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MANAGING THE DESIGN-MANUFACTURING INTERFACE

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MANAGING THE DESIGN-MANUFACTURING INTERFACE

ABSTRACT

This article describes the major barriers across the design-manufacturing interface and examines ways to overcome them to achieve a smooth production start-up. An integration model reveals that formalization facilitates a smooth production start-up. Independent of the degree of formalization during the early development stages, a formal approach is preferred when the new product is introduced into production. Another facilitating factor is the empathy from design towards manufacturing, which can be stimulated by managerial actions. Although the complexity and newness of product and technology hinder a smooth production start-up, their effect seems to vanish by introducing formalization and by striving for a design team that has empathy towards manufacturing.

INTRODUCTION

Product innovation requires expertise and knowledge in a variety of disciplines. The required attributes may exist within one person or organizational system, but often differentiation is necessary to accomplish highly specific tasks professionally (Griffin and Hauser, 1996). Here, differentiation is defined as the segmentation of organizational systems into subsystems (Lawrence and Lorsch, 1967). However, in order to heighten the likelihood of innovation success, many authors point to the need for integration (Lawrence and Lorsch, 1967) to take into account the interdependency of functions and responsibilities (Moenaert and Souder, 1990; Griffin and Hauser, 1996).

Design-marketing integration has been prominent in product development research since the 1970s (Souder, 1977; Gupta et al., 1985; Moenaert and Souder, 1996; Tiger Li, 1999). Many researchers sought ways to stimulate integration (Souder, 1980; Gupta et al., 1987; Lucas and Bush, 1988). Other interfaces such as design-manufacturing (DM) have been subject to much less empirical scrutiny. Despite an increase in interest (Pierson and George, 1989), the number of empirical studies is still limited (Ettlie, 1995). Despite the attention paid to a few mechanisms integrating design and manufacturing (Hales, 1986; Ettlie and Stoll, 1990; Lawrence and Lorsch, 1967), there is little systematic empirical evidence that these mechanisms actually work (Ettlie, 1995). DM integration leaves substantial room for improvement according to practitioners (Vandevelde, 2001).

Gaining a better understanding is often the very first step on the way to better management. Therefore, an analysis of integration mechanisms will be the focus of this paper. Inspired by the design-marketing literature, we first concentrate on the integration barriers and then examine how to overcome them.

INTEGRATION BARRIERS

Although DM integration is deemed important for project performance (Hise et al., 1990; Ginn and Rubenstein, 1986; Bergen, 1986), it seems surprisingly difficult to achieve, and there are many barriers to overcome (e.g., Gupta et al., 1985, 1988). Such barriers include personality, cultural, organizational, physical and language barriers. This description is based on the marketing-design literature and translated to the DM interface via insights from a repertory grid study (Vandevelde, 2001) and the limited literature on the DM interface.

Personality Differences

Many researchers have noted personality differences between functions (cf. Abita, 1985; Gupta et al., 1985, 1986; Lucas and Bush, 1988). Moreover, even if the existence of stereotypes is not based on facts, if one or the other group believes in them, this belief alone may become a barrier to mutual understanding (cf. Griffin et al., 1996). To overcome similar barriers, researchers seek mechanisms to enhance understanding, build trust, and improve the quality of the relation (cf. Gupta et al., 1986, 1987). Table I summarizes some personality differences. The table reveals that the hallmarks for design are autonomy, knowledge creation, publications, patents, and service to mankind. In contrast, the hallmarks for manufacturing seem to be clear tasks, quality and volume at the requested time, organizational recognition, and the reduction of waste and scrap.

Insert Table 1 about here

Cultural Differences

Culture can be defined as the collective mental programming of the people in an environment (Hofstede, 1980). Cultural differences between departments are deemed a major integration barrier (Gupta et al., 1985). How should this be understood with respect to the DM interface?

Professionals from different functional departments often differ in training and background. This causes worldviews and routines to be reinforced in the cultures of the functional subsystems (Griffin and Hauser, 1996). Furthermore, organizational structures or management tools may strengthen cultural differences; for example, functional rewards that stimulate departments to create their own work approach and value system in line with their particular objectives.

Table II identifies some interdisciplinary differences in terms of the main criteria distinguished by Griffin and Hauser (1996). Manufacturing is usually overwhelmed with keeping operations going and tends to sacrifice long-term concerns (Szakonyi, 1998). It focuses on incremental projects, accepts a high degree of bureaucracy and is loyal to the company. Its central point of attention is the process. Manufacturing is output-oriented, trying to realize economies through volume and mechanistic structures (Ginn and Rubenstein, 1986). In contrast, design serves as an agent of change, more decentralized and adaptive in nature. Design prefers the long-term horizon of advanced projects and focuses on scientific development with a loyalty to the scientific profession and less bureaucracy. Although these generalities do not apply to every organization, they indicate identifiable trends. The differences reveal that design and manufacturing run the danger of developing separate self-contained societies (Dougherty, 1987). Even though both functions work for the same organization, and have the same overall corporate goals, the lens through which they interpret these goals may differ (cf. Griffin and Hauser, 1996). Separate views may lead to a misunderstanding of one another's goals, capabilities (Gupta et al., 1985), and solutions.

