive mapping of parameters, engineering information is made accessible and reusable. Data standardization offers a possibility for automation and for some tacit knowledge to be coded in documentations. MBD is not a tool; it is a way of managing product data [6].

Another advantage is that digital models are more readable for the operators. It requires time and training to understand complicated parts in a technical paper drawing. It is often easier to view 3D MBD datasets; they provide a realistic view of the designs. With drawings can deviation with the model occur and then result in non-value added drawing revisions. The main goal for MBD is to improve and accelerate the design, manufacturing and inspection processes by integrating drawing annotation directly in the 3D model [7].

A large difference that MBD can contribute is the off-line learning of operators. The operator can get the whole picture of the work package long before it is possible to actually touch the products. This virtual training off-line will decrease the on-line time, the learning curve will be lowered and the initial failure rate will decrease. With off-line learning is not double-crew needed and the on-line (double-crew) time will be shortened. But notice that the mentor-novice training still is needed; it is only the explicit knowledge that will be exchanged during off-line learning [12].

4 Empirical Data

Aeronautics has gone through a long transformation from supplier of aircrafts to one public client FMV (Swedish Defence Materiel Administration) to tough international competition when offering the aircraft to several countries around the world. This transformation has a great impact on the processes and methods used at Aeronautics; which have gone from local to international applicability [14].

A risk analysis was performed at Aeronautics to investigate which challenges that can arise during production relocation from Aeronautics to a receiver. The risks were graded to find the most critical. When exploring the result; a convincing share involved issues concerning the interface between design and production; these are presented in table 1.

Table 1: Risks connected to the interface between design and production when relocating production.

	Risks
1	A risk that the production includes too much tacit knowledge and is therefore hard to relocate
2	A risk that the design drawings does not conform with the production documentation
3	A risk that the configuration management do not match at the sending and receiving company.

These risks could be connected to common challenges when using traditional 2D drawings instead of a MBD dataset. *Risk 1*: Aeronautics is a company with low staff turn-over, many operators has been at the company for 25 years or more, these experienced people posses much knowledge. The production documentation has followed the operators. It is a large risk that a new operator could have problems to follow the production documentation without an extra long introduction. *Risk 2*: when there is a design change, the production documentation often has to be updated and vice versa. It is always a risk with these types of connections, something can go wrong and the update can be delayed. *Risk 3*: The configuration management is very important within aircraft production, almost every flying part or article from production have to be traceable. This must unconditionally function, and it is always a risk that something can go wrong when relocating production.

Following sections describe the MBD situation at Aeronautics and the empirical data based on the risk analysis.

4.1 MBD at Aeronautics – Now and then

Before MBD was introduced, the production structure was defined within the design documentation. Production documentation, which was produced outside the design documentation, was often "invincible" for the design section. Production changes initialized a formal modification service also on the design documentation. Reports were filed in binders, and regulations, requirements and analysis documentation on paper. The drawing kit (compiled) for Gripen fighter C consists of ~10 000 paper drawings and ~50 000 production documentation. After introducing MBD, the product requirements (both production and maintenance) are within the design models. The models provide the possibility to review the production technique and methodology before the actual production start.

Today Gripen New Generation (NG) consists of an electronic archive for all documentations, no paper drawings. Dimensions and regulations are directly connected to the solid model. Product and requirement documentations are stored within various data bases.

4.2 Relocation of production when MBD is applied

Within this section are interviews from experts within the subjects summarized. Until today production relocation from Aeronautics has mainly been performed along with paper drawings and production documentation on paper. To transfer MBD other requirements are set than within production relocation, it is not possible to perform the transfer in the exact same way.

When determine how to conduct relocation including MBD, the ability to manage Information Technology (IT) on a system level at the recipient is a decisive factor. This ability should preferable exist within the receiving company, but for example in India and Brazil are the IT-maturity very high within parts of the country, but the level varies greatly within the local companies. A challenge with implementing MBD is that it affects almost all levels and segments in the organization. It is difficult to see the overall picture, and which function that will be affected.

