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From Product Development to Production – On the Complexity of Geographical and Organizational Dispersion

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The establishment of low cost production facilities in emerging economies in Asia and Eastern-Europe has resulted in an increased organizational and geographical separation of product development and production processes. This paper elaborates on the complexity of the product development to production interface in dispersed environments and describes two different logics underlying the coordination of the product development to production transition in relation to interface complexity. The paper is based on two case studies of in total three different projects. It is argued that product/process related factors as well as organizational/geographical related factors are important in determining interface complexity. Further, a high degree of interface complexity calls for a predominant knowledge integration logic complemented with some measures of standardization in the product development to production interface. A low degree of interface complexity may be managed by a predominant task partitioning logic complemented with some integration measures.

Keywords: *Product Development; Production; Interface; Complexity; Knowledge Integration; TaskPartitioning*

1. Introduction

Globalization and the emergence of low-cost economies such as Asia and Eastern Europe have resulted in the manifestation of low-cost production facilities in these countries. The global dispersion of production plants has been going on for several decades (Ferdows, 1989), nevertheless relocation of production facilities to low-cost countries has been much in focus the last few years. The drivers behind the global spread of production are numerous and most often related to cost reduction (Ferdows, 1997). Also capacity-related and knowledge-related

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reasons may be underlying the decision to relocate facilities (Fine and Whitney, 1996; Fine, 1998).

The relocation of production facilities has in many cases resulted in a geographical as well as an organizational separation of product development and production activities. At the same time the ability to manage the interface between product development and production has been identified as contributing to product success (Twigg, 2002; Terwiesch et al., 2001; Adler, 1995), emphasizing the importance of a smooth transition from product development to production.

The purpose of this paper is to elaborate on the dimensions of complexity of the product development – production interface in organisationally and geographically dispersed environments. Several factors determining the complexity of the interface between product development and production are identified and interface complexity is related to different logics for bridging the interface.

2. The product development – production interface

2.1 Harmonizing product design and production processes

In previous research on the interface between product development and production, methods such as design for manufacturing, design for assembly and concurrent engineering are highly advocated. It is argued that the utilization of these methods improves the degree of fit between the specifications of the product design and the capabilities of the production process (Adler, 1995). Important factors for measuring this degree of fit are the ease and reliability with which a product can be produced using an organization's manufacturing resources, the time necessary for ramping-up production, production yields and product cost and quality levels (Swink, 1999). Solutions as design for manufacturing and design for assembly may be critical to transfer more routine information but cannot substitute the physical interaction between people (Twigg, 2002). Therefore organizational mechanisms must be put in place in order to bridge the product development - production interface. Early involvement of production personnel in the product development process, cooperation between production and engineering design, team integration and co-location are organizational mechanisms influencing interface integration.

The degree of integration in the product development-production interface has been associated with the fit between the product specifications and the capabilities of the production process (Adler, 1995). As the probability of interaction between people drops off rapidly with physical distance between working locations (Allen, 1977), geographical and (inter)-organizational dispersion implies considerable difficulties for achieving the necessary degree of integration in the product development-production interface.

Geographical and organizational dispersion requires increased attention to the integration between the different actors. It is important to make a distinction between interaction as the effort of exchanging information and collaboration as a purposive relationship aiming at the process of value creation (Kahn, 1996). Especially collaboration is difficult to achieve with traditional structures of communication (Schrage, 1995). According to Kahn (1996) integration concerns both interaction and collaboration and can make the difference between success and failure in product development. An aspect of geographical dispersion between product development and production is the potential difference in language between the different sites (Schrage, 1995).

2.2 Coordinatingtheproductdevelopment – production interface

Several researchers have focused on the coordination mechanisms in the product development and production interface. Clark and Fujimoto (1991) describe five dimensions that determine the nature of integration between design and manufacturing. They include the timing of upstream-downstream activities, the richness of information media, the frequency of information transmission, the direction of communication and the timing of upstream-downstream information flows. They argue that stage overlapping, face-to-face communication, fragmented piece-by-piece transmission, bilateral communication and early release of preliminary information provide the best conditions for integrated problem-solving.

Twigg (2002) has developed a typology with inter-organizational coordination mechanisms for managing the product development to production interface, based on Adler (1995). Four groups of integration mechanisms are described: standards, schedules and plans, mutual adjustment, and teams. Each group is further detailed for the pre-project phase, design phase, and manufacturing phase. Coordination mechanisms may range from designer's tacit knowledge of manufacturing to clear sign-offs, design reviews and joint product/process teams in the design phase to early manufacturing start, prototypes and the utilization of transition teams.