Insert Table 2 about here

Besides differences in status, perceptions stimulate an "we versus they" attitude, and so help to create a cultural barrier. Since in many companies manufacturing is assigned a lower status than the design function (McDonough, 1984), it is no wonder that "we versus they" attitudes arise. Asymmetric relationships with a dominant function substantially differ in character from relationships between equal partners. Finally, differences in national culture between design and manufacturing may cause cultural differences. Hofstede (1980) empirically determined four criteria by which national cultures differ. His cultural maps allow a first estimation of the barriers due to differences in national culture.

Language Barrier

Functional systems show a natural tendency to create a technical language and system of meaning of their own (March and Simon, 1958; Weick, 1969; Dougherty, 1969). Although functional slang tends to increase the efficiency of intradepartmental communication, it may be a barrier to inter-functional information transfer (Lawrence and Lorsch, 1967; Tushman, 1977; Wolff, 1985). A tower of Babel syndrome may occur. The exchanged information may be interpreted incorrectly or misunderstood. Hence, the value of the information is deemed to be low or non-existent in the eyes of the message receiver. Furthermore, subtle language differences may imply vastly different solutions that may determine whether a project is successful or not (cf. Griffin and Hauser, 1996).

Also, the level of detail used by different functional groups may differ. It may cause frustration if the communication is not at the level required for the job. However, this type of language problem is probably not as large in the DM interface as in the design-marketing interface. In contrast with marketing professionals, who speak in terms of product benefits and positions at a rather low level of detail (Griffin and Hauser, 1996), both design and manufacturing use a technical language at nearly the same high level of detail.

Another cause of language problems is almost inherent to the evolution from idea generation to new product in production. Communication about objects that are intangible or non-standardized is extremely difficult (March and Simon, 1958). Those who have the product design in mind are more likely to understand it. Discussions that are not grounded in understandable, concrete facts but in abstractions, may lead to endless conflict and interpersonal animosity (Eisenhardt and Tabrizi, 1995). Misunderstandings and tension can arise if attention is not focused on a specific model but rather on what is thought about it. The latter phenomenon is illustrated by several studies, even outside product development (Murnighan and Conlon, 1991). To summarize, the more abstract the information, the more difficult it is to exchange between people with a different function, background or interest (Jacobs, 1996).

Organizational Barrier

Many organizational barriers can occur. First, functional differentiation tends to focus people on their department's goals. This may weaken their attention to global objectives and misguide loyalties (Crawford, 1983). Moreover, functional goals may be divergent or incompatible. For example, current reward systems most frequently evaluate people on functionally based performance without taking into account the company's overall goals or the objectives of other departments (Zettelmeyer et al., 1995). Senior management's appreciation of short development times may hamper production start-up (Wolff, 1985) if it results, for example, in the elimination of tests or design modifications that would improve the manufacturability of the designs. In summary, all organizational systems that do not reflect the inter-dependency of tasks (cf. Souder and Sherman, 1993; Abita, 1985) may create an organizational barrier. Second, the perceived illegitimacy of product development may cause an organizational barrier (cf. Souder and Chakrabarti, 1978; Dougherty and Heller, 1994; Griffin and Hauser, 1996). Projects that are not supported by senior management (yet) and for example are developed quite secretly in a small corner of the R&D lab by self-willed, creative people are usually not the projects in which manufacturing is likely to invest energy and time. Third, the lack of clarity of goals, roles and responsibilities (cf. Gupta et al., 1987) may cause an organizational barrier. A fourth barrier is people’s and an organization’s reluctance to change (Wolff, 1985). For example, if new technologies, operating rules or philosophies are suggested in one department, resistance to change may arise in the other department. Furthermore, actions to eliminate or circumvent actual integration barriers may create a barrier in and of itself (cf. Griffin and Hauser, 1996).

Physical Barrier

The probability of interaction between people drops off rapidly with the physical distance between their work locations (Allen, 1977). Long distances make informal and face-to-face communication inconvenient. The location of various functions between and within buildings plays an important role in interface management. Badly designed or furnished buildings can separate thought worlds, encourage short-cut, jargon-filled language development and stimulate perceptions of personality differences (Allen, 1970). Current business trends often require geographically dispersed groups to work together, which further complicates product development.