Tightly connected to the implementation of MBD is the traceability of product information. The traceability requirements have changed when digital data has been introduced. Some years ago where more focus on for example the date of manufacturing and who manufactured the materials within the product. Now should that focus be kept but another area added; for example which revision of the program and which application that were used. This is the newest requirement and is important for example when deviations are found in a program. To trace the deviation and correct it is the traceability to correct revision of used program crucial. Several years ago, drawings were signed out from an archive, the archive were often both moisture and fire proof. Today is it harder to control the original model, who is controlling when the drawing is signed out and in?

Another subject of discussion within MBD has been the hardware. What is needed? And are the costs reasonable? At Aeronautics several different hardware types will be used, for example; large screens for Material Review Board (MRB) meetings, stationary computers in production, Iphones for individual operator use in assembly, laptops at the shop floor etc. Today, the operators have a drawing lying on the floor; they climb in and out of the aircraft to look at the drawing. MBD will function in a similar way, but on a screen instead. Now, when the 3D models are readable in programs that call for less capacity than before, are the capacity requirements on the computers considerable lower. Often, local computers at the shop floor are connected to a central computer with significant higher capacity level, this also lower the capacity requirements.

Many of the problems connected to the interface between design and production that can occur when relocating production can be reduced by using MBD. For example the problem with nonconformities between design drawings and production documents will no longer be a problem, with MBD the sender and receiver do see the same model. The risk that the configuration management does not match at the sending and receiving company was earlier a problem, it was no guarantee that the sender and the receiver looked at the same drawing. With an on-line 3D model is the same revision level guaranteed and the sender and the receiver can se the same model at the same time.

MBD can be very time consuming to introduce both in-house and to receiving organizations. But the long introduction time can bee compensated; the lead time for several standard services are shortened, for example the formal modification service will be more efficient when both design and production requirements are in the same model.

However, today much focus is on system and configuration; the practical implementation can sometimes be lower prioritized. It is a risk at Aeronautics that the practical implementation problems are underestimated. A large challenge today is that it already exists one way that works. People are habit-driven, when you find a way of working that functions; it will follow you through your life. To change habits is a challenge. Aeronautics has a low staff turn-over, many operators has been at the company for 25 years or more and are very experienced. It is always hard to implement fast changes, especially when habits are routed. Knowledge within a company like Aeronautics can often be described to be “deeply rooted” or “ingrained in the walls”. The academic literature will describe this type of knowledge as tacit knowledge.

Implementing MBD at Aeronautics involved transfer of production documentation from paper to computer. This update included a validation of the information in the production documentation. Information that seemed to be tacit could some times be coded and made explicit. The role models for the production documentation at Aeronautics are those who set an example on non text based instructions like IKEA and LEGO. There is no text in IKEA’s instructions and they have a well developed language of symbolic. Today Aeronautics has text based work instructions with several hard to read abbreviations.

5 Discussion and Conclusion

The empirical data and the theoretical framework is compared and discussed together with the risk analyses performed at Aeronautics.

5.1 Production includes too much tacit knowledge and is therefore hard to relocate

The work instructions at Aeronautics are most often made by technicians, not educators. Most of the technicians work with their left hemisphere; it sometimes feels like the connection is missing between how we function as humans and how the work instructions are constructed. When designing the work instructions is it desirable that operators are involved. Often are experienced operators promoted to be production engineers, they have their knowledge with them. MBD gives more flexibility when working with the production documentation. When implementing MBD on an existing article is often the production documentation updated when it is transferred to digital data. This improved production documentation often helps to decrease the amount of tacit knowledge and increase the amount of explicit knowledge in the documentation. For MBD, when all production documents are up to date, are all information possible codified. Information that Aeronautics earlier thought were tacit may have been possible to document. This will decrease the stock of tacit knowledge and only the “true” tacit knowledge will remain. In aircraft production is often craft production relocated, this can be for example mould shaped manufacturing, such as hand layup of composites or straightening of sheet metal aluminium parts. These types of craft segments often contain a larger amount of tacit knowledge. And as earlier discussed is often tacit knowledge more difficult to transfer.

