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Interfaces between technology development, product development and production – Critical factors and a conceptual model

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In order to avoid misfits between technology and product concepts and prevent problems related to the fit of the product design and the production process, the interfaces between technology development, product development and production must be managed. In this paper the critical challenges related to these interfaces are analysed and discussed and a tentative model is formulated. The study builds on in-depth case studies of ten product development projects at five manufacturing firms, two workshops and a questionnaire. Results indicate that in the technology development/product development interface factors related to the synchronization (i.e. timing) and transfer management are ranked as most important. For the product development/production interface factors related to transfer management seem to be most important. The tentative interface management model includes a risk assessment of six contextual factors; the complexity and degree of change in the product, the complexity and degree of change in the production process, the degree of technological novelty, the geographical and organizational dispersion between technology development and product development, the organizational and geographical dispersion between product development and production and the market uncertainty in the project, and appropriate recommendations are devised to handle the specific risks related to these factors.

Keywords: technology development, product development, production, interface management

1. Introduction

Industrial innovation processes are usually divided into three separate, but partly parallel sub-processes, i.e. technology development (or applied research), product development and production. Industrial firms often de-couple these sub-processes, both organizationally and geographically. The rationale for this de-coupling is that the characteristics as well as time horizons of these sub-processes differ (Nobelius, 2004; Vandevelde and van Dierdonk, 2003). Whereas both production and product development tend to have very sharp deadlines, technology development has a less clear objective and completion point. Furthermore, technology development is characterised by a high degree of uncertainty with diffuse competence needs. Product development, on the other hand, has a focus on the product system, with more straightforward competence needs and a lower degree of uncertainty. As production usually concerns repeatable tasks, it is possible to foresee the competences needed in this process. Hence de-coupling technology development from product development and production is a common strategy to be able to handle the specific degree of risk in each process, and reduce uncertainty during new product development. However, de-coupling technology development, product development, and production may cause a number of integration problems. Studies in the world auto industry illustrate for example how such separation may cause a misfit between technology and product concepts (Clark and Fujimoto, 1991). Also, problems in integrating product development and production concern the degree of fit between the specifications of the product design and the capabilities of the production process (Adler, 1995).

The interfaces between technology development, product development and production have been studied separately in earlier studies: the technology development/product development interface (e.g. Iansiti, 1995; Drejer, 2002; Nobelius, 2004), and the product development/production interface (e.g. Fabricius, 1994; Eskilander, 2001; Vandevelde and van Dierdonk, 2003), but research lacks a comprehensive view on both interfaces. This is a shortcoming in current knowledge, because decisions made during technology development may have a direct impact on production. Likewise, investments made in production may restrict certain product technology choices. Thus, by addressing both these interfaces in the same study, we are able to provide a more comprehensive picture of the challenges associated with the two interfaces and to analyze similarities and differences. The purpose of this paper is to uncover, analyse and discuss critical challenges in the interfaces between technology development, product development and production and formulate a tentative model for bridging the technology development/product development and product development/production interfaces effectively.

2. Interfaces in industrial innovation processes

2.1 The technology development – product development interface

Focusing on the technology development/product development interface, Eldred and McGrath (1997) view the transfer of technology from technology development to product development as consisting of a number of sequential stages in which the new technology has to pass a number of senior management reviews. They argue that there are three key elements in a technology transfer process: program synchronization, technology equalization, and technology transfer management. Program synchronization refers to the timing of transferring new technology to commercial product development projects. Technology equalization focuses on equalization of core and supporting technologies. Technology transfer management refers to the use of a transition team with clearly defined roles and responsibilities. Iansiti (1995) stresses the importance of the technology integration process that forms an intermediate stage between the exploratory stage where new technical concepts are investigated and the development stage in which the chosen concept is refined and designed in detail. A so-called system focused approach, in which focus is set on discovering and capturing knowledge about the interactions between the new technical concepts and existing ones in the product and the production system seems to support higher productivity and shorter development lead times. Also Larsen et al (2001) advocates the importance of technology integration and outlines a model consisting of three phases: technology characterization, application identification and application evaluation. These phases are aimed at supporting the fit between the new technology and commercial product development. Drejer (2002) presents a model of ways to integrate technology development with product development that includes three dimensions: integration of time horizons, aspects and activities. Integration of time horizons relates to the issue of synchronization between technology development and product development, integration of aspects relates to what is actually transferred, and integration of activities relates to how the transfer process is organized. Similarly, Nobelius (2004) presents three dimensions that are essential for the technology development/product development interface: strategic and operational synchronization, transfer scope and transfer management. Strategic synchronization concerns the issue of matching the technology and product development strategies, whereas operational synchronization refers to the timing of introducing new technology in certain development projects. Transfer scope refers to the subjects in terms of test results, prototypes, blueprints, etc. that are transferred. Transfer management addresses how the technology transfer is carried out.

