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IS DESIGN - MANUFACTURING INTEGRATION THAT IMPORTANT?

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ABSTRACT

There is limited empirical evidence to support the importance of design-manufacturing (DM) integration on the performance of new product development projects. This article focuses on the impact of integration processes and their outcomes on multidimensional project performance. When considering integration as interaction processes, we find that the degree of interaction is positively correlated with respect for time and prestige. If one succeeds in smoothing the production start-up, which is an outcome of integration, a better respect for time, budget and technical specifications is realized. Finally, we provide some insights into the perceived room to improve integration. Even though perceptions do not always correspond with reality, it is interesting to examine them since product development decisions are often taken in response to an individual's perceptions (Kleinschmidt & Cooper, 1995).

INTRODUCTION

Many authors emphasize that the way the interface process between design and manufacturing is managed is important to the performance of new product development projects. It is deemed to be a key for effective designs and highly performing product development processes (Adler, 1995; Braiden *et al*., 1993; McIntosh, 1986). As a result, a thorough understanding of the DM interface and, in particular, of the integration process that takes place at that interface appears to be very useful for improving the efficiency and effectiveness of product development projects.

In contrast to the broadly researched and discussed design-marketing interface (Souder, 1987; Gupta *et al*., 1985; Tiger Li, 1999), empirical literature on the DM interface is limited (Ettlie, 1995). We found only a few studies that examined the impact of the way the DM interface is managed on the performance of product development projects. In one study, Ginn & Rubenstein (1986) investigated determinants of technical and commercial success by intensively examining three business units of a chemical company. With respect to the DM interface, they found that the more successful projects, both technically and commercially, tended to have higher levels of conflict and more superordinate goals than did the less successful projects. Another example is the research of Xie *et al*. (1998), who tested a model suggesting a concave relationship between the level of interdisciplinary conflict between marketing, R&D and manufacturing on the one hand and performance on the other. Finally, we mention the cross-regional studies of Ettlie & Trygg (1995) and Bergen *et al*. (1982, 1986, 1988). In the research on causes of regional differences in productivity, Bergen (1982) found that, in successful projects, there is better communication across functions. At the design-manufacturing interface, the credibility of the project leader and his/her ability to communicate with all company functions was found to be critical. Bergen *et al*. (1988) suggested that, in the USA, there was a greater involvement of senior executives at the production start-up and a greater involvement of manufacturing in the design process in order to get its new products into production more quickly. Furthermore, an improvement in communication and provision of more information on the project throughout the company beneficially influences technical success. For example, the involvement of the manufacturing department in specification decisions seems useful (Bergen *et al*., 1986).

The discrepancy between the claimed importance of the DM interface and our understanding of the interface stimulated us to carry out this research. In particular, we wanted to investigate the impact of the degree of integration between design and manufacturing on project performance.

We shall commence by analysing the literature on interface management in the product development processes. This will help us to formulate some specific hypotheses. Next, we shall describe some methodological aspects of our research. Then, we shall describe and discuss the results. We shall end with some practical conclusions and an outline of some areas for future research.

THE IMPACT OF DM INTEGRATION ON PROJECT PERFORMANCE

DM Integration in the Interface Debate

In this study, we are interested in integration processes, which we define as interaction processes involving information exchange on the one hand and collaboration or co-operation on the other. By doing so, we combine two perspectives: the information perspective and the collaboration perspective.

The *information perspective on integration* (Lapierre & Henault, 1996; Fisher *et al*., 1997) fits in the general systems theory, which views organizations as information processing social structures (Tushman & Nadler, 1978; Daft & Weick, 1984) and considers innovation as an interdependency of information-processing activities requiring input from various functions. Information exchange thrives on the exchange of both explicit and tacit knowledge (Badaracco, 1991; Nonaka, 1991). It may refer to facts, truths, principles, experience-based insights, exemplary practices and empirical results (Glaser *et al*., 1983). Interdisciplinary information helps to reduce uncertainty (O'Dwyer & O'Toole, 1998). With respect to the DM interface, it reduces in particular the uncertainty of the product-process fit (Adler, 1995), which includes technology and resource uncertainties (see Moenaert's & Souder, 1990).

The *collaboration perspective on integration* (Norton *et al*., 1994; Gupta *et al*., 1987) refers to joint involvement, joint responsibility or joint ownership of various functions. It includes interdisciplinary decision-making. Collaboration can be structured in cross-functional teams, for example, or in the participation of manufacturing in the design process and strategic decisions (Vasconcellos, 1994; Griffin & Hauser, 1996).

In summary, both the information and collaboration perspectives concern 'interaction' processes, which may be induced via formal as well as informal channels (Moenaert & Souder, 1990). This study considers integration processes mainly as interaction processes supporting and linking activities in an information or collaboration perspective (c.f. Souder, 1988; Song & Parry, 1993; Tiger Li, 1999).

Relationship between DM Interaction and Project Performance

It is generally believed that interaction enhances project performance. There is some support for this statement in the literature.

First, there is the large amount of published material on communication (Allen, 1970; Shilling & Bernard, 1964; Baker *et al*., 1967; Rosenbloom & Wolek, 1970). The nature and role of communication to realize successful innovation has been a fruitful area of inquiry (Allen *et al*., 1970; Katz & Tushman, 1979; Lee & Allen, 1982; O'Reilly & Pondy, 1979; Rothwell & Robertson, 1973). Twiss (1974) postulated that companies should start analysing communication if they want to facilitate technology transfer and heighten success. Dougherty (1987) underlined that the likelihood of product success is enhanced if marketing, design and manufacturing share information on customer needs and segments, technology and manufacturing capabilities, competitor strategies, business strategy and pricing.

Further, the innovation management literature looks at interdisciplinary collaboration as a key for success. The early and strong involvement of different disciplines, such as cross-functional teams, is said to heighten process performance (Zirger & Maidique, 1990; Clark & Fujimoto, 1991; Stalk & Hout, 1990; Gupta & Wilemon, 1990). We note that the link between cross-functional teams and success is one of the most robust findings in the literature (Brown & Eisenhardt, 1995). Cross-functional teams are found to speed up development for all industry segments (Eisenhardt & Tabrizi, 1995).

