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A CASE STUDY OF THE IMPACTS OF PRELIMINARY DESIGN DATA EXCHANGE ON NETWORKED PRODUCT DEVELOPMENT PROJECT CONTROLLABILITY

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Abstract

This explorative case study analyses the impacts of the product geometry changes (also called iterations) to product development (PD) project lead-time in injection moulding company network. The objectives were to analyse how often product changes take place, at which stage of PD project iteration happens and how much rework iteration causes and thus delays the PD project. Data was collected by interviewing project personnel and from different information management systems.

We found that iterations caused 167 to 252 days of rework per tooling of a plastic component. This is a considerable amount when compared to planned injection mould lead-times, which were 91 to 149 days. Thus, by better iteration control in a PD network it is possible to improve the controllability of networked PD projects. Management aspects should focus on better inter-company PD process, which deals explicitly with iterations and their impacts. Furthermore, document management processes and systems should be extended to cover the whole PD network instead of one company only.

Keywords: design management, workflow management, integrated and distributed product design

1 Introduction

The life cycles of consumer electronics products and, consequently product development (PD) project lead-times have been shrinking constantly. This means that PD projects should be done more quickly than earlier. Not only short lead-time but also good control of the date when the PD project will be finished is essential. This is the case especially in high volume consumer electronics products.

At the same time, the complexity of these products has been increasing. In order to develop products that are more complex in less time, PD projects are conducted in a company network and in a concurrent manner. In addition, large companies have expressed their interest to continuously outsource product development and manufacturing of increasingly complex sub-assemblies to suppliers. Because suppliers are often smaller companies in size, they have to network further with other companies in order to be able to deliver required volumes or complex sub-assemblies of the customer.

The concurrent and networked way of working has set new challenges for PD project management. It is harder to communicate between companies than within one company [1]. Timely overlapping activities in different companies increase the need for design data exchange between the companies. Too much overlapping activities can lead to difficulties in the coordination of the project according to Loch and Terwiesch [2].

This research project was motivated by a group of companies. The client was developing consumer electronics products and the suppliers were developing plastic components to the client's products. The plastic components were demanding components with tight tolerances, strict surface finish requirements (appearance of the components) and volumes of millions of pieces per year.

The companies had noticed that product geometry changes during a PD project cause a lot of unforeseen rework. This rework was considered to be a significant source of project lead-time uncertainty, but nobody knew exactly how big a problem it was and how to manage the impacts of these changes. This paper describes the impacts in four real life projects.

Changes in the geometry of plastic components were communicated by sending *design data*, e.g. CAD models, meeting memos, measurement logs etc. between the companies. This activity is here called *design data exchange*. The CAD models are sent to the supplier in very early stages of the detail design. This is why they will evolve (geometry, dimensions etc.) a lot during the collaboration of the companies. Therefore, the exchange of this data is referred to here as *preliminary design data exchange*. The difference between this activity and "traditional" engineering change is explained in section 3.3.

1.1 Objectives

Our objective was to study the networked PD process, product changes in it and the impacts of the changes. We familiarized ourselves with the activities of the companies during the collaborative phase of the PD project. A challenge was to understand the relationships and the inter-company dependencies of the activities. In addition, we observed all the design data (documents) relevant to changes to product geometry. Especially our objectives were:

1. To analyse how many design data exchange events took place, and in what phase of the PD project these exchanges were made.
2. To measure the impact of design data exchange with respect to the rework done in mould design and manufacturing.
3. To get indications on what kind of improvements the networked PD process and its management might need.

1.2 Research methods and scope

The study was conducted as an explorative and descriptive case study [3]. Data was collected from several sources, interviews being the main source of evidence. In addition, data was gathered from document management, shop floor planning and other systems. If possible, the same data was double-checked from documents (such as drawings and emails). Originally, data was collected from several PD projects, but finally only four projects provided sufficient data for trustworthy analysis. Even within these four projects, not all could provide all the details requested. Only one of these projects was able to deliver all the required information. At the end, the data was validated by presenting it to the related people in both companies.

This paper focuses particularly on inter-company design data exchange in a PD network.

In the next section we will review the theoretical background for this study. Section 3 consists of a description of the case study environment. Section 4 presents the results and section 5 contains conclusions and discussion.

2 Theoretical frameworks for iteration

The theoretical background for this study is related to concurrent engineering, operations management and management science. The following references have been very useful when designing this study.