The various barriers make DM integration difficult to achieve. Failure to realize integration may mean insensitivity with respect to the other department, difficulties in understanding each other (Gupta et al., 1985), a lack of agreement on important topics (cf. Brockhoff, 1989), tension and poor relationships (Crawford, 1983). It may lead to strong 'not invented here' attitudes (Katz and Allen, 1982), where each function only favours the work generated from within its own functional group (Griffin and Hauser, 1996). The ‘not invented here’ syndrome inhibits collaborative information seeking and exchange behaviours (Katz, 1982; Katz and Allen, 1988; Griffin and Hauser, 1992). It blocks information utilization (cf. Hauser and Clausing, 1988). Perceived information utility is an important aspect of information utilization. The MIS literature (Zmud, 1978; Larcker and Lessig, 1980; Ives et al., 1983; Baroudi and Orlikowsky, 1988) indicates that the utility of received information is determined by many elements that are related to one of the four components of the source-channel-message-receiver model of interpersonal communication (Berlo, 1960; Rogers and Agarwala, 1976). Recently, theoretical analyses (cf. Moenaert and Souder, 1990) and empirical inquiries (cf. Griffin and Hauser, 1992; Moenaert and Souder, 1996) in the innovation literature have extensively explored the issue of information use at the individual level. These studies show that poor-quality, inter-functional relationships caused by integration barriers hinder information utilization: they reduce the credibility and comprehensibility of the extra-functional information to the receiver.

HOW TO SMOOTH THE PRODUCTION START-UP

DM barriers should be overcome by neutralizing or circumventing them (cf. Griffin and Hauser, 1996). An interesting perspective may be to look at the smoothness of the interface (cf. Souder, 1988). More specifically, our research question is: "What mechanisms enable us to smooth the production start-up?". An integration model (Figure 1) is developed that reveals the managerial actions necessary to guarantee a smooth production start-up and hence, better project performance: a smooth production start-up results in a better correspondence with time, budget and technical specifications (Vandevelde, 2001).

The Project Nature

National culture (Bergen et al., 1988; Bergen, 1982; Norton et al., 1994; Xie et al., 1998) and project nature (cf. Rueckert and Walker, 1987; Adler, 1995; cf. Hise et al., 1990) are described as situational factors throughout the literature on integration. Since we shall focus on one geographical region, we only consider the project nature, which may differ between task types and development stages.

The project nature should influence both the level of integration needed (cf. Gupta et al., 1986; Rueckert and Walker, 1987) and the effectiveness of integration mechanisms (Tushman and Katz, 1980). Souder (1978) states that the most effective approach for organizing product development is a contingency approach that takes into account market and technological issues and the relative cost of the structural method. Perrow (1967) underlines the importance of notions such as unanalysability and nonroutineness. Hence, we introduce project nature as a situational variable.

Insert Figure 1 about here

A Formal Organization

Formalization is defined as the variety of mechanisms that contribute to a structured and clear innovation management approach. It includes clear and structured implementation of co-ordination mechanisms belonging to the generic categories proposed by Thompson (1967) and Van de Ven (1976), and elaborated by Adler (1995). The categories are: 1) standards or rules, 2) plans and schedules, 3) formal mutual adjustment, and 4) dedicated teams. We describe below how formalization may help to eliminate or circumvent the various DM integration barriers.

The previous description on integration barriers reveals that designers need autonomy and a creative environment, whereas manufacturing requires transparency, clear tasks, plans and procedures. Manufacturing asks for a stronger departmental structure. It aspires to more formalization. Therefore, the development process should be given structure and transparency at production start-up to overcome personal and cultural barriers. At the same time, formalization objectifies and hence, makes things more acceptable, which helps to overcome the personal and cultural barriers as well. For example, formally structured decision-making processes can create more inter-functional harmony (Souder, 1987). Structured processes provided with milestones can also reduce the procrastination caused by integration barriers: they balance the need to stimulate interaction and resolve conflict, while still providing havens into which participants retreat to reflect on and internalize insights (Souder, 1977).

The more abstract the information, the more difficult it is to exchange information between people with different functions, background or interest (Jacobs, 1996), and the more likely it is that conflict and interpersonal animosity may occur (Eisenhardt and Tabrizi, 1995). Formal documents require the author to order and structure thoughts and at the same time provide the receiver with a tangible document. Written communication, which is one method of formalization, is generally more comprehensible than oral communication (Moenaert and Souder, 1996). However, this is only true if the information is written in a common, easily accessible language. In summary, formalization is expected to reduce the language barrier.

Project progress may stall or go off track because of limited or incorrect direction. The product development process may fail because it becomes too unstructured and chaotic (Eisenhardt and Tabrizi, 1995). Clear rules, roles, tasks (Griffin and Hauser, 1996) and performance standards may be useful since they provide the organizational participants with a general framework that helps to reduce conflict (Song and Parry, 1993) and achieve the firm's goals. This requires that the various activities and roles to be performed can be well defined, planned, scheduled and co-ordinated (Moenaert and Souder, 1990). The mechanistic approach is limited to stable and predictable situations (Duncan, 1971). It is applicable to the downstream stages of the product development process.