In summary, the literature suggests that successful development projects rely upon qualitative and frequent interaction between the people crucial to the product development process. Since marketing, design and manufacturing are perceived as crucial during product development (McIntosh, 1986, Myers, 1999), we expect qualitative and frequent interaction to be important for both the design-marketing and the design-manufacturing interface.

Research on the design-marketing interface covers both the information (Dougherty, 1990; Cooper, 1979) and collaboration perspectives (Fisher *et al*., 1997; Gupta *et al.*, 1987; Kahn & Mentzer, 1998). All studies either support (Cooper & Kleinschmidt, 1987; Cooper, 1984; Maidique & Zirger, 1984; Song & Parry, 1993) or are consistent with (Gupta & Wilemon, 1988; Griffin & Hauser, 1992) the hypothesis that integration enhances success, although the conclusions are relative to the measures of success used (for a review, see Griffin & Hauser, 1996). The evidence is strong and consistent across a variety of methodologies. The conclusions are seemingly applicable in both service and product development, in both consumer and industrial markets, and in both domestic and export markets (Tiger Li, 1999).

In addition to design-marketing interaction, we expect the design-manufacturing interaction to be important to project performance. In particular, we postulate that *better DM interaction corresponds with better project performance (H1).* We now describe this relationship.

Project performance: a Multidimensional Construct

Project performance can be represented by a three-polar model, containing process, economic and indirect poles (Vandevelde, 2001). The process pole includes such aspects as respect for time (S1), budget and technical specifications (S2). The economic pole refers to financial and commercial measures (S3). The indirect pole includes the project's contribution to prestige (S4) and business success (S5), respect for innovativeness (S6), and knowledge creation and transfer (S7).

The Impact of DM Interaction on Time Performance

Integration is often associated with reducing time to market; design-marketing (Pearson & Ball, 1993) as well as DM interaction have been associated with time performance (Dean & Susman, 1989; Braiden *et al*., 1993; O'Dwyer & O'Toole, 1998). How should this be understood? Design-marketing interaction adds value by synthesizing specific and crucial knowledge (Griffin & Hauser, 1992, Song & Parry, 1997). DM interaction cross-fertilizes the design knowledge of how to technically develop new products with manufacturing knowledge of how to adequately produce them. Interaction stimulates the awareness of the informational needs of other functions (c.f. Moenaert & Souder, 1990). The information exchange becomes more effective and efficient, which quickens the development process. Since each party contributes enlightened insights to the mosaic of innovation, interaction enhances the individual's capability to solve problems better and faster. Problems are better anticipated and, if they occur, they are detected earlier (McIntosh, 1986), when they are smaller and easier to solve and, thus, are less time-consuming (Dean & Susman, 1989). Furthermore, a reduction in the amount and size of problems results in fewer modifications and rework. The iterations between product and process design stages are minimized (Schilling & Hill, 1998). Hence, DM interaction ensures speed and adaptivity (Adler, 1995, Braiden *et al*., 1993) and corresponds with a better management of the time schedule. In addition, the sharing of information helps people from different departments to define their roles, to determine which tasks each is best able to perform and to agree on the division of labour. It helps with the co-ordination of efforts and improves time management. In summary, we hypothesize that *DM interaction corresponds with a better respect for time (H2).*

The Impact of DM Interaction on Respect for Budget and Technical Specifications

DM interaction is deemed to be useful for obtaining an acceptable product-process fit at the lowest cost (Adler, 1995), which means few mistakes, problems and rework. DM interaction helps detect problems early, which prevents dramatic cost increases (Larson, 1988). Unexpected efforts are reduced and efficiency is increased. This probably translates into lower costs and more successful cost control. Hence, we believe that better DM interaction corresponds with better respect for budget.

Better DM interaction also means cross-fertilization of knowledge, which may contribute to higher technical performance and a better respect for even complex technical specifications. A better product-process fit realized by better DM interaction also leads to fewer mistakes, problems and rework. It facilitates the production start-up and improves quality (Whitney, 1988; Ettlie & Stoll, 1990). Moreover, the development process, which may be shortened by DM interaction, enables firms to incorporate state-of-the-art technologies in their designs. It creates new opportunities to fulfil the specifications. Hence, we hypothesize that *better DM interaction corresponds with better respect for technical specifications and better respect for time (H3).*

Other Relationships

We do not hypothesize further relationships between DM interaction and other project performance because there is not much evidence for them in the literature.

METHODOLOGY

To test the hypotheses, data were gathered by using 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. The standard approach to detect critical success factors consists of retrospectively analysing the characteristics of successful or unsuccessful projects, or by conducting paired comparisons and discriminant analyses of successful and unsuccessful projects. The repertory grid method overcomes some shortcomings of this standard approach. For example, it avoids making assumptions on the construct success in advance or imposing the researcher's cognitive structure onto the interviewee.

The key data collection decisions for our study were 1) the selection of product development projects, 2) the generation of dimensions (potential success factors), and 3) the perception of the product development projects in terms of the dimensions. Approximately six recent and self-contained projects were chosen per company. By comparing different triads of these projects, the similarities and differences were determined and these constituted the dimensions an interviewee used to differentiate between product development projects. Early quantitative data were obtained by rating, firstly, the presence and, secondly, the importance of the elicited dimensions per project on an 11-point scale. Here, each respondent rated his or her own generated dimensions for all the projects he or she had compared. This type of scale, which dominates existing applications of rating grids (Reger, 1990, p. 301), was selected because of its sensitivity to small differences in perceptions. The first of the two scales represented the presence of the dimension in a particular project: ‘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 between complete absence and strong presence. The second scale represented the perceived importance of the dimension to project performance, without specifying what was meant by project performance. ‘0’ meant that the dimension was of absolutely no importance, ‘10’ was the exact opposite and each intermediate value represented a gradation between the two extremes. In total, eight Belgian companies and 49 product development projects were adopted in the sample. 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) suitcases, and h) products for telecommunication and broadcasting. Fifty-three interviewees with different functional backgrounds and interests participated. More details on the repertory grid study are described by Vandevelde (2001).