Terwiesch's et al. (2001) findings indicate that physical separation not always has to be problematic. They identify several aspects facilitating the international product to production transition and find that improvements can be achieved by a gradual, almost continuous process from pilot production to volume production. This fluid transition may be supported by dedicated personnel from both sites and substantial movement of personnel and tools. Also the creation of a common IT-platforms and heavy use of physical and electronic communications may facilitate the transfer process. Cross-functional and cross-located teams supported the geographical transfer in their study (ibid). Finally, product platforms may support the utilization of previous experiences of product to production transition.

2.3 The task partitioning versus knowledge integration logic

Many decisions to outsource or relocate production are based on a task portioning logic. This logic is described by Von Hippel (1990) as the division into a number of tasks and sub-tasks that may be distributed between a number of actors in the innovation process. Task partitioning affects the necessary effort to coordinate the activities across task boundaries. Modularization is an approach in line with task partitioning through decomposing a product through defining stable interfaces among its components. Necessary coordination efforts across the modules are in this way minimized. Also the 'black box' approach by Clark and Fujimoto (1991) is an example of the task partitioning logic.

This task partitioning logic assumes however that there is a perfect overlap between the product boundaries and the boundaries of a firm's technological knowledge, a logic that can not necessarily be applied in all situations as Prencipe (2000) points out. Takeishi (2002) also argues that task partitioning must be separated from knowledge partitioning, i.e. while the actual tasks may be outsourced, companies should retain relevant knowledge to be able to obtain a better product quality and more effective and efficient innovation process.

3. Method

In this paper results from the research project INTERFACE – Interfaces in Industrial Innovation Processes are presented. The project addresses critical factors in the interfaces between technology development, product development, and production. In this paper the complexity of organisational and geographical dispersion and its implications on the interface between product development and production is emphasized. Case studies carried out in two different companies; cCompany Communication and cCompany Automotive, constitute the empirical foundation of this paper. In both companies specific product projects were focused during the studies, two projects in Company Communication and one project in Company Automotive. Data was collected by means of open-ended interviews and through internal company documentation. In total 14 key informants such as R&D managers, production managers, production engineers, project managers and engineers from the three projects were interviewed. 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).

4. Distributed product development and production – Two case studies

4.1 Introducing the cases

Case A involves a Swedish industrialization site of a global contract manufacturer. Two projects were studied; one ongoing project addressing a product to be released on the market in the autumn 2006, the other already terminated a few years ago. A US development site of the Swedish customer was responsible for design and development of these products. The second case, Case B, concerns a manufacturer of load carriers for cars, such as rooftop boxes, roof rails, and bike carriers. This study includes one product project managed from the Swedish site, with production at the fully owned production facilities located in Poland.

4.2 Case A – Company Communication

Company Communication is a global provider of electronics and manufacturing services, globally employing approximately 95,000 persons. The Swedish industrialization site which is in focus in this study has about 200 employees. The Swedish site is part of the industrialization group of the company, represented in Malaysia, Brazil, China, and Mexico. The latter three concern volume production sites, the site in Malaysia can provide industrialization services as well. The study includes activities associated with one product segment representing approximately one third of total revenues.

The Swedish industrialization site takes care of the preparation process for volume manufacturing involving development and validation of production processes, production equipment tests and test equipment. The product is produced in high volumes in a predominantly manual production process which puts high requirements on the assembly and test process. An important part of the industrialization process is the building of prototypes in order to validate the product as well as the production and test process. The first prototypes are built for engineering verification in order to complete the design. Next prototypes are built for design verification. The remaining prototypes are normally built at the volume manufacturing site in order to verify the production process. When the process is transferred to the volume manufacturing site, the Swedish industrialization site is involved for training the employees responsible for the manufacturing line at the volume manufacturing site. After the process verification prototypes are approved and training is completed the responsibility for production is handed over to the volume manufacturing site. The Swedish industrialization site remains responsible for production support, normally lasting about three months.