Clear manufacturability guidelines or rules may help the designers to develop adequate designs and to anticipate problems. An example is the manufacturability rules defined by design and manufacturing staff before any given project begins. Similar rules, which require early interaction and lower the required interaction level downstream (Adler, 1995), may help to anticipate problems and reduce integration barriers. The articulation of design rules is an example of a design for manufacturing method. Generally, design for manufacturing is a way of structuring the product development process to facilitate DM integration and to bring issues of manufacturability into the design process as early as possible. Other examples are manufacturability design reviews, co-ordination committees and formal joint development teams (Adler, 1995). Formal mechanisms that integrate, such as cross-functional teams, are probably the most helpful to overcome the organizational barrier (Griffin and Hauser, 1996). Formalization further legitimizes product development (cf. Souder and Chakrabarti, 1978), which also helps to overcome the organizational barrier. Hence, formalization helps achievement of high levels of integration (cf. Gupta et al., 1987) by reducing the organizational barrier.

To conclude, formalization is expected to tackle various integration barriers and smooth the product start-up. We hypothesize that *given the project's nature, formalization smooths the production start-up (H1).*

Empathy from Design to Manufacturing

Empathy from design to manufacturing refers to designers who explicitly think about the manufacturability of the product during the design stage and are able to recognize inter-functional differences between the world of manufacturing and their own world. It concerns designers who have an eye for the needs, requirements, language, goals, and work approach, and motivators of manufacturing. They are open-minded to manufacturing rather than negatively prejudiced.

Empathy is more than recognizing and *knowing* the differences between the design and manufacturing worlds. It also means that designers have an *ability and aspiration* to take these differences into account. Hence, a global interest is required, along with a certain willingness and technical expertise. There is a need for both functional and inter-functional expertise.

Functional expertise enables the organization to acquire more and better technological information and to make better use of it (Moenaert and Souder, 1990). Inter-functional expertise is crucial to success: a designer should be able to integrate and synthesize complementary knowledge. The design knowledge of how to technically develop new products must be cross-fertilized with manufacturing knowledge on how to adequately produce the products (cf. Griffin and Hauser, 1992). The synthesis of knowledge means that the design proceeds with manufacturing requirements in mind.

Design for manufacturability allows for anticipation of later problems. The reduction of functional uncertainty improves (cf. Moenaert and Souder, 1990), while project iterations between product and process design stages are minimized (Schilling and Hill, 1998) and a better product-process fit results (Adler, 1995).

Hence, we expect the empathy from design towards manufacturing to overcome personal, cultural, language and organizational barriers and to smooth the production start-up. In formal terms, *given the project's nature, empathy from design towards manufacturing smooths the production start-up (H2).*

Factors that stimulate the Empathy from Design towards Manufacturing

One may argue that empathy is innate. We believe that inter-functional empathy can be stimulated to some extent by managerial actions. Here we consider actions such as promoting adequate DM communication and stimulating the participation of designers during the production start-up.

Communication between design and manufacturing

More and better communications between design and manufacturing leads to better insights into the other function’s role, thought world, language, goals, needs, wishes and limits (cf. Souder, 1977, 1987). It increases mutual understanding between the functions and helps the task group members to put their own roles into perspective. Appreciation of the other's contribution is stimulated and the trust between people strengthens (Souder, 1987). This may result in a better relationship (Gupta and Wilemon, 1990) and better information utilization (Moenaert and Souder, 1996). Personal, cultural, language and physical barriers are reduced and the designers better take into account manufacturing's requirements and possibilities during the design phase.

As each party contributes to the mosaic of innovation, communication enhances each individual's knowledge base and inter-functional expertise. The exchanged information permits early detection of problems (Mcintosh, 1986), which means that problems can be caught when they are small, easier and less time-consuming to solve (Dean and Susman, 1989). Designers learn how to better solve problems and even to anticipate them. In other words, early and regular DM communication reduces the amount and size of time-consuming problems (Dean and Susman, 1989), modifications and rework. Regular discussion of problems, presentation of the designer's ideas to manufacturing, and feedback from manufacturing on these presentations are all important if one wishes to design a product that corresponds with the possibilities and requirements of manufacturing (Rosenthal and Thatikonda, 1992; Ridgeway, 1984).