MBD can help knowledge transfer; when the production documentation is updated or created to fit MBD it is possible to differentiate off-line learning from on-line learning. This will save both time and cost, since the learning of an operator can take place at the same time as the production is running by other operators. The off-line training can be performed both if a new product is launched and if an existing product is updated in a new version. It will often take longer time to create new simulations than to update existing, but it is still a valuable tool.

The operator can receive the over all picture of the work package long before it is possible to actually touch the products. This virtual off-line training will decrease the on-line time, they will learn faster and most often will the quality level be kept more stable. With off-line virtual training, can operators be by them self. The on-line time will be shortened when the operators have trained off-line, this will hopefully shorten the time standing behind and learning by an experienced operator. But the training with an experienced operator is still needed; it is only the explicit knowledge that will be exchanged during off-line learning. This discussion is in agreement with Madsen [12], see the theoretical framework.

Another benefit is that it is easier to perform updates, and the documentation contains more illustrations and it is, as earlier mentioned, possible to include simulations.

5.2 The design drawings does not conform to the production documentation

Non-conformities between drawings and model do not exist any more. The sender and the receiver see the same information in the 3D model. This discussion is in agreement with Quintana [7] and Galbraith [4]. Adapting production process to a new environment can be easier to facilitate with MBD, since it is often easier to update the production documentation. This is also argued by Grant and Gregory [5].

5.3 The configuration management does not match at the sending and receiving company

One concern is the maturity level of the IT infrastructure at the receiving organization; it has to be highly developed. This situation can be solved in the same way as many companies in Sweden do, to source the competence outside the company. If the level of the infrastructure is too low, and the competence is not possible to source, the sender has to raise the receiver to a higher level. One way to facilitate the relocation is that the sender has to take the transferability into consideration when designing their own IT infrastructure. Components have to be chosen to make it economically possible to transfer.

It is of great importance to achieve traceability from beginning until the end of the MBD implementation. It is often more difficult to trace changes in information within DPD than within information on paper. It has to be found a secure and logic way to achieve full traceability for DPD. This is a huge challenge for the information society we live in today.

It should be noted that the IT-maturity on the individual level is a risk of lower concern. Today, several employees in the developing countries do not have the requested level. But, to strengthen the individual maturity level is far less effort required than to strengthen the system level.

Single hardware on the shop floor is most probably not a problem when performing relocation of production. A few years ago were

CAD needed on the receiver's computer to be able to read the 3D-models from Aeronautics. Today is not CAD competitive enough, it is too expensive, too slow and the user's licenses are too expensive. Another program is used, that is less costly, faster and with cheaper licenses. The possibility to use more effective programs has opened the door to make relocations more practicable. Another factor is that the prices on computers has decreased dramatically during the last 10 years, they are not that costly any more. If the costs of the required hardware are compared to the costs of the manufactured product, the hardware will appear to be inexpensive. The asset of hardware will not be an issue when relocating production.

5.4 Summary of discussion

It was hard to find gaps in the literature since no literature covering the aim of the research was found. Literature was found within the different areas, not all together. This also made it hard to critically evaluate the literature.

Below is the most important subject of discussion summarized.

- Update or creation of MBD production documentation will most probably decrease the stock of tacit knowledge at the sender.
- Update or creation of MBD production will help the possibility to differentiate off-line learning from on-line learning, which can save both time and cost.
- It is of high importance to keep traceability of revision of the program and application when MBD id implemented.
- If the level of the infrastructure at the receiver is too low, and the competence is not possible to source, the sender has to raise the receiver to a higher level.
- Challenges with IT maturity do not often appear at the operator level, they often have the technical skills.
- Due to the fast development of hardware, it will not be at critical problem at the shop floor.

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Copyright Statement

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