Krishnan [4] has developed a framework for overlapping activities based on the information flow between activities and its components. The components of information are *impact* and *evolution*. Krishnan originally used the phrase “sensitivity” instead of “impact”, but impact is used in this paper. Impact defines the information transfer impact to the receiving task. The impact can be e.g. 4 days of rework to an already machined injection mould. The degree of evolution indicates how mature this piece of information is. If the degree of evolution is high, the information is not likely to be changed anymore.

Loch and Terwiesch [2] have been studying how much the activities should overlap in order to minimise the impact in the downstream task. They combine communication to the amount of overlap level between the activities. They suggest that the optimal meeting frequency follows the frequency of engineering changes. Communication in a PD company network has been found important and challenging in [1] as well.

Smith and Eppinger [6] suggest a methodology for identifying the controlling features of engineering design iteration. That is how to identify those activities, which need to iterate. They suggest that a design structure matrix (DSM) can be used to identify the controlling features of iteration in large projects.

3 Description of the case study

3.1 The structure of the case company network

The network studied consisted of a customer and two of its suppliers. The customer developed and marketed consumer electronics products and its suppliers supplied plastic components to these products. The suppliers were involved in designing injection moulding tooling and supplying prototype plastic components before the mass production phase. The collaboration between the companies lasted about one year in each PD project.

3.2 Inter-company PD design data exchange flow

The most important pieces of product related information exchanged are distilled into different kinds of design documents such as 3D CAD models, project plans and task lists. When the PD project of the customer advances the component geometries will develop as well. This development (evolution of information) must be communicated to the suppliers.

This process (see Figure 1) starts when the customer sends a new version of e.g. a 3D CAD model of a component to the supplier. The supplier then starts to work with this new version, updates the CAD model of an injection mould, designs the manufacturing of the parts of the mould, manufactures the needed parts and finally injection moulds the plastic components. After this, these new plastic components are sent to the customer. The customer starts testing and inspection of the new components. At the same time, the supplier starts measuring the new plastic components and creates a measurement log. This log is then sent to the customer. Based on this log and the inspection results the customer either approves or rejects the components.

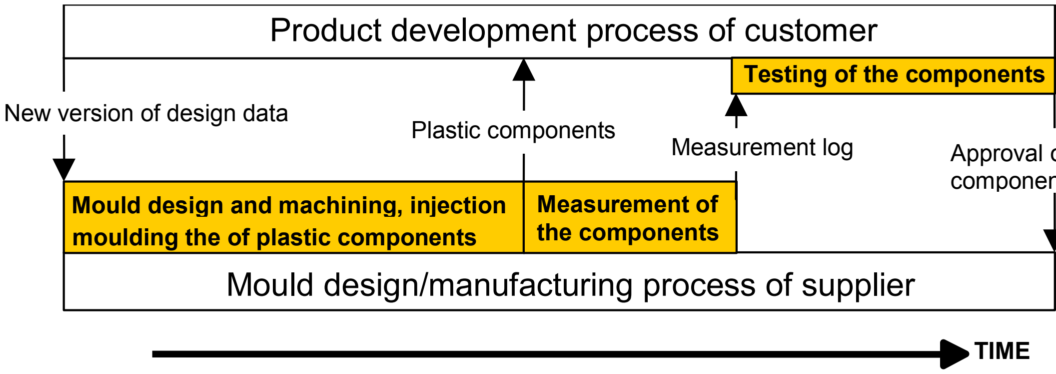

Figure 1. One iteration loop triggered by a new design document version.

This whole procedure can be seen as one *iteration loop* triggered by the new version of design data. One iteration loop can include several individual changes to the geometry of the component.

3.3 The difference between preliminary design data exchange and engineering change

The iteration loop described above is similar to an engineering change. Based on observations of the case network there are differences between these two (see Table 1).

Table 1. The differences between the properties of an engineering change and preliminary design data exchange.

Property	Engineering change	Preliminary design data exchange, "iteration"
Process where executed	Order-to-delivery, product design	Product development
Approval of event	Strict approval process. Involves many stakeholders	No strict approval process involved
Number of events in process	Happens rarely (0…5 times / component)	Happens frequently (tens of times / component)
Starting document state	Once already approved document. E.g. drawing or CAD model.	Incomplete, still evolving draft version of a document
Impact to lead-time, resources or product quality	Well figured out in advance, or at least figured out during the approval process.	The triggering person does not necessarily know the impact to e.g. lead-time.