2.2 The product development – production interface

Focusing on the product development/production interface, Trygg (1991) argues that two dimensions affect the product development to production transition process: technology and organisation. The technological mechanisms affect the involved functions in at least three different ways: new technologies provide the product developers with new ideas, materials, components and tools, the effectiveness of the integration can be enhanced by the use of support tools such as IT-based tools, and implementation of advanced manufacturing technology may increase the capability of the manufacturing processes. The organisational mechanisms include culture, structure and people. Adler (1995) suggests a taxonomy of coordination mechanisms for the product development/production interface. These mechanisms are: non-coordination, standards, schedules/plans, mutual adjustment, and teams. It is argued that for the pre-project, design and the manufacturing phase different mechanisms are appropriate. Vandevelde and Van Dierdonk (2003) claim that formalization in terms of clear goals, roles and responsibilities as well as empathy from product development towards production, which means that the product developers consider production aspects during the design stage, are contributors for smooth production start-up. Adopting a problem solving perspective, Wheelwright and Clark (1994) describe four modes of interaction between design engineers and process engineers: serial mode, early start in the dark, early involvement, and integrated problem solving. Serial mode means that the process engineers wait to begin the work until the design engineers have finished their job. Early start in the dark links the two groups in time, but continues to employ a batch-like communication. Early involvement means that the two groups are engaged in a two-way communication of preliminary information, but the sequence of work between the groups is still evident. In integrated problem solving, an ongoing dialogue is established in order to support the process engineers to get a flying start of their work. Addressing the Design for Manufacturing (DfM) field, Herbertsson (1999) argues that three different types of DfM activities can be distinguished: preparatory DfM where the producibility of new technology is assessed, supporting DfM which aims at identifying and supplying training and new methods and tools to the development organisation, and operational DfM which primarily is the application of methods and tools in ongoing product development projects. Focusing on activities in various phases of product development, Peters et al (1999) includes a phase denoted preproduction validation in their attempt to develop a generic product development model. The purpose of this phase is mainly to take account for the way in which the product is to be produced.

Although the literature discussed above provides some indications on the importance of bridging the technology development/product development and product development/production interface effectively, it does only provide a limited insight into what factors are important and how the interfaces can be handled. With our study we intend to identify the factors important in the interfaces in more detail, and moreover provide recommendations to bridge the two interfaces.

3. Method

The paper is an outcome from the research project INTERFACE – Interfaces in Industrial Innovation Processes. The project, which involves five manufacturing companies actively taking part and giving access to their knowledge and premises, is financially supported by the Swedish Agency for Innovation Systems (VINNOVA). Results in the paper build upon in-depth case studies of ten product development projects. In order to diminish bias the projects studied are a combination of retrospective and real-time cases (Leonard-Barton, 1990). Data for the retrospective cases have been gathered through interviews with key informants complemented by archival data such as project plans and project evaluation reports. The real-time cases employ longitudinal data collection between 2005 and 2007, primarily by interviews on several occasions and by studying project documentation. For an overview of the participating companies, studied projects and number of meetings and interviews see table 1. Data analysis followed the three flows of activities suggested by Miles and Huberman (1994): reduction, display, and conclusion drawing/verification. Within-case as well as cross-case analysis was carried out (Yin, 1994).

