DUAL PERSPECTIVE ON INFORMATION EXCHANGE BETWEEN DESIGN AND MANUFACTURING

Jessica Bruch[1, 2] and Glenn Johansson[1]
[1]Department of Industrial Engineering and Management, School of Engineering, Jönköping University
[2]School of Innovation, Design and Engineering, Mälardalen Universtity

ABSTRACT
This paper addresses the exchange of information between the design and manufacturing interface from both perspectives in order to ensure interdepartmental integration and improve the performance of new product development projects. Based on two in-depth case studies, this article illustrates that there are differences in the type of information transferred between design and manufacturing as well as how this information is shared. While design engineers ask for feedback to their work regarding both the product and the project, relies the production system designer heavily on feed-forward information concerning the product per se. For effective new product development, it seems however beneficial that design engineers also should give feedback to the production system concept. The implication is that project managers need to carefully consider how to improve the sharing of information upstream in new product development projects and what communication medium to apply to transfer the information between design and manufacturing.

Keywords: Interface management, Information sharing, Product design, Production system design

1 INTRODUCTION

New Product Development (NPD) creates both opportunities and challenges for manufacturing companies. The manufacturing companies depend on the ability to frequently introduce new products to the markets in time [1, 2] in order to achieve and retain a competitive market position on a global market. Since NPD is defined as the transformation of a market opportunity into a product available for sale [3], it necessitates that functionally specialized departments need to be integrated to achieve an efficient NPD process. It appears that projects with a high integration are successful while low integration across functional areas cause project fail [4]. As a result, manufacturing companies that are able to manage interfaces between various functions effectively can realize considerable competitive advantages with respect to the performance of the NPD process [5, 6].

One interface that has particularly great potential for improvements in NPD performance is design – manufacturing (DM) interface [7, 8]. Design and manufacturing activities are largely interdependent since each function is influenced by the decision and actions of the other, or has information that the other needs to meet its specific responsibilities [9, 10]. However, to achieve integration between design and manufacturing is problematic for many manufacturing comapnies due to the ambiguity involved [7, 11]. One means for improved integration is the sharing of necessary and relevant information between design and manufacturing. The sharing of information between design and manufacturing leads for example to better insights into the other functions role thought world, language, goals, needs, wishes and limits [12]. Improved information sharing should ensure cross-functional integration and allow the design engineer and production system designer to make better-informed decisions in the design phase of the product and the production system respectively. Despite the attention paid to the DM interface and the vital role of information sharing for integration between specialised functions, there is little systematic empirical evidence that consider the perspective of both design and manufacturing.

2 LITERATURE EXPOSITION

2.1 Why is Design-Manufacturing Integration Difficult?

Integration between different departments and functions plays an essential role for the success of a development project [4, 13] and can be defined as *"the quality or state of collaboration that exists among departments that are required to achieve a unity of efforts by the demands of the environment"* [14, p. 1]. However, many manufacturing companies find it difficult to achieve integration between design and manufacturing [e.g. 7, 8]. For example, Griffin and Hauser [15] point out that as integration between functions decreases, their ability to combine skills to develop and produce successful products decreases causing suffers in the companies. The origin of integration problems are the differences that exist between design and manufacturing (see Table 1).

Table 1. Differences between design and manufacturing (Modified from [16])

Dimension	***Design***	***Manufacturing***
Project orientation	Solution-focused	Output-oriented
Projects preferred	Advanced	Incremental
Time horizon	Medium-long term	Both short-term and long-term
Process repeatability	Medium-low; the process involves some routine tasks that can be formalized but development project is unique	High (for high-volume products); routine tasks that are easy to formalize
Completion point	Sharp; ending with release of documentation for production start-up	Very sharp; defined by the production plan
Bureaucratic orientation	Less	High
Professional orientation	Science	Process