In an effort to standardize working procedures company-wide, the overall company introduced a product development process model a few years ago. As the model focuses on product development processes and not on industrialization processes specifically, the Swedish industrialization site has found it difficult to completely utilize the model. Many project managers follow their own interpretation of the existing model, and working methods and procedures are not standardized from project to project.

project A

Project A concerns the industrialization, ramp-up and verification of a new product of medium complexity developed by a US design site of an external customer. The Swedish industrialization site received full responsibility for the industrialization process and transfer to volume sites. Total industrialization project budget concerned about 20,000 hours. The project started in May 2002 with a pre-study, followed by a feasibility study. In November 2002 the project reached the execution phase. In January 2003 the project was introduced and presented for the volume manufacturing sites. Besides some remaining issues, the project was finalized at the Swedish industrialization site in December 2003. In total, six prototype builds took place during the project, some consisting of several sub-builds. The last two were performed in Malaysia as the project initially was transferred to the Malaysian volume production site. Employees from the Swedish site supported these prototype builds on-site in Malaysia. Later the product was also produced at production facilities in China, Mexico and Brazil. The total global volume for the product was set on 10 million products. In the autumn 2005 the product was still in production and thus far 23 million products have been sold to customers.

In general, the cooperation with the external customer worked well throughout the project. However, on many occasions documentation for the prototype builds was delivered late by the customer. Also, the customer implemented many changes rather late in the process. Project members felt that nearly every time a prototype build started, information was missing which created a necessity for high flexibility from the project team at the Swedish Industrialization site. During the prototype builds the project team experienced difficulties as there were some delays in the delivery of test fixtures. Besides this, the prototype builds went rather well. Due to late and wrong documentation and some problems with material supply the pre series were delayed with two-three weeks.

project B

In the beginning of March 2005, the Swedish industrialization site received a new assignment from the US design site. The project's budget was estimated on 24,000 hours and the product concerns a product of medium complexity including many features where especially space is an important limitation. The product is expected to be launched in the beginning of September 2006. Compared to earlier projects and to Project A in this study, the industrialization site was involved earlier in its customer's design process. Detailed design was not fixed yet, and the industrialization site had some latitude to influence the design. One of the main reasons for involving the industrialization site early however was the new test platform. In earlier industrialization projects the test platform of company Communication was used. However, as the customer did not want to become too dependent on the provider of electronic manufacturing services a Swedish design site part of the external customer had developed a new test platform. Project B was the first project utilizing this test platform and risks associated to the change of platforms had to be assessed. In April 2005, the project had a kick-off on-site at the US design site. During three days, five project members from the industrialization project had the possibility to discuss the product and its features with the design team at the customer. The pre-study was finalized in the end of July 2005. The first prototype build (engineering verification) was performed in November 2005. Five members of the design team of the customer and two employees of the Malaysian volume manufacturing site were present during this prototype build.

On a higher management level it was decided to give the volume manufacturing site in Malaysia more responsibility in the project. As a consequence process development was carried out under the responsibility of the volume manufacturing site while test responsibility remained at the Swedish industrialization site. Therefore, design verification and process verification prototype builds took place at the industrialization department in Malaysia and the volume manufacturing site (located next to each other). These prototype builds were supported by employees from the Swedish site during several months. Figure 1 showstheproductdevelopmenttoproductioninterface in project B.

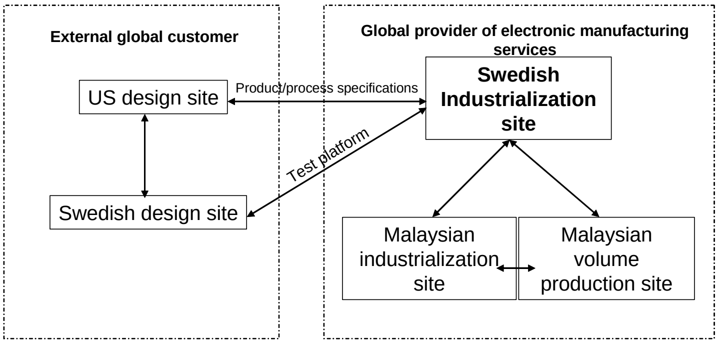

Figure 1. Product development – productioninterface in project B

comparing project A and project B

Both projects concerned similar products, The same external customer and customer's US design site initiated the projects, and the industrialization projects were both initially transferred to the same volume manufacturing site, part of the same global concern as the Swedish industrialization site. However, there were also some differences, summarized in Table 1.