Table 1 Overview of the companies, projects, meetings and interviews

Company and projects	**# interviews and meetings**
Company Outdoor Project Outdoor A Project Outdoor B	35
Company Automotive Project Automotive C Project Automotive D	19
Company Office Project Office E Project Office F	20
Company Home Project Home G Project Home H	33
Company Communication Project Communication I Project Communication J	10

The case studies were complemented by data gathered during two workshops involving participants from the studied companies. The first workshop on May 17, 2006 was attended by 21 participants from four of the participating companies. These participants provided us with additional information on the critical challenges in both interfaces. Based on results from the first workshop, a questionnaire was formulated in order to gather further information on the relative importance of critical challenges. The questionnaire was sent to 56 of our interview respondents and workshop participants. 23 respondents returned the questionnaire. On February 28, 2007 a second workshop was held with in total 18 representatives from all five companies, with a focus on evaluating a preliminary version of the model.

4. Critical factors in the interfaces

4.1 Results from workshop I: critical factors

The first workshop in the project focused on critical factors in the interfaces technology development/product development and product development/production. During an exercise the participants were asked to first individually and then in a group of 3-5 participants determine the critical factors in one of the interfaces. During and after the workshop the proposed factors were reduced to a number of critical factors shown in table 2 and table 3.

Table 2 The technology development/product development interface

Critical factors in the technology development/product development interface identified at workshop I

- Specific resources are dedicated for technology development
- The technology is verified before taking into the product development project
- There is a clear hand-over between technology development/product development
- The product development team is able to influence technology development
- The development team has information about the different technological solutions that have been considered during technology development
- The new technology does not constrain the different alternative solutions for product development
- Technology development takes the conditions related to production technology into consideration
- There are clear goals for technology development
- Technology development is performed in project form
- Technology development is performed under a high degree of freedom
- Technology development and product development have a common vision
- Technology development and the product development team have developed an understanding of each other's work
- Technology development and product development are located close to each other
- The product development team is able to handle technological uncertainty

Table 3 The product development/production interface

Critical factors in the product development/production interface identified at workshop I

- The product manufacturability is analysed with methods such as DFM/DFA
- Production is involved early in the product development project
- Specific resources (e.g. time) are dedicated for production to participate in the product development project
- Production and the product development project communicate continuously
- Production is actively involved in the product development project
- The product development project and production have developed an understanding of each other's work
- The product development project and production have a common vision
- The product development project is delivering according to predetermined deadlines
- Production gets access to prototype products early in the development project
- The product is verified according to product specifications before start of production
- Late design changes are avoided
- There are clear plans for production ramp-up
- There exists a clear decision on production volumes
- Pre-series are manufactured in the final production system
- The production system is verified in a full-scale test before start of serial production
- A common system exists for handling engineering and production data
- Strategic production development activities are undertaken
- Supplier are involved early in the product development project
- The product development project and production are located close to each other

4. 2 Results from the questionnaire

In the questionnaire the respondents were asked to rate the relative importance of the different critical factors in the interface between technology development/product development and product development/production. Respondents include project managers, product engineers, production engineers, development managers, production managers and group leaders. Most of the respondents stated that they were affected by both interfaces in their work. The respondents received the possibility to either fill in the questionnaire for one of the interfaces or both. Most of the respondents answered questions on both interfaces.

The questionnaire showed a considerable support for the factors identified for the interface technology development/product development. Two factors were assessed as important to a lesser extent; 'the development project can influence technology development' and 'technology development is performed in project form'. Four factors were perceived as most important (see table 4).

Table 4 Results from the questionnaire for the technology development/product development interface

	# of respondent that ranked factor as			
Factor	**of crucial importance**	**important to large extent – crucial importance**	**ranked number 1**	**part of ranking (5 most important factors)**
Specific resources	6	23	5	20
Technology is verified	8	21	7	18
Clear hand-over	3	22	0	8
Understanding for each other	10	23	0	6

For the interface between product development and production the results point almost unanimously at one direction as fourteen of the twenty factors for this interface were ranked by all respondents on the interval important to a large extent – of crucial importance. Excluding the assessment of factors that were ranked on the interval important to a large extent – of crucial importance, six factors emerge as most important (see table 5).