Studies have revealed certain barriers that might hamper integration. Such barriers refer to personality dissimilarities, cultural differences, language problems, organizational structure, and physical location [8, 15]. Among individuals representing different organizational units there might exist inherent personality dissimilarities. Mutual understanding between (groups of) individuals can be hindered due to such dissimilarities. Differences in training and background might spur development of cultural differences between persons from different organizational. This leads to that company goals, time orientation, etc. might be viewed differently. Another factor is that different organizational units tend to develop self-contained societies in which they reside leading to difficulties in understanding and appreciation of each others' capabilities. The differences in training and background often also induce language problems, because it is not uncommon that persons possessing different competencies develop their specific terminology. The level of detail in their terminology may also vary among professional groups, which may cause frustration when communicating with each other. There are various reasons why organizational barriers arise. Examples are lack of clarity, unclear roles and responsibilities, and reward systems which poorly consider the inter-dependency of tasks. Clearly, physical proximity has an effect on people's communication frequency. For example, long distances hamper spontaneous meetings and face-to-face meetings.

To sum up, this section has highlighted the fact that manufacturing companies have to find means to overcome integration barriers to allow for NPD success. As the following section outlines, an effective sharing of information between different between design and manufacturing is one means to overcome these barriers.

2.2 Sharing Information: A Key Ingredient to Achieve Integration

The level of integration can be approached as an information processing phenomenon, where shortages occur due to a lack and asymmetry of information or an inability to share information [17].

Frishammar and Ylinenpää [18, p. 447] define the sharing of information as “the transfer of information across boundaries of departments and functions and among organisational members”. Thus, information sharing contributes to the interaction and collaboration between design and manufacturing in those design tasks that are dependent on each other in order to ensure successful NPD. Previous research indicates that an efficient sharing of information is fundamental in order to achieve integration between different organizational units [19, 20]. For example Moenert and Sounder [21] conclude that the transfer of information between different functions and departments is the driving force for individuals involved in NPD projects to become integrated. Information transfer should reduce equivocality and ambiguity in organisations and contributes to consensus on a shared interpretation of what to [22].

The need to work with overlapping activities in NPD projects, i.e. decisions about the production system are being taken before the product design is completed, has consequences on the information sharing. Because each task’s design is dependent on the others task’s design, it would be beneficial to not only provide product information to the production system designer, but also provide production system information to the product designer [10]. However, project members cannot expect to receive the same type of information with the same accuracy in development projects with or without overlapping activities [23, 24]. There is a reluctance to use incomplete and uncertain information and unwillingness to release early information [e.g. 5, 25]. Further, the diversity of functions lead also to problems in information exchange [8, 14]. Information collected by one department is not automatically shared with the other depatments and functions [26]. This is in line with the results by Johansson [27] who argues that problems in the sharing of information between departments are not only related to the overlapping of activities but also to the release and use information.

In general, different types of information need to be shared between the different functions and departments during the NPD process. Häckner [28] conclude that different types of information are useful for different decision-makings processes, but also that usually a combination of different types of information are combined. Zahay et al. [29] suggest eight different types of information relevant for NPD project, which are further categorised according to their origin. The authors identify three types of internal information (strategic, financial, project management), two types of external information (competitor, regulatory) and three types of information that either can have their origin internal or external (customer, needs, technical) [29]. In comparison, Frishammar and Ylinenpää [18] also studied the type of information relevant for different phases in the NPD project and conclude that in the early phases the sharing of information about customer needs and problems as well as technical, competitive and regulatory information is crucial for NPD success..

In situations where people from different functions, background and interests are involved the transfer of information becomes more difficult the more abstract the information [30]. As a result, the communication media, i.e. the media information is processed with, has to be carefully chosen. Hertzum and Pejtersen [31] point out that written information such as documents lacks information about the context surrounding, i.e. they miss explanations about why specific decisions are made as well as what purpose is served by individual parts of the design. Daft and Lengel [22] advocate that the communication media has to be dependent on the type of information transferred. If the purpose is to reduce equivocality, there has to be a possibility for debate and clarification and consequently a rich communication media such as face-to-face communication is recommended. But when information transfer is about reducing uncertainty, a media of low richness such as documents or numeric databases is effective [22].

2.3 Summary and Purpose

To sum up, the literature exposition in this section has revealed that information sharing plays a central role for the integration between design and manufacturing in NPD projects. However, there is studies that concurrently address information sharing from both the design and manufacturing perspectives are missing. Consequently, this paper compares and contrasts which information is required and which information is provided from the design and manufacturing perspectives, respectively. The paper also focuses on which types of communication media are used for proper information sharing between design and manufacturing.