Table 1 Case A: Comparing project A and project B

	Project A	**Project B**
Responsibility in industrialization process	Total responsibility at Swedish site	Separation of process and test responsibility
Transfer to volume manufacturing site	At the end of industrialization process	With design verification prototype build
Test platform	Company Communication's own test platform	Newly developed test platform by Swedish design site of external customer
Prototype builds	Two engineering, two design and two process verification builds	One engineering, one design and one process verification
Sub-interfaces	Sub-interfaces between US design site external customer, Swedish industrialization site, and Malaysian volume production site	Sub-interfaces between US design site external customer, Swedish design site external customer, Swedish industrialization site, Malaysian industrialization department, Malaysian volume production site

4.3 Case B – Company Automotive

Company Automotive represents one of in total five divisions in a larger group. The group has more than 2000 employees of which 950 belong to the focused division. The division's sales in 2005 represented slightly more than 40 % of the group's total sales. Company Automotive is a leading manufacturer of load carriers for cars, such as rooftop boxes, roof rails, and bike carriers. The study includes activities associated to one product segment. Within this segment product development is carried out in Sweden and production at the fully owned production facilities located in Poland. The ambition is to renew the product range every third year with a new generation of the product. Large product projects within Company Automotive normally have a lead-time of 1-2 years, from the initial specification until production. The project activities are guided by a company specific project system, comprising five phases (Phase A-E) and five checkpoints (Check point A-E). The project system is fairly detailed, different activities are described and a number of documents associated to the different activities are included. According to the project system the project is responsible until everything is running smooth in production, and thereafter the project can be terminated.

Project C

Case B addresses a product project, project C, where product development was carried out at the Swedish site and production in Poland. A fourth generation of the product was developed in the studied project. Estimated volume per year was approximately 30 000 products. The project specification was described as unclear, the requirements were vague. The project was initiated in August 2001 and concluded in the beginning of 2004. Start of production was in November 2003, with first delivery to customer in December. Initially production start was planned in December 2002, thus the project was delayed for almost a year. In explanation why the project was delayed low activity in the project due to absent project leader was mentioned.

The observance of the project system and the prescribed activities and checkpoints varied between the two sites. The production unit in Poland was not working strictly according to the project system. This was explained as due to cultural or managerial differences, but also a lack of time since daily production activities were prioritized. To compensate for the deficient observance, the production unit in Poland described themselves as flexible and able to solve problems that occur. From the projects point of view it was described as difficult to get production started. Low respect for check points was mentioned as one problem, a lack of guidelines concerning product transfer as another problem.

A number of persons were involved, and responsible for different areas, during the project. The project leader was selected from the product development department. The project leader together with the other representatives from product development participated from the early phases of the project until start of production and worked full-time in the project. They constituted the foundation in the project group. The other members of the project group were representatives from purchasing, quality, test, production, and market. The degree of involvement from the different functions varied during the project, both concerning how much time they spent and when. Some functions were doubled, i.e. people were involved both from departments in Sweden and from corresponding departments in Poland. As one observation of the collaboration between departments the information structure between the different organizational units within the company was described as insufficient, and yet not fully developed. Another observation was that the allocation of responsibility between the two production units was not sufficiently clear.

The local production department in Sweden and the production unit in Poland were in involved in the project. During the early phases of the project, one production engineer from the production unit in Sweden was the voice of production in the project group. Participation from the production function was sparse during the early phases of the project, both from the production department at the site in Sweden and from the production unit in Poland. The involvement from production increased palpable after tool ordering. A messenger was appointed between the project and the production site in Poland. A problem was however described concerning the work instruction for the messenger. The project group in Sweden expected the messenger to be a link between the project and production, whereas the production site expected increased knowledge in engineering design. During the project the role as messenger was manned with at least two different persons.

The interface between the project and the production site in Poland was described as a hand over with a low degree of integration. The production unit in Poland did not consider themselves to be inside the project, they only had a small part of the project. The actual hand over consisted of drawings and the task for the production unit was to produce the product on the drawings. The limited maturity of the production unit in Poland was given was mentioned as one problem obstructing the hand over. Increased experiences from production was required, and increased staffing within production engineering.

It was also described as necessary to change the approach among the engineers in Poland towards their assignment. A holistic view on product development and production was described as required. Another difference in perspectives was that the production unit in Poland had a strong focus on daily production problem solving which made it difficult to commit them before the product was handed over. This was however not solely a geographical problem, similar problems were also found in other product segments when production took place in Sweden.

