REDUCING ON-GOING PRODUCT DESIGN DECISION-MAKING BIAS

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Acknowledgment: The authors thank Ad de Jong, Joëlle Vanhamme, Jeroen Schepers and the *JPIM* anonymous reviewers for their very constructive comments on earlier versions of this article. Also, thank you to all employees from the case company for their collaboration. Finally, special thanks to the *JPIM* editor for his suggestions and responsiveness.

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ABSTRACT

The objective of this exploratory study is to add to our understanding of on-going product design decision-making in order to reduce eventual decision-making bias. Six research questions are formulated with the aim to establish *if* and *how* functional membership and informal patterns of communication within an organization influence *whether* and *why* employees are willing to engage in product design modifications.

We selected as a field site for our study, (a) an industrial company that (b) had an internal research and product development operations, (c) and where the employees were located on the same site. A three-step approach within the manufacturing case company was designed: (1) in-depth interviews were carried out with managers and employees, (2) a survey questionnaire was sent out to all employees involved with a specific product that is subject to potential design modifications, and (3) a post hoc group feedback session was organized to further discuss our findings with the management.

First, analysis of the nine in-depth interviews establishes a taxonomy of product design decisions involving four types of criteria; product-related, service-related, market-related, and feasibility-related criteria explain why employees would engage or not in product design modifications. Second, it is demonstrated that functional membership has a significant influence on the concern for these decision-making criteria, as well as on the decision to proceed or not with product design modifications. In other words, functional membership influences whether and why employees are more or less willing to make product design modifications. In this manufacturing company, a global industrial player, the differences in concern appear especially for service- and market-related criteria, and pertain particularly to the R&D and service function. Overall, even though the perceived performance of the specific product under study did not differ significantly among the different departments, it is observed that R&D employees were significantly less in favor of proceeding with product design modifications than other employees were. Third, using UCINET VI software, we provide some explanations for this finding. It is shown that informal patterns of communication (i.e., employee degree centrality) operate a *situational* opportunity to make modifications to an existing product and a *cognitive* opportunity influencing the decision to modify product design following an inverted U-shaped function.

Ultimately, we derive practical guidelines for an ideal product-team composition in order to reduce product design decision-making bias.

INTRODUCTION AND RESEARCH BACKGROUND

Many products, although having gone through an extensive new product development (NPD) process, fail once in the market (Carbonell, Rodriguez, and Munuera, 2004; Cooper, 2001). This was the case for the early generation of Ericsson mobile phones: while often incorporating superior technology, the aesthetic and ergonomic appeal of these phones was not successful (Loudon, 2006). Product design is also essential for manufacturers: it determines a significant part of manufacturing costs (Bloch, 1995). The objective of this study is to add to the understanding of the product design decisions employees make.

NPD is a complex and uncertain process, involving various functional areas exchanging information in order to work their way through several successive stages to bring a product to the market (Song and Montoya-Weiss, 1998). The importance of these stages varies according to the newness of the product (Song and Montoya-Weiss, 1998). This study will focus exclusively on *incremental* design modifications to a product; i.e., modifications made after the first commercialization of a product. These incremental product design decisions are thus *on-going*. They are defined as the willingness of employees to adapt, refine, or enhance the design of a commercialized product (Song and Montoya-Weiss, 1998).

On-going product design decision-making can be relatively obscure (Englund and Graham, 1999). Two exploratory studies recently identified the product design decision-making criteria considered between each of the stages of the NPD process (Carbonell, Escudero, and Munuera, 2004; Zahay, Griffin, and Fredericks, 2004). Prior research demonstrates that the market opportunity and analysis phase is particularly important for incremental product design modifications. The firm is likely to obtain customer and employee feedback on the performance of the commercialized product and the needs and desires of customers (Song and Montoya-Weiss, 1998). In the present article, we first seek to establish which decision-making criteria are considered by manufacturers as they work their way from the market opportunity and analysis stage to the design stage of the NPD process. Second, we contribute to the literature by estimating if and how much concerns for these decision-making criteria differ between (1) the different departments of an organization and (2) employees' position in the company's informal communication network. Social network analysis is used to explore the influence of informal communication networks on product design decisions. Justifying this approach, several researchers have put forward that "*informal contacts often substitutes for formal new product processes*" (e.g., Griffin and Hauser, 1996, p. 205).