A purification process eliminated the dimensions that only differed in formulation. Three researchers independently analysed the content of the interview notes 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 allowed more quantitative data to be obtained since the repertory grid technique only provided information on the self-supplied dimensions of a respondent.

Each questionnaire represented an evaluation form for 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 for their importance in project performance. The 11-point scales were similar to those used during the repertory grid study. In addition, information was gathered on inter-functional interaction as well on the background of both the respondent and the company.

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 manufacturing or quality. Other functions that were represented in the sample were marketing, purchase, sales, planning and general management. Fifty-five per cent of the respondents had a university degree.

All analyses were exploratory. We checked for second-order relationships in the reported analyses. We are convinced that we could take the respondent as a unit of analysis1.

THE IMPORTANCE OF DM INTEGRATION

Initial Insights

The repertory grid study allowed a first estimation of the importance of DM integration according to practitioners. The number of times a dimension was elicited is a yardstick for the perceived importance of the dimension within the respondent's cognitive structure (Reger, 1990). Nevertheless, it is only a rough yardstick since it also depends upon the number of triads compared. We considered people's quantitative ratings of their self-supplied dimensions on the importance scale as the major yardstick for perceived importance. The dimensions quoted at least 10 times

[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 follow. 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 into two groups. This was done for all the projects of the sample. In projects that were evaluated an odd number of times, the data*

were noted and ranked by decreasing value of importance. The top of the list is represented in Table 1. It reveals the five dimensions that are deemed most crucial to success. The presence of two dimensions concerning the DM interface in Table 1 hints at the perceived importance of DM integration. A first dimension is the smoothness of interaction and concerns the integration process. The other dimension refers to an outcome of the integration process; it looks at the degree of completion of the design at the production start-up, which is an indication for the smoothness of the production start-up.

Insert Table 1 about here

Another estimation of the importance of DM integration was obtained via the survey data. All integration characteristics elicited during the repertory grid study were adopted in a questionnaire. The characteristics concerning the integration process were a) the quality of information exchange, b) the smoothness of interaction, c) the frequency of interaction, d) the amount of formal contacts, e) the amount of informal contacts, and f) the strength of structural integration. Five of these characteristics concern interaction processes. Each respondent rated the six characteristics for their presence and perceived importance on a binary scale for various interfaces. It concerns the DM interface and six other interfaces, each of which includes either the design or manufacturing function in combination with marketing, sales or purchase. Afterwards, a 'presence mean' and an 'importance mean' were calculated over all respondents for each of the integration characteristics and each of the interfaces. Table 2 summarizes the results.

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

Insert Table 2a and 2b about here

Table 2a provides a large body of information on the perceived relative and absolute importance of inter-functional integration. For the DM interface (second column of Table 2a), the six integration characteristics are all deemed very important with scores of at least 0.77. As well as this perceived absolute importance of DM integration, the relative importance can be derived from the ranking list containing the 6 x 7 ‘importance means’ in descending order of importance (Appendix A). The top five of that list, with mean scores above 0.94, includes three DM integration characteristics: a) the quality of DM information exchange, c) the frequency of DM interaction, and b) the smoothness of DM interaction. Moreover, except for the strength of integration, all DM characteristics precede the corresponding integration characteristics of other interfaces. The quality of DM information exchange and the frequency of DM interaction, the two highest scores on the ranking list, have the lowest variance, suggesting unanimity across respondents and projects. Hence, the exploratory data give an indication of both the perceived absolute and relative importance of DM integration.

The Importance of DM Integration to Multidimensional Project Performance

To examine the proposed hypotheses, correlation analyses were conducted between the presence of DM integration and the project performance.

Variables

Project performance is considered multidimensional; it contains seven success aspects as we described previously. Apart from these seven success aspects, we constructed a yardstick for 'global success' as the means of the success aspects. Note that this is only one measure for global success. The relative weights attached to the success aspects may differ over time, respondents and projects.

In addition, we considered ***DM interaction*** as a yardstick for DM integration. It is constructed as a linear combination of the integration characteristics (a) to (e) mentioned previously. The quality of information exchange (a) and the smoothness of interaction (b) refer to the quantity of interaction. The other characteristics (c) to (e) concern the frequency of interaction. Note that the values on the 'presence scale' are also considered.

A similar aggregated measure was constructed for ***design-marketing interaction.*** This yardstick for design-marketing integration is used as a control variable in the analyses because many researchers underscored it as a critical success factor (see previously). Inspired by the design-marketing literature (c.f. Souder, 1988), we also looked at the smoothness of the DM interface, which is more an outcome than an aspect of the DM integration processes. More specifically, we consider the ***smoothness of the production start-up.*** This dimension was elicited and deemed critical during our repertory grid study and, afterwards, was measured for its presence in the survey.

Results

Partial correlation analysis reveals that there is a relationship between DM interaction and global project success ($\rho = 0.357$, $p = 0.026$, $N = 37$, controlled for design-marketing interaction). Hence, we found evidence for the ***first*** hypothesis. The ***second*** hypothesis predicted that better DM interaction corresponds with better respect for time. The results presented in Table 3 (see S1) support this. In contrast, we found no support for the ***third*** hypothesis; we found no significant correlation between DM interaction and respect for budget and technical specifications (S2). Note that the results should be interpreted with care since the ratings on both DM integration characteristics and project performance are perceptual survey ratings deriving from the same respondent.

Insert Table 3 and 4 about here

Discussion

DM interaction can be associated with respect for time (S1). Hence, as firms come under greater pressure to shorten time-to-market and better manage their time schedule, interface management becomes more crucial. In contrast to what we expected, there seems to be no relationship between DM interaction and respect for budget and technical specifications (S2). The fact that interaction improves respect for time but not respect for budget and technical specifications may suggest that time issues are discussed or negotiated and that issues on budget are not or to a lesser extent. The strong pressure on time-to-market issues may focus attention on time. Alternatively, it may be easier to compromise on time issues than on budget matters. Respect for budget requires global thinking across functional boundaries. However, several interface barriers can impede this global thinking (Vandevelde, 2001) and negatively influence the outcome of the integration process; namely, the smoothness of the production start-up. In other words, we believe that better interaction does not necessarily correspond to a smoother production start-up and that only a smooth production start-up is associated with respect for budget. The same reasoning may hold for technical specifications. Table 4 shows a strong relationship between a smooth production start-up and respect for time and also for budget and technical specifications.