The need for design for manufacturing and assembly (DfM/DfA) was described as low when the products were to be produced in Poland. It was for example not considered as equally important to reduce the amount of assembly operations. The prerequisites for production were described as different in Poland, and therefore it was not sure that the same design solutions were preferable.

4.4 Comparing case A and case B

Case A and case B had some different characteristics. Case A concerned more complex products including mechanical and electronical features, as well as integration of software, whereas the product in Case B was mainly mechanical. Furthermore, the products in case A were produced in much higher volumes than the products in case B. Another important distinction concerned the number of actors involved. In case A product development, industrialization and production took place at different locations dispersed over different organizational units of two companies (inter-organizational and geographical dispersion). In case B product development as well as production facilities are part of the same company and only separated geographically (intra-organizational and geographical dispersion). In case A, especially in project B, the people involved in the interface were dispersed on different locations but had frequent contact with each other. During prototype builds they worked in an integrated manner. Transfer of personnel was common, often for short periods of time,. In case B, although certain efforts were made to achieve integration, the interface was more characterized by a hand-over of drawings to the production site.

There were also similarities between the two cases. In both cases employees involved in product development as well as volume production had a limited understanding of, and paid little attention to, the industrialization process. The result was late deliveries from the development process and consequently quick fix solutions were necessary in the production process. At several occasions language problems led to misunderstandings and communication difficulties. In both cases differences in expectations and focus was enhanced with the organizational and geographical dispersion. In both cases production facilities were described as highly output oriented. The production facilities seemed to have limited time available for the industrialization and production ramp-up process, often due to delays in the development process and delayed deliveries from sub-suppliers. Furthermore, project models, with specified deliverables, milestones, and a description of roles and responsibilities, did not seem to support the interface between product development and production to a great extent. Also, in both cases there were no clear communication channels IT-systems between the product development team and the production facilities were not synchronized.

5. Interface complexity and bridging logics

5.1 Interface complexity

Our case studies indicate that the specific characteristics of an interface may be important for identifying the appropriate coordination mode. In case A the interface between product development and production is characterized by a high degree of complexity in terms of number of actors involved, number of organizations involved, number of facilities involved, etc. Literature has not been clear on the dimensions of interface complexity and its relationship to interface coordination. Kahn (1996) for example found that collective goals, a mutual understanding, informal activity, shared resources, a common vision and working together as a team are important indicators of interdepartmental integration associated with product development success. Interaction by meetings, telephone calls, e-mail on the other hand was not found to be associated with product development success. Kahn (1996) however, does not elaborate on the type of interfaces that exist between the different departments in his study. Adler (1995) distinguishes between four modes of coordination – standards, schedules and plans, mutual adjustment, and teams – and hypothesizes that a higher degree of integration, i.e. a preference for mutual adjustment and teams, is more appropriate for novel product/process fit and difficult to analyse product/process fit problems. A low novelty and easy to analyse problems on the other hand could be coordinated through standards, schedules and plans. These two predicators are related to the underlying product and process complexity and do not take into account important factors related to the organizational and geographical complexity as emerge in our study. Twigg (2002) extends Adler's typology to inter-firm coordination but does not comment on the factors determining the appropriate coordination mechanism at all.

Our case studies put the attention to several additional factors determining interface complexity. Many decisions leading to geographically dispersed product development and production are based on cost arguments. Moving productions facilities to low-cost countries implies important savings. However, also knowledge-related and capacity-related arguments may be the underlying rational for dispersion (Fine and Whitney, 1996; Quinn, 1999). In case A both knowledge related arguments (the Swedish industrialization site represents important industrialization capabilities) and cost arguments (low-cost production in Asia) prevail. In case B the main reason for acquiring the production facilities in Poland however, were cost and capacity related. In general, a knowledge-related rationale leads to a higher degree of interface complexity to integrate the different knowledge sources. Another factor is related to geographical dispersion. Distance, but also cultural, language and time zone differences, all prevalent in our cases, influence the exchange of technical information negatively (Sosa et al., 2002) and thus contribute to interface complexity. Interface complexity may also be related to the number of actors involved in the interface and the number of sub-interfaces created. The issue of sub-interfaces created becomes more important as the timing of inter-site transfer is moving earlier (Terwiesch et al., 2001) (cf. case company Communication project B). In figure 2 the factors determining interface complexity are summarized.