In summary, we hypothesize that *more and better DM communication corresponds with more empathy from design towards manufacturing (H3a).*

Involving design in the production start-up

The involvement of designers in the downstream stages of the product development process (Gupta et al., 1987) reduces the physical barrier. Physical proximity results in more interaction (Allen, 1977) and confronts one function with the world of beliefs, needs, vision, possibilities and requirements of the other function. Hence, designers learn to better know manufacturing and to recognize such inter-functional issues as personal, cultural, and language differences. Since knowing each other is the very start of mutual understanding, it may finally result in more respect for the other function. It may lead to actions that take into account the concerns of manufacturing. Moreover, bringing the designers onto the factory floor may make them cope with manufacturability problems and with any bad aspects of their designs. The increased knowledge base helps to improve the manufacturability of future designs.

Bringing the designers onto the factory floor may also strengthen their feeling of being involved (Gupta et al., 1986). Participation increases the personal commitment of the designers to the project. It motivates them to make qualitative designs ready for manufacturing. Designers start thinking in terms of high volume production with a minimum of waste and scrap. Moreover, this is particularly true if the designers are responsible for the production start-up. Hence, an organizational barrier is overcome and empathy is expected to increase.

To recapitulate, we expect the designers' participation during the production start-up to overcome some integration barriers by the physical presence of people from design and manufacturing, the increased manufacturing knowledge of the designers and their stronger feeling of involvement. This probably corresponds with a stronger empathy from design towards manufacturing. Hence, we hypothesize that *involving design in the production start-up corresponds with more empathy from design towards manufacturing (H3b).*

METHODOLOGY

In order to test the hypotheses, data were gathered by means of a detailed questionnaire. It was built on the insights gained in a pre-study based on Kelly's (1958) repertory grid method. This method from cognitive research was used to detect potential success factors without making assumptions on the construct success in advance. Fifty-three interviewees with different functional backgrounds and interest participated. The sample of companies included the design and manufacturing of: a) adhesives, b) aluminium products, c) measuring equipment, d) electronic components, e) railroad vehicles, f) steel and fibre products, g) suit cases, and h) products for telecommunication and broadcasting.

The key data collection decisions when designing our study were: 1) the selection of product development projects, 2) the generation of dimensions or potential success factors, and 3) the perception of the product development projects in terms of the dimensions. Approximately six quite recent and self-contained projects were chosen from each company. By subsequently comparing different triads of these projects, the similarities and differences that constituted the dimensions an interviewee used to differentiate between product development projects were elicited. Early quantitative data were obtained by rating the presence and the importance of the elicited dimensions per project on an eleven-point scale. Here, each respondent rated his or her own generated dimensions for all the projects he or she had compared. More details on the repertory grid study are described in (Vandevelde, 2001).

A refining process eliminated the dimensions that only differed in formulation. Therefore, three researchers independently analysed the interview notes by content and studied the quantitative data. The remaining list of dimensions was adopted in a questionnaire, which was tested by three colleagues and four people from different companies and business sectors. The questionnaire provided more quantitative data since the repertory grid technique only provided information on the self-supplied dimensions from a respondent.

Each questionnaire represented an evaluation form of a product development project. It contained 212 potential success factors and 25 items concerning project performance. The latter were measured for their presence, whereas the potential success factors were judged both for their presence and importance to project performance. The scales were similar to those used during the repertory grid study. In addition, information on inter-functional interaction as well as some background information on both respondent and company were gathered.

The random sample included 25 of the 126 Belgian innovative companies that were contacted. The companies represented a variety of business sectors including the design and manufacturing of food products, textiles, machinery, chemical and photographic material, micro-electronics, consumer electronics, luggage and handbags, fabricated metal products, electrical machinery and apparatus, television and communication equipment and apparatus, motor vehicles, railway locomotives and rolling stock, cargo handling equipment, lighting materials and components, precision instruments, and plastic products. The sample contained 103 respondents rating 61 different product development projects. Sixty per cent of the projects lasted a maximum of two years. Ten per cent were categorized as fundamental research. The median respondent had 10 years of work experience, had been working approximately eight years for the company, and had six subordinates. The respondents represented various disciplines: 32% had been working in R&D for the last four years, and 28% in production or quality. Other functions represented in the sample were marketing, purchasing, quality, sales, planning, and general management. Fifty-five per cent of the respondents had a university degree.

Measures

All variables in this article are dimensions measured for their presence on eleven-point scales. '0' indicated that the dimension was completely absent in the project, '10' indicated that it was strongly present, while the nine intermediate values represented a gradation.

The dependent variable

Inspired by the design-marketing literature (cf. Souder, 1988) we consider the smoothness of the production start-up. This dimension was elicited and deemed critical during our repertory grid study. Afterwards, it was measured for its presence in a survey.

The other variables

All other variables are aggregated measures. Therefore, the dimensions were qualitatively categorized per theme by three independent researchers. Differences of perception were discussed afterwards in order to obtain consensus. Employment of multiple raters increased the reliability of categories. After the elimination of outliers in three iterations, the grouped dimensions were reduced to a stable set of principal components. Dimensions causing instability, low Cronbach alpha's (α), or eigenvalues below value one, were not adopted. We report the principal components considered in this article.