The article is based on two in-depth case studies analysing the collection, sharing and use of information in at which one studied on the perspective of design and the other one on the perspective of manufacturing in NPD projects. This paper therefore presents an analysis of two studies where one focused on a production system development project, whereas the other put attention towards a product design project. In both cases, however, information exchange between design and manufacturing were key issues in the projects.

3 RESEARCH DESIGN

In order to ensure a comprehensive assessment of the complex and iterative process of information processing activities between design and manufacturing in NPD [5], two in-depth case studies have been carried out. An exploratory case study research strategy is deemed appropriate when limited knowledge of a phenomenon exists [32] and particularly when analysing processes [33]. To investigate how the information exchange is organised and managed between design and manufacturing, two manufacturing companies were selected, henceforth referred to as Company A and Company B. Both companies have their headquarters and main R&D activities in Sweden, but manufacture and sell their products on a global market. The NPD projects followed included both a product and an industrialisation part. While the former part deals with the development of a product and on the manufacturability of the product design, the latter part covers the development of a production system from concept to serial production. During the case study carried out at Company A the focus of the study has been the industrialisation part, i.e. the information needs of the production system designer. At Company B, in contrast, emphasises was on the information needs of the product design engineers. Furthermore, the projects displayed differences regarding geographical proximity. Design and manufacturing were located at the same location at Company A, while at Company B design was performed in Sweden and manufacturing in China. Although in both cases NPD projects have been followed over a longer period there have been differences regarding the collection of data. How the data has been collected for each case is briefly described below.

At Company A the industrialization project, i.e. from the concept of the production system to serial production has been followed. The study focused on the information acquired, shared and used during the production system design process. Data was collected on site and in total 36 days have been spent at the company. Due to ability to follow two NPD projects over a long time, the data collection methods changed as the research progressed. At the beginning of the case studies the data collected contributed to the understanding of the company and the studied project, i.e. companies documents were studied and as well as introductory interviews were carried out. After the introductory phase the most important sources for obtaining information during data collection were interviews as well as passive and active observation. The respondents were chosen to embrace different perspective of the development projects including vice president, manager production engineering, project manager industrialization, project manager advanced engineering, program manager, facility manager, quality assurance engineer, purchaser, logistic manager, maintenance engineer, product manager, production engineer, workshop manager, team leader, assembly operator. Additional sources of data have been participation at project meetings and informal discussions as the visits last during whole days. Workshops have also been arranged at the company to discuss preliminary results.

The study at Company B has been performed as a as a longitudinal study, where the project has been followed from early phases until the current phase of production start-up. The study has focused upon the challenges associated with design-manufacturing integration in a dispersed setting. Various means have been used to collect data such as interviews, participation at project meetings, and studies of internal documentation. In total, the researchers have met with product development team members on more than 80 occasions (including interviews and participation at project meetings). The interviewees were selected due to their potential to display different perspectives of the project and include the project manager, product development engineers, laboratory engineers, purchasers, manufacturing representatives, etc.

The main unit of analysis in this paper is the information transferred between design and manufacturing, focusing in general on the exchanged information and the information needed as well as how the information was exchanged. The collected data has been analysed according to the guidelines provided by Miles and Huberman [34]. In order to reduce and display the data in an appropriate way, directly after each time of data collection the findings were summarised and transferred into a worksheet for further analysis. Conclusions were drawn in two stages. First, a within case analysis has been carried out followed by a cross-case analysis. Consequently, the data gathered from each case study has been analysed on a stand-alone basis, which allowed for identifying the unique patterns of the manufacturing perspective and the design perspective with respect to what information had been shared and how this information has been transferred. Secondly, the reduced data from the within case analysis was used to compare the patterns found with each other in the cross case analysis. All analysis was exploratory in nature.