The lack of a relationship between DM interaction and respect for budget and technical specifications may also be explained as follows. Moenaert and Souder (1996) concluded that, with respect to the design-marketing interface, information utilization is an important success factor. However, interdisciplinary interaction does not necessarily imply information utilization (Goldhar *et al*., 1976). Extrapolating the findings to the DM interface, one may argue that it is not the DM interaction, but the use of the information exchanged by interaction, that is important to respect for budget and technical specifications.

Other results

Table 3 reveals a relationship between DM interaction and prestige (S4). No other relationships were found.

At the first sight, it is surprising to see that DM interaction, which includes information exchange and thus knowledge transfer between people (Badaracco, 1991; Nonaka, 1991), does not correspond with the performance aspect 'knowledge creation and transfer' (S3). However, the result is in line with the literature if we recognize that the performance aspect concerns the project level and that DM interaction only affects knowledge creation and transfer at the individual level and not at the project level. A particular product development project always goes from design to manufacturing, with or without interaction between design and manufacturing. Hence, each function adds its specific knowledge, although not always in an efficient manner.

Another explanation may be that both design and manufacturing knowledge are technically oriented. Hence, although designers concentrate more on the product whereas manufacturers bother more about the process (Adler, 1995), the knowledge bases are not significantly different. This contrasts with the knowledge differences between design and marketing, for example, which are related to knowledge creation and transfer, according to the literature (Griffin & Hauser, 1996). Another reason may be that it is not the DM interaction as such, but the use of extra-functional information and, hence, the internalization of insights by design or manufacturing that stimulates knowledge creation.

DM interaction correlates positively with prestige (S4). This suggests that interdisciplinary interaction improves a person's perceived added value over functional barriers. In addition, the increased respect for time (see previous section) may also contribute to prestige. Achieving success provides the various agents with satisfaction and pride, which reinforces their motivation and may start the efficacy-performance spiral (Lindsley *et al*., 1995). In other words, performance affects self-efficacy, which, in turn, affects performance and so on. Furthermore, the status of manufacturing is perceived as being lower than that of design (McDonough, 1984). Hence, interaction with design may increase manufacturing's organizational status and affect their prestige. Finally, one may argue that, by interacting, people from design and manufacturing acquire extra knowledge, which strengthens their self-actualization and social recognition. Moreover, innovation lifts manufacturing people out of their more routine tasks.

Table 4 stresses that there is no relationship between a smooth production start-up and prestige. One explanation may be that a smooth production start-up is only realized in the easier and less prestigious projects. Or, perhaps only the projects that coped with start-up problems and were brought to a good end increase prestige because they are deemed to be difficult. In that case, we could go further and argue that projects need some conflict and difficulties to make them look difficult and attract prestige. If the latter were true, managers should look for ways to maintain people's prestige while continuing to strive for integration. For example, managers may introduce a culture that associates a smooth production start-up with an adequate management rather than with an easy, less prestigious task. Our results further suggest that increased visibility and status perception rather than the extra individual knowledge are the prestige winners in the relationship between DM interaction and prestige.

DM interaction is not associated with a better respect for innovativeness (S5). There are two counteracting forces. DM interaction may allow better realization of the expected innovativeness because it guarantees a better product-process fit (Adler, 1995), which avoids innovativeness being lowered because of technical problems. However, at the same time, interdisciplinary interaction leads to more empathy with the role, wishes and limitations of the other department (c.f. Souder, 1977, 1987). The increased empathy may reveal that design humours manufacturing's wishes and limitations at the expense of the respect for innovativeness. It is called the danger of being too-good friends (c.f. Souder, 1988). Since both design and manufacturing are strongly internally oriented, good internal relationships are probably important and the desire for designs to be appreciated by manufacturing may be strong.
Besides, one may argue that design and manufacturing are technically oriented and are mainly concerned with respect for technical innovativeness rather than for the global innovativeness, which is also market related.

The project's contribution to business success (S6) reflects the establishment of the long-term strength of the organization (Shenhar *et al*., 1997). It reveals the degree to which a particular product development project contributes to the firm’s growth and helps in building a positive and innovative image. Looking at this definition, we see no reason for a direct relationship between DM interaction and contribution to business success. Customers are confronted with the outcome of the development process; they see the designed product rather than the process behind it. Even so, no relationship is found between DM interaction and economic performance (S7), which is not too surprising given that economic performance is influenced by so many other factors that it becomes difficult to measure the effect of DM integration in our research design. This might also explain why we did not find other relationships between DM integration and project performance.

In a nutshell

In summary, better DM interaction corresponds with better project performance, by assuring respect for time and prestige. A smooth production start-up corresponds with better respect for time, budget and technical specifications.

Other interesting Findings on Inter-functional Integration

The perceived room to improve interfaces

By subtracting the presence ratings of the integration characteristics from the perceived importance ratings of the integration characteristics (Table 2b), one acquires a rough yardstick for the perceived room to improve the integration at a particular interface. According to the respondents, there is room to improve DM integration. Only the amount of informal contacts is deemed sufficient.

The repertory grid data led to a similar conclusion. All elicited dimensions were ranked in increasing order of the delta variable, which is constructed as the gap between the presence and perceived importance of a dimension. The top fifteen of that list are reported in Table 5. It shows the elicited dimensions corresponding with strongly negative delta values and thus calling for more attention according to the respondents. The table reveals that more than 40 per cent (7/15) of the dimensions explicitly concerns the DM interface. Hence, DM integration is considered an area for improvement. In addition, one more global integration characteristic is detected, namely the smoothness of interdisciplinary information exchange. Analysing the ratings on the DM aspects per company further underlines the perceived room for improvement. Hence, the perceptions of the people in our study are still in line with the conclusion of Carlsson (1991) made one decade earlier; namely, DM integration has substantial room for improvement.