The perceived ***project complexity and uncertainty*** are considered as situational variables. The project uncertainty is broken down into market and technological aspects (Griffin et al., 1996; Souder, 1978). The technological *uncertainty* (α=0.68, # dimensions= 2) is determined by: a) the newness of the product, and b) the newness of the technology. The market-related uncertainty (α=0.72; # dimensions= 3) reveals: a) the extent to which a project is oriented to a new market, b) whether it is innovative in the market, or c) whether it is developed for existing markets. The last dimension is reversed. The project *complexity* (α= 0.64, # dimensions= 2) includes: a) the complexity of the product, and b) the complexity of the technology. No data are available to measure the market complexity. Project complexity is in line with Perrow's notion of unanalysability; uncertainty is related to the nonroutineness faced by people (Perrow, 1967).

Formalization (α= 0.88, # dimensions= 4) reveals the extent to which the product development project is characterized by: a) well-defined procedures, b) distinct responsibilities, c) a formal approach, and d) a structured management.

Empathy from design towards manufacturing (α= 0.90, # dimensions= 5) reveals whether the designers: a) understand production, b) anticipate manufacturing problems during the design phase, c) consider the manufacturability of the product during the design phase, d) take into account the possibilities and limits of production, and e) know the vision and objectives of manufacturing.

DM communication (α= 0.75, # dimensions= 4) indicates whether: a) the designers receive feedback from production, b) there is a distinct conversation partner for the project in production, c) production obtains adequate information to understand the project, or d) there are often project meetings.

Designer's involvement in the production start-up (α= 0.83, # dimensions= 2) is constructed by two dimensions. The first dimension tells whether the designers participate in tasks such as the start-up in production. The second one concerns the designer's feeling of being involved in the production start-up.

Analyses

We checked for second-order relationships in the reported correlation analyses. In the regression models, the underlying assumptions were tested. The data were checked for normality and linearity using standard regression diagnostics. Multicollinearity was checked for by using point correlations between the different independent variables. We are convinced that we could take the respondent as a unit of analysis[1]. All analyses are exploratory in nature.

RESULTS

Facilitating Factors for a smooth Production Start-up

Regression analyses (Table III) reveal that the higher the complexity and uncertainty of product and technology, the more difficult it is to realize a smooth production start-up (model 1). However, from model 2 it becomes clear that the introduction of

[1] *We checked for interdependency between respondents. We successively conducted a paired-sample correlation test for each of the variables considered. The groups compared by the test were composed as follows. We took into account the data from the projects that were evaluated by more than one respondent. Afterwards, we equally divided all the data on the same project in two groups. This was done for all the projects of the sample. In projects that were evaluated an odd number of times, the data from*

formalization eliminates the negative effect of project uncertainty. Furthermore, formalization (model 2) and empathy from design towards manufacturing (model 3) seem to be important in facilitating factors for a smooth production start-up. These results support our first and second hypotheses. Model 3 also tells us that once these facilitating factors are introduced, the project nature no longer affects the smoothness of the production start-up.

Insert Table 3 about here

In summary, our analyses show that all management systems and structures enabling formalization or an increase in designer's empathy assist to smooth the production start-up. Although the perceived complexity and uncertainty of product and technology hinder DM integration, their negative effect is eliminated if one succeeds in introducing formalization and increasing the empathy from design towards manufacturing. We came to the conclusion that the market-related situational variable has no effect on any of the models and is therefore excluded from Table III. This is not too surprising since DM integration is more related to technical aspects such as the product-process fit (Adler, 1995) than to market-related issues: the technically-oriented complexity and uncertainty are more important when studying smoothness of the production start-up.

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one respondent were eliminated. The paired-sample correlation coefficients revealed that there was no relationship between the groups.

Formalization

Clear goals, schedules, roles and responsibilities are a few examples of organizational formalization. Standardized manufacturing rules or formal documents such as technical guidelines are technical ways to formalize the product development process.

Formalization is not always easy to accept. In some situations it is even unwanted. The correlation analyses in Table IV show that formal approaches mean better process success, but have a negative impact on respect for innovativeness. In innovative projects characterized by much uncertainty, designers need a creative environment instead of processes restricted by formalization. Indeed, environmental uncertainty is an important aspect during the design phase. Several studies in the literature describe the link between uncertainty of the task environment and formalization. In general, it is argued that the higher the perceived uncertainty, the more organizational structure will be organic in nature (Duncan, 1971; Burns and Stalker, 1961). Although the literature in general suggests this fit for total organizations, a number of writers view organizations as composed of both structures (Thompson, 1967; Leifer and Huber, 1977).