4 Results

The data was collected from four PD projects. The amount of work done by the supplier was calculated from the date when the supplier received a new version of a 3D CAD model to the date when the customer received a new version of the plastic component. Note that approval time (from measurement log to approval in Figure 1) is not included in Table 2. "10 tenders" in Project 5 refer to 10 iteration loops that included several individual changes. The exact amount of individual changes remained unknown.

Table 2. Amount of rework caused by iterations compared to planned lead-time.

	Planned lead-time, days	Rework caused by iterations, days	Number of changes	Rework/Planned lead-time, %
Project 1	98	252	6	257 %
Project 2	149	208	59	140 %
Project 3	91	167	37	184 %
Project 5	101	208	10 tenders	206 %

The iterations caused from 167 to 252 calendar days of rework to be done by the supplier. This is very remarkable because an average injection mould was scheduled to be designed and manufactured within 91 to 149 days. When comparing the amount of rework to the planned lead-time of mould design and manufacturing we can notice that the duration of rework alone is a lot longer in every project than the planned lead-time. It must be noticed that in Table 2 a "Project" is only one injection mould for one single plastic component. All these projects belonged to a product, which actually consisted of ca. 10 plastic components. Therefore, the total amount of rework per product is bigger than mentioned in Table 2.

The following results are from one of the four projects (Project 2). This is the first production mould of one plastic component. There were three preceding prototype moulds done already for the same component.

4.1 When did iterations take place?

Figure 2 illustrates the timing of iteration loops (total amount of 10) in one of the projects. V's are the iteration loops that are represented with vertical bars. Bar height indicates (in calendar days) how many days work each iteration loop caused. Bars are plotted on a time-scale from first loop (V1) to the last one. The original planned lead-time (149 days) of mould making is represented with an arrow.

Collaboration phase took 13 months in this case. We can see that the amount of work per iteration (starting from 56 days of rework) decreases when the project advances. After the iteration V6, the amount of rework is dramatically decreased.

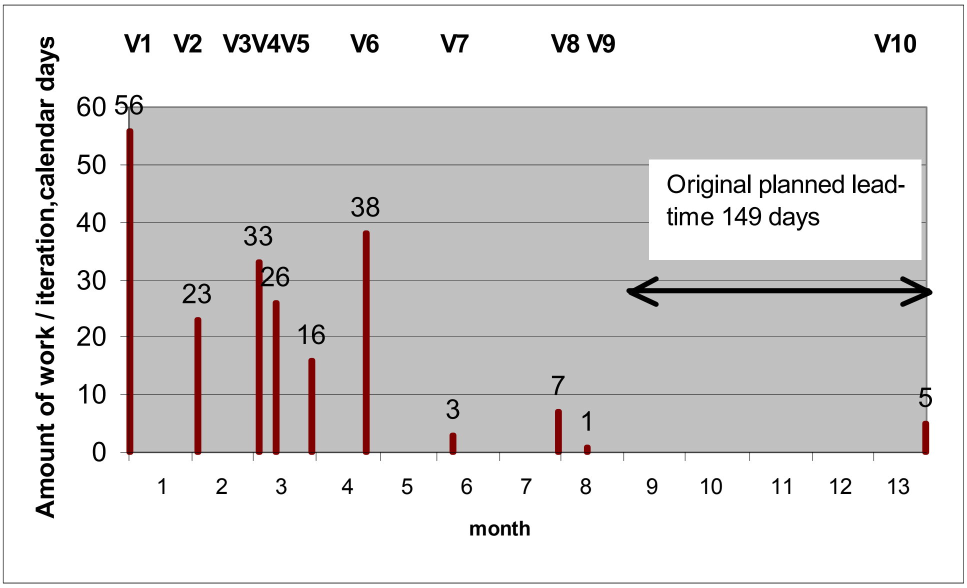

Figure 2. Iteration loops ("V"s) and their impacts on a time-scale.

Not all the changes were equal in impact. Table 3 illustrates the number of the individual changes in each iteration loop, the amount of rework and the average amount of rework per change. Thus, the last row implies how difficult the changes were to implement. The iteration V6 was obviously the most difficult one. Only two individual changes caused 38 calendar days of rework. This iteration included one major change to the product's geometry that originated from marketing. This change caused a considerable revision to the whole mould construction.

Table 3. The number of individual changes and rework in each iteration loop.