Insert Table 5 about here

Besides the room to improve design-manufacturing integration, our study stresses (Table 2b) a significant dissatisfaction with the current levels of design-marketing integration (c.f. Gupta *et al*., 1985; Song & Parry, 1992). The results relate to an earlier study that raises questions on the capabilities of managers to manage integration (Kleinschmidt & Cooper, 1995) and to overcome interface barriers (Griffin & Hauser, 1996). Nevertheless, design-marketing integration is deemed very important (Table 2a), and design-sales integration is perceived to be very important

(Table 2a) and has room for improvement (Table 2b). Specific managerial literature that may guide the realization of better design-sales integration is scarce. We only know of some marketing studies that also focus on sales (Kotler, 1999).

The perceived relative importance of various integration characteristics

Throughout various interfaces, the quality of information exchange is quasi-unanimously seen as the most important integration characteristic with respect to project performance (Table 2a). Nevertheless, the quality of information exchange still has much room for improvement, according to the respondents, despite the many insights from research on information processing structures and interdisciplinary information exchange (e.g., Badaracco, 1991; Nonaka, 1991; Glaser *et al*., 1983; Daft & Weick, 1984). The interfaces with sales and marketing are found to need most attention. We note that the amount of informal contacts is deemed sufficient for most interfaces, except for the interfaces with marketing and for the manufacturing-sales interface.

The strength of structural integration and the number of formal contacts are usually the least important integration characteristics. They appear not to be a priority if other mechanisms, such as fruitful informal contacts, assure integration. More importantly, they are deemed irrelevant with respect to the design-purchase, manufacturing-sales and manufacturing-marketing interfaces. Too much integration may mean that team members lose their functional skills over time or that they lose sight of other goals if they focus too hard on integration (Griffin & Hauser, 1996). This statement, formulated for the design-marketing interface, seems applicable to some other interfaces, but not to the manufacturing-purchase interface. Manufacturing and purchase seem to have a strong task interdependency, which makes formal contacts and structural integration useful. There appears to be a similarity between the goals and work approach of the departments and reduced danger of losing skills and sight of the goals.

CONCLUSION

This paper contributes to the literature on design-manufacturing interface by investigating the impact of design-manufacturing integration on project performance and by presenting some quantitative data on how well the interface is managed, according to practitioners.

The study underlined both the perceived absolute importance of DM integration and the relative importance with respect to six other interfaces. Each of the other interfaces includes the relationship between design and manufacturing in combination with marketing, sales or purchase.

Furthermore, the study sheds light on the specific aspects of project performance that are affected by DM integration. In particular, the quality and quantity of DM interaction processes seems to correspond with a better respect for time and a higher prestige. A smooth production start-up means better respect for time, budget and technical specifications. Hence, as firms come under greater pressure to shorten time-to-market and improve the respect for time and other process characteristics, interface management becomes more crucial. It may explain why interface management has been gaining importance during recent decades.

Despite the importance of DM integration, we found that the DM interface still has much room for improvement, according to practitioners. Because of the importance of DM integration and the perceived room for improvement, we conclude that a deep understanding of the DM interface would be useful. Gaining a better understanding is often the first step on the way to better management.

Future research

This study is exploratory and only includes data from people working for a Belgian company or business unit in a limited number of industrial sectors. It would be interesting to conduct confirmatory analyses and to replicate the study in a variety of settings.

We note that DM interaction is operationalized in our study as a construct including the quality and quantity of interaction in both the information and collaboration perspective. One could refine the study and investigate the specific impact of the quality and quantity of interaction separately. Furthermore, it would be useful to repeat the analyses with objective performance measures where possible. Finally, we recommend an examination of the role of information utilization at the design-manufacturing interface to further explore the impact of integration on project performance. Inspired by the design-marketing literature, we proposed that not only interaction as such, but also the use of inter-functional information, is an important success factor.

REFERENCES

[1] Adler, P.S. (1995), 'Interdepartmental Interdependence and Co-ordination: The Case of the Design / Manufacturing Interface', *Organization Science*, 6, 2, 147-167.

[2] Allen, T.J. (1970) 'Communications networks in R&D laboratories', *R&D Management*, 1, 14-21.

[3] Allen, T.J. (1977) '*Managing the flow of technology'*, Cambridge MA: MIT Press.

[4] Badaracco, J.L. (1991) '*The knowledge link'*. Harvard Business School Press: Boston MA.

[5] Baker, N.R., Siegmann, J. & Rubenstein, A.H. (1967) 'The effects of perceived needs and means of the generation of ideas for industrial research and development projects', *IEEE Transactions Engineering Management*, 14, 156-162.

[6] Bergen, S.A. & McLaughlin, C.P. (1988) 'The R&D/Production interface: a four country comparison', *International Journal of Operations and Production Management*, 8, 7, 5-13.

[7] Bergen, S.A., Miyajima, R. & McLaughlin, C.P. (1988) 'The R&D/Production Interface in Four Developed Countries', *R&D Management*, Oxford, 18, 3, 201-216.

[8] Bergen, S.A. & Miyajima, R. (1986) 'Productivity & the R&D/Production Interface in Japan', *R&D Management*, Oxford, 16, 1, 15-24.

[9] Bergen, S.A. (1982) 'The R&D/Production Interface-United Kingdom and West German Practices and Achievements in the Scientific Instrument Industry', *R&D Management*, Oxford, 12, 1, 21-25.

[10]Berlo, D.K. (1960) '*The process of communication'*, Rinehart & Winston, New York.

[11]Braiden, P.M., Alderman, N. and Thwaites, A.T. (1993) 'Engineering design and product development and its relationship to manufacturing: A programme of case study research in British companies', *International Journal of Production Economics*, Amsterdam, 30-31, 265-272.

[12]Brown, S.L. & Eisenhardt, K.M. (1995) 'Product development: past research, present findings and future directions', *Academy of management review*, 20, 2, 343-378.

[13]Carlsson, M. (1991) 'Aspects of the integration of technical functions for efficiency', *R&D Management*, 21, 1, 55-66.