4 CASE DESCRIPTIONS AND EMPIRICAL FINDINGS

4.1 Project A - The manufacturing perspective

Company A, is a supplier in the automotive industry providing system solutions to the global automotive industry. The company is responsible for delivery of the finished product including product development and continued technological renewal. The case study, addressing project A, focuses on the development of a new product in one of the company's product families, which partly replace an already existing product. The ability of handling effectively changing production volumes and a wide variety of product variants is seen as a prerequisite to survive on the dynamic market. Further, it was specifically pointed out that the concept of the production system has to be applicable to future production system generations. The development project was organised in a project following the company's stage-gate model (cf. [23]). The development and industrialisation have been in Sweden at the same manufacturing site but due to time pressure project leadership was separated, i.e. one project leader who was responsible for the development of the product and one for the industrialisation.

Table 2 summarises the results of Project A concerning the information required and provided as well as the communication media applied. In order to design and develop the production system the system designer requested mainly information related to the product from the system designer such as product components or tolerances. To satisfy the information need, various types of information were provided to the system designer including different text documents, drawings and a prototype of the product.

At the beginning of the industrialisation project, the information provided by design was incomplete. For example, test or packaging instructions were absent and system designers had to ask for and remind design engineers several times to obtain the required information. Another important aspect was that there was a lack of credibility for some parts of the provided information such as the amount of lubricant, which should be used during the different assembly stages. There was no reference to how the information was obtained and it seemed that this information was based on experience than on facts.

Latter in the project when the production equipment was ordered the handling of changes in the product design became more important. During the project, the freezing of the design was shifted to a latter point of time, which allowed design to make further changes. However, manufacturing was not included early in the discussion of these changes but rather got informed when the possibility to influence the result was limited. Thus, to get control about design activities and to keep the cost of the production equipment reasonable routines were changed. A so called "change order" document was introduced, forcing the design engineers to get approval from all concerned functions when design changes of the product were made. Worthwhile, it is important to highlight that manufacturing does not require any feedback on the proposed production system. Rather, the work of the system designer is based on feed forward information i.e. information that was processed downwards in the organisation. Manufacturing get back to design only in cases of ambiguous information, i.e. information, which needs to be further clarified to improve the understanding.

Table 2. The manufacturing perspective on the information exchange between design and manufacturing

	Empirical findings
Information required by manufacturing	• Properties, functions and capabilities of the product • Product components • Requirements placed on assembly of the product, e.g. required function tests or packaging instructions • Tolerances • Sequence of assembly stage • Changes and adjustments made in product design
Information types provided by product design	• Bill-of-material (BOM) • Product drawings and models (prototype), • Test specifications • Packaging instructions for raw material and assembled products • Assembly instructions • Change order, a document informing about planned changes and asking for approval at the affected functions
Communication media	• Advanced technical tools: physical prototypes, simulation • Less advanced technical tools: e-mails, text documents • Human direct contacts: face-to-face meeting, conversation

4.2 Project B - The design perspective

Company B produces a wide variety of products for outdoor use. The company's activities spans worldwide and it carries out development and production in different countries. The case study, addressing project B, focuses on a new product intended to replace one of the products in the company's product portfolio. Key product criteria are weight, sales price, design and exhaust emission levels, among other things. As guidance for the project, the company's project stage-gate model is used. The project time schedule is very tight in order to "hit" the window of opportunity on the market. Development of the product is carried out in Sweden whereas production will be performed in a production site in China.

The empirical findings of Project B are summarized in Table 3. Early in project B, the product design engineers requested feedback from the manufacturing site regarding the product's ease of manufacturing and assembly. To get such information they submitted 3-D CAD models, but also physical prototypes made by rapid prototyping equipment. The response from the manufacturing site was given as written comments on paper prints of the 3-D models. Also a report was supplied to the product design team.

Continuously during the project, information in the form of various documents specified by the company's project model has been exchange by the product design team and the manufacturing site. Extensive exchange of information has taken place regarding the supplier selection. Based on 3-D CAD models, design drawings, and BOMs the manufacturing site has been responsible for sending out requests for quotations from potential suppliers. The quotations have then been used in the dialogue between the manufacturing site and the product design team regarding costs and component quality. The dialogue regarding supplier selection has been part of the bi-weekly telephone meetings and though emails.