Table 5 Results from the questionnaire for the product development/production interface

	# of respondent that ranked factor as			
Factor	**of crucial importance**	**important to large extent – crucial importance**	**ranked number 1**	**part of ranking (5 most important factors)**
Analysing manufactur-ability	2	18	2	5
Production involved early	12	22	12	18
Specific resources	9	22	2	10
Continuous communica-tion	10	22	2	13
Active involvement	11	22	0	9
Common vision	11	22	1	5

4.3 Results from the case studies

The case study projects were analyzed specifically as to their characteristics related to the technology development/product development interface and product development/production interface. The specific interface characteristics of the case study projects are summarized in table 6.

Table 6 Interface characteristics of the case study projects

Company Outdoor *Project Outdoor A (retrospective study)* Project Outdoor A concerned the development of the first new product in a new product family. Weight and performance requirements were central in the project. These requirements necessitated a completely new product design and some new technical solutions. As this turned out more complex than expected, the project was delayed in the engineering phase, which resulted in a compressed industrialization phase. DFA aspects were taken into consideration in the project to a limited extent and the design was not completely ready when production was initiated. Start of production occurred in the Spring 2005, almost one year late according to the original time schedule. *Project Outdoor B (retrospective study)* The project was initiated due to new environmental requirements, which required the development of novel technology. Company management gave the project high priority and support for the project was considerable in order to achieve the critical and non-adjustable deadline. About half of the components in the product were newly developed. Design for assembly aspects were considered early in the project and production preparatory activities (including a test plant arena, extensive product and process verification) were carried out to a large extent. Start of production took place in the autumn 2004.
Company Automotive *Project Automotive C (retrospective study)* A new product generation was developed in the project. Product development and production were geographically separated. Product development and process development occurred with limited involvement from the production site. The interface was characterized by a hand-over with limited interaction. Different priorities of the product development team and the production site were complicating the interface. Start of production occurred in the autumn 2003 *Project Automotive D (studied in real-time)* A new technological component solution in the new generation of the product delayed the engineering phase considerably. As a consequence tools were released before product engineering was finalized, which was time-saving but also resulted in some rework and a cost increase. Product release in the Spring 2007 was speeded up by increasing the pre-series from 500 to 6000.
Company Office *Project Office E (retrospective study)* New functionality required a completely new technological solution for the high-end product under development. Technology development was performed within the project and problems related to the novel solution resulted in changing product specifications, many design iterations, delayed process development and setbacks for the project. Although not all problems were solved, the product was delivered to the customer in Spring 2005. *Project Office F (real-time/retrospective study)* The project was initiated in order to complement the existing product assortment. Based on a new design concept, the product was intended towards the low-end segment. Small size and low costs were essential product requirements, still not compromising functionality and capacity. Time pressure was an inherent feature of the project and due to delays caused by a material shift, among other things, there was limited time to carry out pre-production activities to ensure smooth product start-up. However, no severe production problems occurred and the first products were delivered in Summer 2005 as scheduled.
Company Home *Project Home G (retrospective study)* The project aim was to up-date the exterior design of existing products in the mid-range segment. Software development was also an important part of the project. The project was the first to follow a formal project model that was introduced in the company. In terms of final deadline, the project fulfilled its target and the products were introduced in due time, beginning in autumn 2002. The sales, however, failed to meet expectations. *Project Home H (retrospective study)* The project entailed a major re-design effort to develop a new high-end product. New functionality, partly relying on new technology, was added There was overlap between technology and product development, something that resulted in several changes of the specification. A new software platform was also developed within the project. The production department was involved on a continuous basis, and more intensely during the final stages. Particularly software and electronics development caused delays during the final stages and production test series were run under significant time pressure. The product was introduced to the market in 2004 and the product launch was considered very successful.
Company Communication *Project Communication I (retrospective study)* The project considered the industrialization of a new complex product model with limited new features and the product was released on the market in 2003. Late design changes, the exchange of some components and delayed documentation before the prototype builds from the engineering team resulted in an increased number of disturbances during the prototype builds and required flexibility of the industrialization team. Product volumes exceeded expectations considerably and the product was considered as very successful. *Project Communication J (studied in real-time)* This industrialization project of a new complex product including new features was characterized by the geographical and organizational distribution of product development, industrialization and high-volume manufacturing. The main focus on the industrialization process revealed difficulties in the industrialization process as a consequence of late design changes. Also early transfer of the industrialization project to the high-volume manufacturing site was a main characteristic. The product was released on the market in the autumn 2006.