[14]Clark, K. and Fujimoto, T. (1991) '*Product development performance'*. Boston: Harvard Business School Press.

[15]Cooper, R.G. & Kleinschmidt, E.J. (1987) 'New products: what separates winners from losers?' *Journal of Product Innovation Management*, 4, 169-194.

[16]Cooper, R.G. (1984) 'How new product strategies impact on performance', *Journal of Product Innovation Management*, 1, 1, 5-18.

[17]Cooper, R.G. (1979) 'The dimensions of industrial new product success and failure', *Journal of Marketing*, 43, 3, summer, 93-103.

[18]Daft, R.L. & Weick K.E. (1984) 'Toward a model of organizations as interpretation systems', *Academy of Management Review*, 9, 2, 284-295.

[19]Dean, J.W. & Susman, G.I. (1989) 'Organizing for manufacturable designs', *Harvard Business Review*, Jan-Feb, 28-36.

[20]Dougherty, D. (1990) ‘Understanding new markets for new products’, *Strategic management journal*, 11, 59-78.

[21]Dougherty, D. (*1987) ‘New Products in old organizations: the myth of the better mousetrap in search of the beaten path’*, Unpublished Ph. D. Thesis, Sloan School of Management, MIT, Cambridge, MA.

[22]Eisenhardt, K.M. & Tabrizi, B.N. (1995) ‘Accelerating adaptive processes: product innovation in the global computer industry’, *Administrative Science Quarterly*,.40, 84-110.

[23]Ettlie, J. E. (1995) ‘Product-process Development Integration in Manufacturing’, *Management Science*, 41, 7, 1124-1237.

[24]Ettlie, J. E. & Trygg L. D. (1995) ‘Design-Manufacturing Practice in the US and Sweden’, *IEEE Transactions on Engineering Management*, 42, 1, 74-81.

[25]Fisher, R.J., Maltz, E. & Jaworski, B.J. (1997) ‘Enhancing communication between marketing and engineering: the moderating role of relative functional identification’, *Journal of Marketing*, New York, 61, 3, 54-70.

[26]Ginn, M. E. & Rubenstein, A. H. (1986) ‘The R&D/Production Interface: A Case Study of New Product Commercialization’, *The Journal of Product Innovation Management*, New York, 3, 158-170.

[27]Glaser, E.M., Abelson H.H. & Garrison K.N. (1983) ‘*Putting knowledge to use’*, Jossey-Bass, San Francisco, CA.

[28]Goldhar, J.D., Bragaw, L.K. & Schwartz, J.J. (1976) ‘Information flows, Management styles and technological innovation’, *IEEE Transactions on Engineering Management*, EM-23, 1, 51-62.

[29]Griffin, A. & Hauser, J.R. (1996) ‘Integrating R&D and Marketing: a review and analysis of the literature’, *Journal of Product Innovation Management*, 13, 191-205.

[30]Griffin, A. & Hauser, J.R. (1992) ‘Patterns of communication among marketing engineering and manufacturing – a comparison between two new product teams’, *Management Science*, 38, 3, March, 360-373.

[31]Gupta, A. & Wilemon D. (1990) ‘Accelerating the development of technology-based new products’, *California Management Review*, 32, 2, 24-44.

[32]Gupta, A. K. & Wilemon, D. (1988) ‘The credibility-co-operation connection at the R&D – marketing interface’, *Journal of Product Innovation Management*, 5, 1, 20-35.

[33]Gupta, A. K., Raj, S.P. & Wilemon, D. (1985) ‘The R&D-Marketing Interface in High-Technology Firms’, *The Journal of Product Innovation Management*, New York, 2, 1, March.

[34]Gupta, A. K., Raj, S.P. & Wilemon, D. (1987) ‘Managing the R&D-Marketing Interface’, *Research Management*, Washington, 30, 2, 38-43.

[35]Kahn, K.B. & Mentzer, J.T. (1998) ‘Marketing’s integration with other departments’, *Journal of Business Research*, New York, 42, 1, 53-62.

[36]Katz & Tushman, M.L. (1979) ‘Communication patterns, project performance and task characteristics: an empirical evaluation and integration in an R&D setting’, *Organizational behaviour and human performance*, 23, 139-162.

[37]Kelly, G.A. (1955) ‘*The psychology of Personal Constructs’*, Norton, New York.

[38]Kleinschmidt, E.J. & Cooper, R.G. (1995) ‘The relative importance of new product success determinants – perception versus reality’, *R&D Management*, 25, 3, 281-298.

[39]Kotler, P., Armstrong, G., Saunders, J. and Wong, V. (1999) ‘*Principles of marketing’*, Prentice Hall Europe.

[40]Lapierre, J. & Henault, B. (1996) ‘Bi-directional information transfer: An imperative for network and marketing integration in a Canadian telecommunications firm’, *The Journal of Product Innovation Management*, New York, 13, 2.

[41]Larson, E.W., & Globeli, D.H. (1988) ‘Organizing for Product Development Projects’, *Journal of Product Innovation Management*, 5, 3, 18-90.

[42]Lawrence, P.R. & Lorsch, J.W. (1967) ‘Differentiation and integration in complex organizations’, *Administrative Science Quarterly*, 12, 1-47.

[43]Lee, D.M.S. & Allen, T.J. (1982) ‘Integrating new technical staff: implications for acquiring new technology’, *Management Science,* , 12, 1405-1420.

[44]Lindsley, D.H. Brass, D.J. & Thomas, J.B. (1995) ‘*Academy of Management Review’*, 20, 3, 645-678.

[45]Maidique, M.A. & Zirger, B.J. (1984) ‘A study of success and failure in product innovation: the case of the U.S. electronics industry’, *IEEE Transactions on Engineering Management*, 31, 192-203.

[46]McDonough, E. F. (1984) ‘Needed: an expanded HRM Role to bridge the gap between R&D and Manufacturing’, New York, *Personnel*, 61, 3, 47-53.

[47]McIntosh, J. (1986) ‘Changing relationships at the R&D/production interface’, *International Journal of Operations & Production Management*, 6, 4, 74-86.