Iteration loop #	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**
Individual changes, pcs	28	4	9	6	4	2	2	1	1	2
Amount of rework, days	56	23	33	26	16	38	3	7	1	5
Rework / change, days	2,0	5,8	3,7	4,3	4,0	19,0	1,5	7,0	1,0	2,5

4.2 Who needed these iterations originally?

In order to manage iterations better we wanted to know the origins of the changes. These were traced to the manufacturing of the customer, marketing, mechanical design or electronics design. Supplier means the injection moulder here. As seen below, most of the changes originated from the mechanical design of the customer.

Table 4. The origins of the individual changes.

	Number of changes	**% of changes**
Own manufacturing	2	3 %
Marketing	6	9 %
Mechanical design	48	70 %
Suppliers	10	14 %
Electronics design	3	4 %
Total	**69**	**100 %**

Mechanical design is a "natural" origin of iterations because of the concurrent nature of mechanical design and injection mould design and manufacturing.

The explicit amount of the impact per e.g. electronics design could not be estimated. The impact to the lead-time could only be traced per iteration loop, which could include several individual changes from different functions of the companies. This is a big defect since with current data we cannot accurately say which function (mechanical design, marketing etc.) within the companies actually caused the biggest impacts to rework.

4.3 Implications for inter-company process improvements

The number of iterations is not the problem. For example, we can check certain issues (such as light or sound propagation in the component) only when we have physical components at hand. This is why many iteration loops are needed. There were few iteration loops, which had a very big impact on the lead-time. Since iterations are done to improve the quality of the product, they should be done unless their impact to lead-time is too big.

The main problems in the case networks can be classified according to existing theoretical frameworks, see Krishnan [4].

Impact of preliminary information

As Table 2 indicates, the impact of preliminary design data exchange causes a lot of rework in PD projects compared to planned lead-time. Thus, this data exchange impacts considerably the lead-time of the project as well. By managing the impacts of preliminary design data exchange in a PD network, it is possible to improve the controllability of the lead-time of a PD project. The problem is that the customer rarely has a clear image of the impacts of sending new design data to the supplier. The supplier is the one who can make the estimate of the impact to lead-time, costs and resources.

According to Table 3 not all the changes were equal in impact. Marketing (who originally set the specifications for the product) specification changes in this very late stage of the PD project were little surprising. This may imply that the internal projects (mechanical, engineering, electrical engineering and marketing) should be managed as whole, not as separate functions of a company.

Second mechanism that affects the impact is timing of a change. Even a couple of days difference in change implementation can make a big difference in impact. This is because machining and assembly of the mould are the bottlenecks in the supplier, since they cannot be fully automated. Workload of the workshop varies on daily basis. If the iteration implementation happens during a busy day, it will take longer to implement. At the same time, other simultaneous projects suffer as well. The customer rarely has any visibility to the workshop capacity of the supplier. However, in the interviews we made the customer indicated that in most cases it would be possible to adjust the implementation of a change by couple of days.

Evolution of preliminary information

In Figure 2 we can see that after iteration V6 there were four iterations that had actually very little impact (16 calendar days total, 7,7% of total rework) to the project lead-time. After the V6 iteration, product geometry had evolved almost to the final form. As seen on Figure 2 very much effort was put in iteration rework between V1 and V6. Considering the controllability of the project, one could argue afterwards that mould design should actually have started right after V6, that is six months after it actually did. In this way, 192 days of rework could have been saved in the project lead-time. As [2] suggest there seems to be an optimal level of overlapping mechanical engineering and mould design activities.

However, it is not this straightforward in practise. In every iteration, both the customer and the supplier learn something about the component. Thus, it is possible that even if mould design had started six months later, the amount of the total iteration rework would have been more than just 16 days.

The problem related to information evolution is that the supplier does not know the degree of evolution of e.g. a 3D CAD model. It is the mechanical design of the customer who has the knowledge e.g. in which features or parts of the 3D CAD model the degree of evolution is high or low. Because of this, the supplier cannot e.g. start mould making from the features with highest degree of evolution.

Lack of inter-company transparency, processes and document management

It seemed to us that not enough effort was put in the inter-company dimension of these kinds of distributed product development projects.

The lack of inter-company transparency refers to the fact that especially the supplier had very little visibility to the whole product and its design process at the customer. This means that the supplier did not know about e.g. near future changes to product geometry or projects schedule in advance (even if these were known at the customer). This kind of information would be very useful in order to minimise the impacts of product changes to the lead-time. For example, if the supplier knows that a certain feature is still very much under design the supplier could leave the machining of that feature to the latest possible moment. If this feature changed before its machining to the mould the impact to rework and thus to lead-time would be smaller.