A preliminary model for bridging interfaces in industrial innovation processes

The study shows considerable support for the factors identified as important for bridging the interfaces in the industrial innovation process. Some factors can be related to a more strategic synchronization of the different processes and functions involved in the interface, e.g. the development of a common vision (Nobelius, 2004). However, most of the factors are related to operational synchronization, transfer scope and transfer management, i.e. the timing of introduction of new technology in the product (e.g. technology must be verified before taking into the product development project), what is being transferred (e.g. production gets access to prototypes early in the project) and how it is transferred (e.g. a common system for engineering and production data). In addition, the factors identified at the workshop include some necessary conditions for a smooth transfer (e.g.related to location, the ability to handle uncertainty, product verification etc.). In some situations it may not be possible to fulfil all these conditions. Therefore, dependent on the characteristics of the development project and the product different practices must be devised to manage the product development process.

Also the case study projects provide some evidence that specific characteristics of the project and the product influence the importance of the critical factors in the interfaces and consequently the best practice of bridging the interface. Technological novelty for instance emerged as an important constraint in Project Office E, Project Automotive D and Project Outdoor A. In the Interface project, technological novelty has been in focus in Magnusson et al. (2006) but technological novelty is also frequently mentioned as an important contextual factor in new product development literature (e.g. Henderson & Clark, 1990; Shenhar & Dvir, 1996; Engwall, 2003; Veryzer, 1998; McDermott, 1999). Also other factors emerge from the case studies as product complexity (e.g. Project Communication J), process complexity (e.g. Project Communication J, Project Communication I), market uncertainty (e.g. Project Office E), geographical and organizational dispersion for either the technological development/product development or the product development/production interface (e.g. Project Automotive C, Project Automotive D, Project Communication J, Project Communication I). These factors have received considerable support in the literature and have shown to be important determinants of best practices in product development management (e.g. Eisenhardt and Tabrizi, 1995; Liker et al., 1999; Shenhar and Dvir, 1996; Engwall, 2003). Based on the above results a preliminary model is formulated including six contextual factors; the complexity and degree of change in the product, the complexity and degree of change in the production process, the degree of technological novelty, the geographical and organizational dispersion between technology development and product development, the organizational and geographical dispersion between product development and production and the market uncertainty in the project. Assessing these contextual factors for a specific product development project will provide information about the specific conditions for this project. Management practices must be devised according to these specific conditions. The model provides recommendations for project management at the start of concept design, product engineering and production ramp-up. An overview of the model is shown in figure 1.

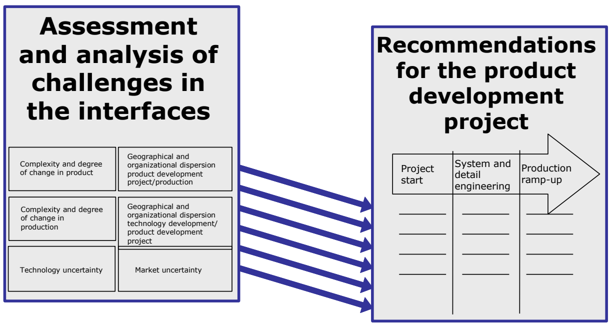

Figure 1 Overview of the Interface Management Model

The Interface Management Model aims at providing an overview of the risks related to a certain development endeavour and work out appropriate management practices for this project. Each of the six contextual factors can be assessed by several statements. In order to assess product complexity for example, the following statements have been discussed to assess this factor:

1. The product includes a large number of different product technologies (electronics, mechanics, material, software, etc. related) compared to an average product
2. The product consists of a large number of components that are affected and/or changed.
3. There are many dependencies between the components in the product that are affected and/or changed.
4. The project brief includes developing a new product platform.