[48]Moenaert, R.K. & Souder, W.E. (1990) ‘An information transfer model for integrating marketing and R&D personnel in new product development projects’, *Journal of Product Innovation Management,* 7, 2, 91-107.

[49]Moenaert, R.K. & Souder, W.E. (1996) ‘Context and antecedents of information utility at the R&D/marketing interface’, *Management Science*, Providence, 42, 11, 1592-1610.

[50]Moller, K.K. & Halinen, A. (1999) ‘Business relationships and networks: managerial challenge of network era’, *Industrial Marketing Management*, 28, 5, 413-427.

[51]Nonaka, I. (1991) ‘The knowledge-creating company’, *Harvard Business Review*, 69, 6, 96-104.

[52]Norton, J., Parry Mark, E. & Song, X.M. (February 1994) ‘Integrating R&D and marketing: a comparison of practices in the Japanese and American Chemical Industries’, *IEEE Transactions on Engineering Management*, 41, 1, 5-20.

[53]O’Dwyer, M. & O’Toole, T. (1998) ‘Marketing-R&D Interface contexts in new product development’, *Irish Marketing Review*, Dublin, 11, 1, 59-69.

[54]O’Reilly, C. & Pondy, L. (1979) ‘Organizational communication’, in *Organizational Behaviour,* S. Kerr. (Ed.) Grid, Columbus, Ohio, 119-150.

[55]Pearson, A.W. & Ball, D. (1993) ‘A framework for managing communication at the R&D-Marketing interface’, *Technovation*, Amsterdam, 13, 7, 439-447.

[56]Reger, R.K. (1990) ‘The repertory Grid Technique for Eliciting the Content and Structure of Cognitive Constructive Systems’, in Huff A.S., *mapping strategic thought*, 301-309.

[57]Rosenbloom, R.S. & Wolek, F.W. (1970) ‘*Technology and information transfer’*, Harvard University, Boston, MA.

[58]Rothwell, R. & Robertson, A. (1973) ‘The role of communications in technological innovation’, *Research policy*, 2, 204-225.

[59]Schilling, M.A. & Hill Charles, W.L. (1998) ‘Managing the new product development process: strategic imperatives’, *The Academy of Management Executive*, 12, 3, 67-81.

[60]Shilling, C. & Bernard, J. (1964) '*Informal communication among bio-scientist'*, report 16A, George Washington University, Washington, D.C.
[61]Song, X.M. & Parry, M.E. (1997) 'The determinants of Japanese New Product Success', *Journal of Marketing Research*, 34, 64-76.
[62]Song, X.M. & Parry, M.E. (1993) 'How the Japanese manage the R&D-marketing interface'; *Research Technology Management*, Washington, 36, 4, 32-41.
[63]Song, X.M. & Parry, M.E. (1992) 'The R&D-Marketing Interface in Japanese High-Technology Firms', *The Journal of Product Innovation Management*, New York, 9, 2, 91-112.
[64]Souder, W.E. (1987) *'Managing new product Innovations'*, Lexington, Mass: Lexington Books.
[65]Souder, W.E. (1977) 'Effectiveness of nominal and interacting group decision process for integrating R&D and marketing', *Management Science*, 23, 6, 595-605.
[66]Souder, W.E. & Chakrabarti, A.K.(1978) 'The R&D/Marketing Interface: Results from an Empirical Study of Innovation Projects', *IEEE Transactions on Engineering Management*, New York, , 25, 4, 88-93.
[67]Souder, W.E. (1988) 'Managing Relations Between R&D and Marketing in New Product Development Projects', *The Journal of Product Innovation Management*, New York, 5, 1:6-19.
[68]Stalk, G. & Hout, T.M. (1990) '*competing against time: how time-based competition is reshaping global markets*'. The free Press: New York
[69]Tiger, Li. (1999) 'The impact of the marketing-R&D interface on new product export performance: A Contingency analysis', *Journal of International Marketing*, East Lansing.
[70]Tushman, M.L. & Nadler, D.A. (1978) 'Information processing as an integrating concept in organizational design', *Academy of Management Review*, 3, 613-624.
[71]Twiss, B.C. (1974) '*Managing technological innovation'*. London: Longman.
[72]Vandevelde A. (2001), *The design – manufacturing interface and the role of prototyping with respect to the performance of a new product development project*, Unpublished dissertation, February, University of Ghent.
[73]Vasconcellos, E. (1994) 'Improving the R&D-production interface in industrial companies', *IEEE Transactions on Engineering Management*, New York, 41, 3, 315-321.
[74]Whitney, D.E. (1988) 'Manufacturing by design', *Harvard Business Review*, 83-91.
[75]Wolff, M.F. (1985) 'Bridging the R&D Interface with Manufacturing', *Research Technology Management*, Washington, 28, 1, 9-11.
[76]Xie, J., Song, M. & Stringfellow, A. (1998) 'Inter-functional conflict, conflict resolution styles, and new product success: A four-culture comparison', *Management Science*, Providence, 44, 12, 192-206
[77]Zirger, B.J. & Maidique, M. (1990) 'A model of new product development: An empirical test', *Management Science*, 36, 867-883.
[78]Zou, S. & Myers, M. (1999) 'The R&D, manufacturing and marketing competencies and the firm's global marketing position: An empirical study', *Journal of Global Marketing*, New York, 12, 3, 5-21.

APPENDIX A

Ten most important interaction characteristics (range: 0 to 1)

1. The quality of information exchange between design and manufacturing	0.972
2. The frequency of interaction between design and manufacturing	0.955
3. The quality of information exchange between design and sales	0.953
4. The smoothness of interaction between design and manufacturing	0.944
5. The quality of information exchange between design and marketing	0.887
6. The amount of informal contacts between design and manufacturing	0.871
7. The smoothness of interaction between design and sales	0.866
8. The smoothness of interaction between design and marketing	0.859
9. The quality of information exchange between manufacturing and sales	0.833
10. The amount of informal contacts between design and marketing	0.828

TABLE 1
The five most important dimensions ranked by decreasing n (n > 10)

Dimensions	**N**	**'presence' (0 - 10)**	**N**	**'importance' (0 - 10)**
1) a high degree of completion of the product design when introducing it in production	24	5.7	25	9.5
2) attention to the project from the project start	21	7.1	19	9.5
3) a high product quality	13	9.0	26	9.4
4) smooth marketing – design - manufacturing interactions	10	6.1	10	9.4
5) transparency of the customer specifications	10	7.0	10	9.4

Legend: N: the number of times a dimension has been elicited; 'presence': the degree to which the dimension is present in a project; 'importance': the extent to which a dimension is deemed important to project performance.