Insert Table 4 about here

Irrespective of the organizational mode during the design phase, that is, whether the design phase has been informal or formal, when the design is introduced into production the process should be formalized to smooth the production start-up. A smooth production start-up requires transparent and complete designs ($\rho = 0.650$, sign $= 0.00$, $N = 94$). Formalization helps to realize this increase in transparency. If one succeeds in formalizing, the hindering effect of project uncertainty vanishes, the production start-up smooths and the process performance increases (Table IV).

An additional analysis demonstrates that written documents, which represent a formal way of communication, correlate with a smooth production start-up ($\rho = 0.418^{**}$; sign = 0.001; N = 65). Hence, even formal mechanisms without an integrative character can be associated with DM integration.

Managing the empathy from design towards manufacturing

As Table III shows, more empathy from design towards manufacturing smooths the production start-up. Table V seems to confirm our hypotheses (H3a and H3b) that empathy can be managed to some extent. It reveals that DM communication and designer's involvement in the production start-up both positively correlate with the designers' empathy. In other words, managers are able to increase the empathy from design towards manufacturing by stimulating DM communication and by involving design in the production start-up.

Empathy relates to project performance in a similar way as formalization (Table IV). More empathy associates with better process performance but less with respect for innovativeness. Hence, empathy probably means that the designers better take into account the existing manufacturing processes, capabilities and requirements during the design phase at the expense of the expected degree of the project's innovativeness. It does not say that fewer breakthrough products are realized, but that more divergence occurs between the realized and proposed degrees of innovativeness.

Insert Table 5 about here

CONCLUSIONS

This article sheds light on some mechanisms that smooth the production start-up and improve the performance of new product development projects. It describes an integration model revealing some facilitating factors for a smooth production start-up. The factors help to overcome five major barriers to design-manufacturing integration that were identified by means of a qualitative repertory grid study and a study of the literature. The barriers appear to be due to personal, cultural, language, physical, and organizational differences between design and manufacturing.

The integration Model

The study shows that formalization is a primary facilitating factor for a smooth production start-up. Independent of the degree of formalization during the early development stages, a formal approach is preferred when the new product is introduced into production. Formalization can be through both organizational and technical aspects of production.

The empathy from design towards manufacturing is a second contributor to a smooth production start-up. The designers' empathy can be stimulated by managerial actions. Striving for more DM communication and designers' involvement in the production start-up both positively influence the designers' empathy.

Furthermore, the integration model sheds light on the impact of the project nature. Although the complexity and newness of product and technology hinder a smooth production start-up, the negative effect vanishes if one succeeds in introducing formalization and empathy from design towards manufacturing. No market-related project characteristics appear to affect integration.

The model is a general framework that helps us to understand and improve the production start-up, rather than a catalogue of mechanisms to handle inter-functional smoothness. The method of implementation is not critical. The degree to which the integration idea as a whole is realized is important (Brown and Eisenhardt, 1995). The model shows that not only mechanisms introduced at the start-up (e.g., formalization), but those introduced during the whole design process, are useful to smooth the production start-up. For example, the empathy from design towards manufacturing affects the development process from the very start of the project and finally results in a smoother production start-up.

This study is exploratory in nature and only includes data from people working for Belgian companies or business units in a limited number of industries. It would be interesting to conduct confirmatory analysis and replicate the study in a variety of settings.

Implications for Senior Management

Senior management fulfils an important role in implementing the tested framework and strongly influences the level of integration achieved (cf. Gupta et al., 1986, 1987) by affecting various interface barriers.

Senior management can strive for organizational climates that promote DM communication and inter-functional empathy to overcome personality and cultural barriers. For example, senior management can provide opportunities for the exchange of views and perspectives. It can set an example to the organization by communicating openly and frequently. Senior management may stress the value of inter-functional information exchange and co-operative innovation (Lucas and Bush, 1988; Song and Parry, 1993) and show its appreciation for actions that take into account the needs and requirements of other departments. Smoothing the DM interface is a challenging job within the designer's task (see also Vandevelde, 2001).

Secondly, managers can strive for the implementation of organizational structures that promote formalization at production start-up, or stimulate DM communication and collaboration. Furthermore, management can account for the designer’s empathy in the selection, assessment and training of personnel within its responsibility.

Thirdly, senior management can help to break down the language barrier by providing more opportunities to interact. Examples concern the establishing of formal integrative mechanisms such as cross-functional teams or the formal dedicated role of the designers during the production start-up (Souder, 1987; Vasconcellos, 1994). Cross-functional teams are *formal* mechanisms, suited to facilitate *communication* (Allen, 1977) and stimulate joint and early involvement of various functions (cf. Souder, 1988; Bergen and McLaughlin, 1988). Often, managers also provide opportunities to interact more informally by supporting recreational activities or collective lunches. However, it is difficult to force the development of informal networks (cf. Griffin and Hauser, 1996).