A company can use these statements for assessment of a product development project relatively to the company's 'normal project'. 1 indicates a ranking similar to a 'normal' project in the company. 5 indicates a large deviation from a 'normal' project. 0 indicates a lower degree of complexity than the 'normal' project.

The cumulated score for a certain contextual factor is then indicating the degree of difficulty related to this contextual factor and the extent to which recommendations related to this factor have to be taken into account by project management. The recommendations focus specifically on projects that deviate considerably compared to the company's 'normal' project, i.e. projects with a considerable higher product complexity, process complexity, degree of technological novelty, market uncertainty, organizational/geographical separation.

5. Discussion and conclusions

Literature on product development and innovation management offers some general guidelines on how to overcome integration problems in the interfaces between technology development, product development and production (e.g. Clark and Fujimoto, 1991; Eldred and McGrath, 1997; Drejer, 2002; Markham and Kingon, 2004, Vandevelde and Van Dierdonk, 2003; Fabricius, 1994). Drawing upon empirical studies in different organizational settings, this paper argues that such general guidelines provide insufficient support for effective management. Our study provides in-depth insight into the factors that are found important in the interface between technology development/product development and product development/production respectively.

For the technology development/product development factors related to synchronization seem to be of utmost importance which is in line with/supported by results presented by e.g. Eldred and McGrath (1997, Nobelius (2004), and Drejer (2002). Technology development should be performed outside the product development project and only verified technologies must be taken into the project. Also factors related to interface transfer management emerge as most important (cf. Eldred and McGrath, 1997; Nobelius, 2004; Drejer, 2002). Transfer must take place in a clear hand-over. In addition, an understanding of each other's work must be developed.

Transfer management related factors seem to be even important in the product development/production interface. Five of the six most important factors are related to transfer management; product manufacturability analysis, early production involvement, continuous communication, active involvement and dedicated resources for production involvement. Besides these organizational-related aspects (cf. Trygg, 1991; Adler, 1995) the development of a common vision is considered as important to develop empathy for each other's work (cf. Vandevelde and Van Dierdonk, 2003).

Furthermore, we argue that managers need to take into account a number of contextual factors in order to devise effective approaches. Based on our findings we propose a contingency model according to which effective management of the interfaces depends on six contextual factors. An assessment of these factors in relation to a specific product development project may result in appropriate management recommendations for the individual project. These recommendations are currently under development in the Interface research project. Tentative recommendations include for instance in the case of high product complexity to put a strong focus on product specifications, work breakdown structures and project planning at project initiation; co-locating product and process engineers during the engineering phase; and assigning a full-time integrator to bridge the product development/production interface and coordinate production ramp-up (Shenhar and Dvir, 1996; Liker et al., 1999). In case of high technological novelty, uncertainty can be reduced to individual components and sub-systems through a modular design and a sequential process (in contrast to overlapping phases) may provide the necessary 'peace of mind' for product and process development (McDermott and Handfield, 2000; McDermott, 1999; Henderson and Clark, 1990). During product engineering uncertainty can also be reduced by extensive prototype testing and working with several alternative technical solutions in parallel (Shenhar and Dvir, 1996; Engwall, 2003; Veryzer, 1998).

The model provides project managers with an important instrument to reduce risk and uncertainty related to the interfaces between technology development, product development, and production. Some of the companies involved in the Interface research project have already started to implement parts of the model in their project management systems. During the autumn 2007 and spring 2008 the model will be further developed and tested in collaboration with the companies part of the project.

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