TABLE 2A

Rankings of 'importance' means of the integration characteristics (a to e) in descending order

N = 40	*design - manufacturing*	*design - sales*	*design - marketing*	*design - purchase*	*manufacturing. - sales*	*manufacturing. - purchase*	*manufacturing. - mktg.*
importance means	a,c,b,e,d,f	a,b,e,c,f,d	a,b,e,c,f,d	a,b,e,c//d, f	a,b,e,c//d, f	a,b,d,f,c,e	a,e//b,c,d, f
max [0,1]	a: 0.972	a: 0.953	a: 0.887	a: 0.806	a: 0.833	a: 0.818	a: 0.635
min [0,1]	f: 0.769	d: 0.645	d: 0.655	f: 0.467	f: 0.367	e: 0.520	f: 0.320
range [0,1]	0.203	0.308	0.232	0.339	0.466	0.298	0.315

TABLE 2b

Rankings of delta values of the integration characteristics (a to e)

in ascending order

N=24	*design - manufacturing*	*design - sales*	*design - marketing*	*design - purchase*	*manufacturing. - sales*	*manufacturing. - purchase*	*manufacturing. - mktg.*
**) delta	a,f,b,d,c/e	a,d,f,b/e,c	a,b,f,d,c,e	a,b,f/d,c,e	a,b,f,d,e,c	a,f/d,b,c,e	a,b,e,d,c,f
min [-1,+1]	a: -0.127	a: -0.239	a: -0.253	a: -0.072	a: -0.218	a: -0.079	a: -0.293
max [-1,+1]	e: +0.029	c: +0.077	e: -0.028	e: +0.171	c: -0.046	e: +0.236	f: -0.043
range [-1,+1]	0.156	0.316	0.225	0.243	0.264	0.315	0.336

Legend. **a,** the quality of information exchange; **b**, the smoothness of interaction; **c**, the frequency of interaction; **d**, the amount of formal contacts; **e**, the amount of informal contacts; **f**, the strength of structural integration; range, maximum-minimum; **//,** the subsequent integration characteristics in that cell have values lower than 0.5; whereas those before the **'**//' sign correspond with values between 0.5 and 1; **/,** the subsequent integration characteristics in that cell correspond with positive values; whereas those before **'//**' correspond with negative values; purchase, buying department; sales, selling department, marketing, responsible for marketing research, advertising, etc.; note that in some organizations sales is integrated in the marketing department.

The Structure of Table 2a. Consider, for example, the second column concerning the 'design-manufacturing' interface. In order of descending importance, the integration characteristics are a) the quality of information exchange, c) the frequency of interaction, b) the smoothness of interaction, e) the amount of informal contacts, d) the amount of formal contacts, and f) the strength of structural integration. The quality of information exchange (a) is thus perceived to be the most important integration characteristic with respect to the DM interface. Its average rating over all respondents is 0.972. The least important DM characteristic concerns the strength of structural integration (f) with an average rating of 0.769. The other integration characteristics have ratings between the previously mentioned maximum and minimum values.

The Structure of Table 2b. Interpret, for example, the column 'design-manufacturing'.

The most negative delta value is found for a) the quality of information exchange (-0.127). The highest delta value, which corresponds in this case with a positive value, is e) the amount of informal contacts (+0.029). Since only characteristic e follows on the sign '/', characteristic e is the only one corresponding with a positive delta value and, hence, receiving more attention than is deemed necessary.

TABLE 3

Partial correlation analyses between DM interaction and multidimensional project performance

N=37	**Partial correlation**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
DM interaction	Pearson Correlation	0.496**	0.028	0.153	0.428**	0.053	0.131	-0.053
	Sig. (2-tailed)	0.001	0.866	0.351	0.007	0.748	0.429	0.748

Controlled for design-marketing interaction; similar findings are obtained when the missing values are excluded pair-wise instead of list-wise (N is between 47 and 72).

TABLE 4

Correlation analyses between a smooth production start-up and project performance

N=50	**Correlation**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
A smooth production start-up	Pearson Correlation	0.342**	0.565**	-0.100	-0.021	-0.218	-0.179	-0.060
	Sig. (2-tailed)	0.014	0.000	0.486	0.881	0.125	0.210	0.673

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

Top fifteen of the list of dimensions ranked by increasing 'delta' (N > 9) and decreasing 'importance'

dimensions	**N**	**'importance'**	**delta**
1) anticipating manufacturing problems during the development process	24	8.6	-3.9
2) the degree of completion of the product design when introducing it in manufacturing	25	9.5	-3.8
3) adequate tests and up-scaling	19	8.9	-3.8
4) smooth marketing - design - manufacturing interactions	10	9.4	-3.3
5) a clear product definition from the beginning	13	8.6	-3.3
6) a strongly committed project leader	17	8.9	-3.2
7) strong expertise of manufacturing	10	8.4	-2.9
8) openness of the product developers	13	8.9	-2.5
9) adequate knowledge of manufacturing's needs and possibilities in design	18	8.6	-2.5
10) attention to the project (from the project start)	19	9.5	-2.4
11) transparency of the customer specifications	11	9.4	-2.4
12) involvement of manufacturing in the design stage	16	7.9	-2.4
13) clear responsibilities (from the beginning)	26	9.2	-2.3
14) the smoothness of the introduction of the product design in production	32	7.8	-2.3
15) a smooth information exchange between various departments	19	8.7	-2.2

Legend. N, the number of times a dimension has been evaluated; 'presence', the degree to which the dimension is present in a product development project; 'importance', the extent to which a dimension is deemed important to the performance of a project; 'delta', difference between 'presence' and 'importance'.