Finally, senior managers determine the geographical location, the architecture and infrastructure of the company. They can provide opportunities to interact more interfunctionally by co-locating multifunctional design teams and relocating functions so that they work in close proximity with each other (Allen, 1977). Other examples are the decentralization and relocation of design units close to production units or the creation of informal meeting places at strategic points (Van den Bulte and Moenaert, 1998; Gupta et al., 1987; Vasconcellos, 1994). These managerial decisions increase DM communication and hence, the designer's empathy.

In summary, managers are able to smooth the production start-up by provision of guidance, support, structure and resources, and by setting an example of the right attitude. Apart from stimulating a smooth production start-up, managers should also stimulate respect for innovativeness during the design phase, since actions to smooth the production start-up have a negative impact upon respect for innovativeness.

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TABLE 1

Personality differences between marketing, design and manufacturing

characteristics	marketing	design	manufacturing
goals & aspirations	❖ organizational survival & growth ❖ activities relevant to firm's objectives ❖ organizational recognition	❖ knowledge as a source of value to mankind ❖ research for research's sake ❖ peer evaluation and recognition	❖ delivering quality/volume on time ❖ minimizing waste and scrap ❖ clear tasks, relevant to senior management
needs	❖ plans, procedures, policies, rules ❖ organizational recognition ❖ team work ❖ increased organizational status	❖ autonomy, creative environment ❖ peer recognition ❖ education, personal development ❖ support for advancing knowledge in society	❖ analysable, transparent tasks ❖ increased organizational status ❖ organizational recognition
motivation	❖ rewards and sanction system with pay and advancement through the organization	❖ service to mankind ❖ publications, professional recognition, patents with name attached ❖ freedom to solve problems and advance knowledge	❖ rewards and sanction system for the production volume, quality and flexibility

(based on Griffin and Hauser, 1996, and extended to the DM interface)

TABLE 2

Cultural differences between marketing, design, and manufacturing

characteristics	marketing	design	manufacturing
time orientation	short	long	short
projects preferred	incremental	advanced	incremental
ambiguity tolerance	high	low	low
departmental structure	medium	low	high
bureaucratic orientation	more	less	high
orientation to others	permissive	permissive	less permissive
professional orientation	market	science	process

(based on Griffin and Hauser, 1996, and extended to the DM interface)

TABLE 3

Regression analyses searching for facilitating factors of a smooth production start-up

	A smooth introduction in production					
	Model 1		**Model 2**		**Model 3**	
N=50	beta	s.e.	beta	s.e.	beta	s.e.
constant	**	1.120	**	1.162	**	1.144
control 1: project complexity	-0.291*	0.285	-0.244*	0.263	-0.176	0.256
control 2: project uncertainty	-0.347**	0.155	-0.123	0.166	-0.020	0.164
formalization			0.439**	0.296	0.479**	0.282
designer's empathy					0.302*	0.273
adj.R^2	**0.17****		**0.30****		**0.37****	
F	6.13		8.28		8.52	
significance level	0.004		0.000		0.000	

*Legend: *: significance level < 0.05, **: significance level < 0.01, s.e.: standard error,* ***control 1****: the complexity of the product and technology,* ***control 2****: the newness of the product and technology, the market-related measure was excluded since it did not affect any of the models*

TABLE 4

Correlation analyses between formal approaches and designer's empathy on the one hand, and multidimensional project performance on the other hand

	Correlation	S1	S2	S3	S4	S5	S6	S7
Formal approach	Pearson Correlation	.289*	.312**	-.147	-.006	-.232*	-.085	.119
	Sig. (2-tailed)	.011	.010	.171	.957	.035	.438	.301
	N	76	67	89	81	83	86	78
Empathy from design to manufacturing	Pearson Correlation	.270*	.399**	-.064	.137	-.261*	-.066	.076
	Sig. (2-tailed)	.025	.002	.580	.246	.026	.571	.529
	N	69	56	77	74	73	75	71

*Legend: **S1**: respect for time, **S2**: respect for budget and technical specifications, **S3:** knowledge creation and transfer, **S4:** contribution to prestige, **S5:** respect for innovativeness, **S6**: contribution to business success, **S7:** financial and commercial success, ***:** the correlation is significant at the 0.05 level (2-tailed), ******: the correlation is significant at the 0.01 level (2-tailed).*

TABLE 5

Correlation analyses between DM communication, designer's involvement in the production start-up and empathy from design to manufacturing

Partial Correlation, N=50			
Between		***Controlled for***	***Coefficient***
X	Z	Y	0.439**
Y	Z	X	0.559**
X	Y	Z	0.009

*Legend: X = DM communication, Y = designer's involvement in the production start-up, Z= empathy from design to manufacturing, *: significance level < 0.05, **: significance level < 0.01*

FIGURE 1

The hypothesized integration model