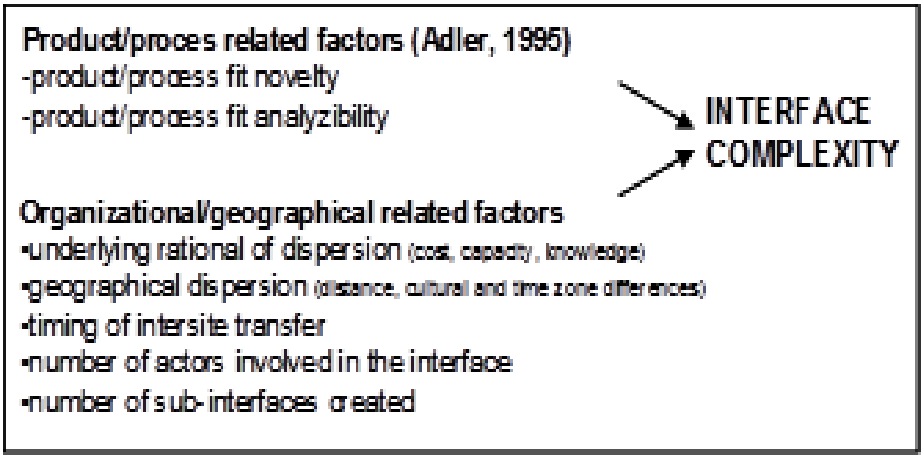

Figure 2 Determinants of productdevelopment-productioninterfacecomplexity

5.2 Taskpartitioningandknowledge integration logic

Taking into account the determinants of interface complexity may help in identifying the appropriate coordination mode in the product development – production interface. We argue that interface complexity can be associated with task partitioning and knowledge integration. Adler (1995) argues that the appropriate coordination mode is able to deal with the uncertainty in the interface at the least cost. The cost of a certain coordination mode is difficult to assess but in general it may be maintained that a higher degree of integration in terms of achieving collaboration is associated with higher coordination costs (Kahn, 1996). Takeishi (2002) argues that knowledge integration logic should underlie highly innovative projects, in contrast to efficient and clear-cut boundaries as is the case with the task partitioning logic. Also, system complexity and a high number of people involved from different functional disciplines and projects seem to benefit from a high degree of integration in the product development-production interface (Novak and Eppinger, 2001; Swink, 1999).

Exchanging technical information in organizational and geographical dispersed environments may be difficult, however there are indications that knowledge integration related measures, such as exchange of personnel, may be used to overcome physical separation (Terwiesch et al., 2001). Therefore, we hypothesize that a high degree of complexity in the product development - production interface is connected to predominant knowledge integration logic. It is expected however, that this predominant knowledge integration logic is complemented by standardization measures such as the creation of a common IT platform and heavy use of electronic communications (Terwiesch et al., 2001; Sosa et al., 2002). Further, we hypothesize that a low degree of interface complexity may be associated with a logic predominantly based on task partitioning, i.e. clear-cut boundaries between the tasks of the different actors involved supported by a common project management model. This logic may be complemented by some integration measures in order to handle for instance engineering changes.

6. Conclusions

Bridging the interface between product development and production is not a smooth ride. In this paper we have elaborated on factors affecting the complexity in the product development-production interface, based both on the product/process and of geographical and organization dispersion. We suggest that the determinants of interface complexity may help in identifying the appropriate coordination mode in the product development – production interface since interface complexity can be associated with task partitioning and knowledge integration.

It seems that interface complexity is not only determined by the underlying product/process fit complexity, previously described by Adler (1995), but also by factors related to geographical and organizational dispersion. Our two case study focus the attention on these factors. When many actors on different locations are involved and the process is characterized by many 'hand-over' points, there seems to be a considerable need for overlapping and complementing competencies. Although measures for integration by transferring personnel should create opportunities for bridging the gap between product development and production, this transfer of personnel may also enhance an 'it is not my problem' attitude as 'the transferred personnel will take care of it'. Additional measures to manage knowledge partitioning instead seem to be necessary (cf. Takeishi, 2002). A high degree of interface complexity calls for a predominant knowledge integration logic complemented with some measures of standardization in the product development to production interface. A low degree of interface complexity may be managed by a predominant task partitioning logic complemented with some integration measures.

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