Companies in case-projects had implemented some kind of engineering change processes within the companies. However, these processes were not dealing with inter-company dimension, all the actions and relevant people were within one company. These processes were not synchronised either. If a change to a component occurred it was mainly communicated by sending a new 3D CAD file to the supplier. In some projects, the companies agreed upon the actions that happened in the supplier after a change. For example, how quickly the supplier should react and send estimated costs and impact to the planned lead-time to the customer.

Lack of inter-company process also caused a phenomenon where a design engineer at the customer sent a new version of his design to the supplier even two times per day. A mould design engineer used a couple of hours daily just receiving the 3D CAD files sent and analysing what was changed and how it affected his work. This delayed considerably the progress of mould design work. This could be avoided if a certain time just before a change implementation to the mould would be restricted from any kind of new changes.

Inter-company document management problems and possible solution are discussed further in [5].

4.4 Reliability of the results

As mentioned in section 1.2, we had difficulties in finding reliable information about many projects. Bookkeeping procedures and accuracy were different in the companies. Not all companies had stored dates to any kind of information system. That is why pieces of information were collected mainly by interviews, emails and documents.

The data presented in this paper were checked from the personnel of the customer and the supplier. The information provided by both companies was found consistent. Possible errors in the total amount of rework per project can be 1 to 2 days because of bookkeeping procedures in shop-floor systems. For example, if injection moulding was actually finished one day but the plastic components delivered to the customer the next day. In this case, there could be one extra day added to rework. This is not the usual case, since the components were usually sent immediately to the customer after injection moulding.

5 Conclusions and discussion

The main problem is the considerable impact of iterations to the PD project lead-time. This impact was (rework in calendar days) 1,4 to 2,5 times original planned lead-time of the collaboration. Injection moulding is one of the last phases of a product development project and all delays at this point affect to the lead-time of the whole product. With this kind of (often unforeseen) rework, it is impossible to meet the original schedule of a PD project.

5.1 Recommendations: How to manage the impact of iteration?

PD processes and procedures must be devised to reflect the realities of the design work in company networks. Inter-company dependencies require that current iteration management processes (which already exist within companies in some level) should be integrated and synchronized to one common inter-company iteration management process of the whole PD network. This common process should be supported with inter-company document management.

The iteration management aspects should be focused on:

1. Establishing inter-company transparency
2. Implementing common, inter-company iteration management processes
3. Integration of design data management systems between companies which drives the inter-company processes

The companies should define and implement common inter-company processes. These processes should deal explicitly with at least iteration management (evolution and impact of design data) and synchronisation of intra-company processes of the company network. Evolution and impact of information should have a major role when implementing processes and transparency. For example, the suppliers could show their workshop capacity to the customer. In addition, the customer should indicate (e.g. with different colours in 3D CAD model) the evolution of product information.

These processes should also deal with inter-company transparency: which events (such as delays in the schedule, changes in production capacity etc.) should be communicated to whom and how. Communication between people is essential. However, we need to complement this communication with information systems. If we rely on humans as information carriers, we will have problems when data should be exchanged quickly and reliably. People tend to be on a business trip or ill every now and then and block information exchange at the wrong moment. The exchange of design data triggers events in the PD network in a very straightforward way. Thus, document management has a very important role in PD management. PD is fundamentally just refining information. This information is stored in documents, e.g. 3D CAD models. In addition, many process steps, such as changes to product geometry, are directly related to these documents.

5.2 Future work

Further research is required to better understand the requirements of good iteration management practices in networked product development projects.

Special attention should be paid to the facilitation of information exchange between companies. The exchange process should be clearly defined, communicated and include a mechanism to deal explicitly with the impacts of iterations.

Present document management systems are designed mainly for intra-company use. They are not specially designed for PD either. They support better e.g. order-to-delivery process and do not give sufficient support for inter-company PD processes. For example, documents are typically treated and approved as a whole. In PD, documents evolve (information evolution) partially (e.g. different features of a CAD model) and they are revisited frequently. In addition, in PD formal, lengthy document approval processes are not usable.

Ideas about better document management frameworks for company networks are discussed further in the reference Kotinurmi, et. al. [5]. It presents a framework for PDM (Product data Management) system integration in a company network using RosettaNet standard messages.

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