Later in the project, when suppliers were selected, the dialogue has focused on when various components can be delivered from the suppliers and from in-house manufacturing in China. Manufactured components have been sent to the engineering laboratory in Sweden to test and verify their functionality and quality. Modifications to be implemented based on these tests, have been sent back to China in engineering change request documents. However, these documents proved to be insufficient to initiate the changes. Thus when design changes of the product were introduced and called for modification in the manufacturing process (mainly modifications of the tooling), 3D-drawings from the CAD-system were used to indicate which changes should be made. The design engineers used these 3D-drawings to comment and mark with different colours what and how the changes were to be made.

In addition to the more "technical" media, also personal face-to-face meetings have been used later in the project. Both design engineers and laboratory engineers have travelled to the manufacturing site to facilitate information exchange and reduce potential misunderstandings regarding the product and its preparation for manufacturing.

Table 3. The design perspective on the information exchange between design and manufacturing

	Empirical findings
Information required by design	• Feedback on design solutions, especially about manufacturability • Regarding supplier selection, including cost, quality, etc. • Plans and dates for delivery of components • Regarding implementation of changes made to the manufacturing process (tooling)
Information types provided by manufacturing	• Comments on ease of manufacturing and assembly • Quotations from suppliers • Manufactured components for test and verification
Communication media	• Advanced technical tools: on-line video meetings, Team Room (an application in Lotus Notes), 3D computer models/drawings, physical prototypes • Less advanced technical tools: e-mails, text documents • Human direct contacts: Face-to-face meeting

5 CROSS-CASE COMPARISION

Comparing the studies presented in the previous section provides interesting insights into similarities and differences regarding the need and access to information in the DM interface. In project A, on the one hand, much information focused on product-related issues. The required information from the manufacturing development team concerned to a high degree product-centric issues, i.e. this type of information focuses on the product *per se* and provides the manufacturing site with essential input regarding the product. Examples are properties and functions of the product, product components, and assembly sequences. The character of the information can be classified as primarily feed-forward information where the production system development team received information that was needed from the product design team. However, the production system design team did not request any response from the product development team regarding planned production system solutions. In project B, on the other hand, design engineers requested explicitly feedback from the manufacturing site regarding the product's ease of manufacturing and assembly, supplier selection and progress in the production system development. Consequently, the requested information concerned both product-centric and project centric information. The latter aspect concerns status and progress of the production system development project, which has consequences on the overall schedule of the NPD project. For example, the product design team needed feedback on when components for testing could be produced.

The comparison between the projects indicates that design engineers require feedback to their work regarding both the product and the project, while system designers request feed-forward information related to product-centric information. There are several possible explanations for these differences. First, the differences between design and manufacturing might play a role. Previous research emphasizes the distinction between the product design and the manufacturing teams' responsibility and goals [8, 14]. The product design team has responsibility to deliver engineering data to the production system design team with a clear-cut deadline. The information exchange from the product design team's perspective therefore need to involve aspects related to the project *per se*. Feedback on plans and status regarding responsibilities related to manufacturing such as when components for testing are available is essential if the product design team should be able to deliver final engineering data in due time. In contrast, the production system design team is mainly focused on preparing for continuous manufacturing. Further, as the production system design team relies heavily on feed-forward information it has to "wait" until such information is available. The manufacturing development team has to accept the pace of the product design activities and thus project-centric information is of less interest compared to product-centric information, which is of direct use for the teams' work. Hence, it seems natural for the manufacturing development team to focus primarily on the type of information that is a key for its activities, i.e. the product-centric information.

Another factor that might affect the information needs is the applied stage gate model (cf. [23]). As demonstrated by the two cases, production system design team relies primarily on feed-forward information and receives the information when submitted from the product design team. The timing for access to this information is defined to a high degree by the deliveries of the different gates in the development project. Surprisingly, the manufacturing development team did not request any feedback information from the product design team regarding potential manufacturing solutions. One reason for this might be that the stage gate model states explicitly a feed forward flow of information in the organisation, i.e. from product design to manufacturing, while the information flow backwards from manufacturing to product design is note supported. Ottum and Moore [26] noted that the information collected by one department is not automatically shared with the other depatments and functions. However, the comments and ideas of product design engineers' on manufacturing solutions could be relevant input to the production system design team [10]. Engagement in such exchange of information might lead not only to modified and better manufacturing solutions, but also to a change in the product design solution. The reason is that there exist a mutual interdependency between product design solutions and manufacturing solutions. Thus, there is a need for structures supporting the information exchange also backwards in the organisation.

Still another possibility is related to the (assumed) knowledge of each other's work. The literature often advocate that manufacturing involvement is key in product design activities [e.g. 8, 11], but there is scarce literature that emphasizes the opposite. This indicates that manufacturing engineers are expected to be knowledgeable of the product design process, but that less expectations relies with the product design engineers regarding how to develop a suitable production system. Differences in education and training manifest this [8] and thus there might exist an incorrect belief among the manufacturing engineers that the product design engineers cannot contribute to their work.

Further, the differences in the education and training may affect the ability of the design engineer to give valuable feedback to the production system design team. Jacob [30] noted that the exchange of information becomes more difficult the more abstract the information. At the beginning of the production system design the information may be difficult to understand for the design engineer but once the equipment has been ordered and is built, i.e. the result of the production system design becomes clear the ability for changes is limited. Product development usually includes the developments of prototypes, which makes it easier for the system designer to get insight into the goals of product design. In comparison, the concept of the production system cannot be tested by means of a physical prototype. Another reason might be the reluctance to the use of incomplete information and unwillingness to release early information [e.g. 5, 24, 25].

With regard to the preferred communication media, the two case studies reveal that the communication media used in the development project spans from advanced technical tools including on-line video meetings or physical prototypes to human direct contact such as face-to-face meetings and informal conversations. Consequently, a combination of codified and personalisation strategies is applied to transfer the required information in the DM interface [cf. 35]. A codified information exchange strategy relies on a people-to-documents approach. In the case studies, this is exemplified with the use of 3-D CAD models, drawings, BOMs, and other types of documentation. However, also a personalization strategy, which relies on direct person-to-person contacts, was used as well in both case studies. For example, informal meetings took frequently place in project A, where product design engineers and manufacturing representatives exchanged information. In project B, product design and laboratory engineers visited the manufacturing site to exchange information and to engage in a dialogue regarding the product and potential manufacturing flaws.

The communication media most frequently applied is paper documents, which made it possible to transfer large amounts of information without time-consuming activities. However, both cases revealed difficulties related to the understanding of the content of the paper documents. For example, in case B the engineering change request documents transferred have been supplemented by 3D-drawings in order to highlight where modifications were needed, while in Case A production system designer met design engineers for further clarifications when the information is ambiguous. Further, the strategies for transferring information were continuously adjusted in the projects in relation to the project status. Thus, the choice of the appropriate communication media should be carefully chosen as suggested by earlier research [e.g. 22, 31].

6 CONCLUSIONS

This paper revolves around two in-depth case studies of NPD projects within two manufacturing companies. By studying the information exchange in NPD projects from both the manufacturing and the design perspectives our study contributes to the DM interface theory. The results suggest that design and manufacturing require different types of information to carry out their work. While the production system designer relies largely on feed-forward information in terms of information concerning product-centric issues, design engineers request feedback information in form of both product-centric and project-centric information. The need for working with overlapping activities in NPD projects supported by stage gate models has highlighted the benefits of including manufacturing competencies in product design. Surprisingly, this study shows that manufacturing does not request any feedback from design with respect to the production system design. However, for effective production system design to take place, it seems advantageous that design engineers should also give feedback to the production system concept.

Furthermore, the results suggest that authors of information need to carefully consider the communication media applied. This is because different communication media are suitable in different situations. When comparing the empirical findings with theory, it is shown that in order to minimise ambiguity of the exchanged information standard text documents are not sufficient as the only communication media.

Our findings stress the need for a more encompassing approach when studying the DM interface. Most of the studies carried out in the DM interface focuses on the design perspective. Therefore, further research is needed that broadens the scope by studying also the specific needs of the manufacturing perspective.

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