The Stages of NPD and Product Design Decision-Making Criteria

While it is difficult to reduce the NPD process to a strict serial diagram, the generic NPD process typically consists of six stages (Song and Montoya-Weiss, 1998) (Figure 1). In the third stage – market opportunities and analysis – product features and attributes, as well as development feasibility, are identified based on market trends, competitor products, and customer needs (Perks, Cooper, and Jones, 2005). The fourth stage of NPD refers to the design, engineering, and building of the desired physical product entity. The term 'design' therefore can refer to both engineering and industrial design which "*seeks to rectify the omissions of engineering; [it is] a conscious attempt to bring form and visual order to engineering hardware where the technology does not of itself provide these features*" (Moody 1984, p. 62). Decision-making between these two stages of NPD are re-examined for three reasons. First, product design is critical for industrial products and determines a large part of manufacturing costs (Bloch, 1995). Second, the extant empirical findings regarding the nature of the decision-making criteria for these NPD stages differ. The study by Carbonell et al. (2004) demonstrates the important role of technical and customer-related decision-making criteria. Technical criteria refer to *"the availability of resources, the leverage of the firm's technical resources, and the project's total cost for a given cycle time"*. Customer-related criteria refer to *"the customer satisfaction, product quality, and market acceptance"* (Carbonell et al., 2004, p. 94). The study by Zahay et al. (2004) highlights customer information, project management information, and technical information and excludes financial aspects as decision-making criteria. The differences in findings may be attributable to the sample size and research settings of the previous studies. Both studies were conceived as exploratory. Carbonell et al. (2004) derived their findings from a sample of 77 Spanish companies, while Zahay et al. (2004) derived theirs from in-depth interviews of 20 NPD practitioners. Third, it is precisely between these two stages of NPD that decision-making criteria least explain the variance of product success in the market (Carbonell et al., 2004). Therefore, to enrich previous findings on decision-making criteria between stages three and four of NPD, it is justified to formulate the following research question:

RQ 1: Which decision-making criteria are considered during on-going product design decisions?

[Insert Figure 1 about here]

The Influence of Functional Membership on Decision-Making

Within the innovation field, differences in employees' personality, profiles, and the nature of the task to perform within R&D and marketing departments have been acknowledged (Griffin and Hauser, 1996). Prior research demonstrates the importance of functional membership, which was found to influence employees' interpretations and strategies for actions regarding environmental issues, as well as their possession of specific types of knowledge (Howard-Grenville, 2006; Ruekert and Walker, 1987). We therefore expect the concern (i.e., perceived importance) for product design decision-making criteria to significantly vary between employees from different departments. The functional experience is influential in shaping belief structures, leading to decision-making differences (Bowman and Daniels, 1995). Product design decisions integrate a complex and diversified set of activities, e.g., responding to customer demands on product aesthetics (color, shape, etc.) as well as product engineering of highly complex components (Bloch, 1995). Also, the mere consequences of on-going product design decisions on projected functional involvement and workload may influence the decision outcome (Silver, 1974). For example, under financial and time constraints, the more the incremental modifications to the product's design, the higher the likelihood that R&D employees will be distracted from the development of advanced/radical science-based projects, which they are known to prefer (Griffin and Hauser, 1996). None of the prior research studies have identified how functional membership influences (a) the concern for product design decision-making criteria and (b) the willingness to proceed with design modifications:

RQ 2(a): To what extent does functional membership influence the concern for decision-making criteria during on-going product design decisions?

RQ 2(b): To what extent does functional membership directly influence on-going product design decisions?

The Influence of Informal Patterns of Communication on Decision-Making

Information acquisition in the market opportunity and analysis stage of NPD and information dissemination can reveal interesting findings on the communication patterns between employees. These patterns are neither explained by NPD theory nor by market orientation, which here is defined as information generation, dissemination, and use (Jaworski and Kohli, 1993). Effectively managed market intelligence from customers and competitors creates value by helping companies develop successful new products (Griffin and Hauser, 1996). Highlighting the importance of communication patterns in managing marketing intelligence, Jaworski and Kohli (1993) note that the use of market intelligence can be improved by "*designing appropriate dissemination processes*" (p. 48).

Previous communication studies have mostly tackled information dissemination between dyads (Moenaert and Souder, 1990) or triads (Ruekert and Walker, 1987; Song, Montoya-Weiss, and Schmidt, 1997) by measuring the frequency of communication using key informants without making further precisions on the communication patterns of the constituent individuals embedded in the company. These studies assume that each department involved in NPD brings a fair contribution to the development of the product. A more holistic approach, using communication network analysis, enables the identification of employees who are more degree central in the communication processes. Degree centrality is defined as "*the number of individuals with whom an actor is directly connected*" (Ronchetto, Hutt, and Reingen, 1989, p. 60). The more an actor is connected, i.e., the more degree central s/he will be, the more information - and therefore power - s/he will have (Powell, Koput, and Smith-Doerr, 1996). Compared to a dyadic relationship, Iacobucci and Hopkins (1992) define a network as *"a composite of a larger number of actors and the pattern of relationships that ties them together"* (p. 5). Rather than focusing on personal attributes, the network approach takes the standpoint that the internal structure of collaboration and information exchanges influences decision-making. Such an approach to communication helps identify informal dominance within the communication network and in the decision-making process. This is in line with the theory of power influence (Pfeffer, 1981), which has also shown its importance in NPD between the marketing and the R&D departments (Atuahene-Gima and Evangelista, 2000). Influence refers to *"the degree to which information offered by participants in the NPD process leads to changes in behaviors, attitudes, and/or actions of the recipient"* (opt. cit., p. 1269). Therefore, the following research question is formulated:

RQ 3: Which employees are relatively more central during product information exchanges?

Individuals embedded in a communication network can learn from others (knowledge absorption), but also create knowledge by teaching others (knowledge creation) (Antonelli, 1997). To unravel knowledge flows, we first establish who the main knowledge creators and absorbers are, and where they are positioned in the informal communication network. Further, it is posited that the degree centrality of actors in the network will have a dual effect on product design decisions. It is expected that the mere proximity to other central actors may influence central actors to be more in favor of product design modifications because they feel more involved and, therefore, concerned with product success (Salancik and Pfeffer, 1978). However, it is also posited that the impact of degree centrality on product design decisions may be mediated by 'experimental learning' or 'knowledge absorption' (Kayes, Kayes, and Yamazaki, 2005). Experimental learning *"focuses on how individuals draw on direct experience with the world to create new knowledge"* (opt. cit., p. 89). Strong ties in a network have been significantly linked to the receipt of useful information (Levin and Cross, 2004). The more interactions with employees in the network (i.e., the higher degree centrality) the higher the experimental learning will be. However, too much experimental learning may negatively affect product design decisions. Indeed, organizing and creating frameworks for understanding knowledge is a necessity to reach experimental learning (Kayes, Kayes, and Yamazaki, 2005) and information overload may complicate the decision-making process and lead to higher product design change resistance (Yen et al., 2006). Therefore, an inverted U-shaped relationship between the level of experimental learning and favorable product design decisions is expected. The three concluding research questions are the following:

RQ 4: Does employee degree centrality during product information exchanges lead to more favorable on-going product design decisions?

RQ 5: Does employee degree centrality during product information exchanges lead to higher experimental learning?

RQ 6: Is there an inverted U-shaped function between the amount of experimental learning and favorable on-going product design decisions?

METHODOLOGY

Communication Network Case Study & Selection of the Field Case

Qualitative methods are appropriate when studying complex phenomena, and when there is a need to take into account numerous variables for studying the issue(s) at hand (Eisenhardt, 1989). One-site sampling was chosen due to the complexity and nature of the research questions (Eisenhardt, 1989): a high response rate is imperative for social network analysis (Tsai and Goshal, 1998). With the help of two professional consultants, we selected as a field site for our study, (a) an industrial company that (b) had an internal research and product development operations, (c) and where the employees were located on the same site. In addressing the research questions, it was mandatory that the field site invested in in-house product development. Moreover, we choose an industrial company as product design modifications occur frequently in such context, as a consequence of customer requests or order specifications (Lee et al., 2004). Providing a competitive offering requires the integration of inputs from different functions (e.g., product development, process engineering, marketing and sales, production, etc.). This was best served by having the respondents located on the same site.

The company that was selected is one of the world's leading suppliers of distribution systems. In 2006, the company reached consolidated net sales and net income of approximately $ 600 million and $20 million respectively. To reach the company's growth objective, management continued investing in R&D. The specific project under study, *'Multisorter'*, is a solution for sorting mixed flows from small to large products. Seven departments are involved in developing, building, selling, and servicing the product: R&D, (operations) engineering, (operations) installation, systems, sales, service delivery, and service development. Clarifying the roles, the role of engineering is to build the product. The service delivery department provides basic services such as maintenance, system updates, and repair. It also offers additional services such as training, logistics management, and audits. The systems department develops the software that monitors and manages the tracking and dispatching of the products.

Research Design

In order to examine the five central research questions of this study, a three-step approach within the manufacturing case company was designed:

- in-depth interviews were carried out with managers and employees (Research Question 1);

- a survey questionnaire was sent out to all employees involved with a specific product that is subject to potential design modifications (Research Questions 2 – 6); and
- a post hoc group feedback session was organized to further discuss our findings with the management.

The heads of the seven departments, as well as employees involved with the *Multisorter* project were interviewed. Interviews lasted between 45 and 60 minutes. The interviewees had been with the company for 10.8 years on average. Interviewees were asked individually to discuss and establish decision-making criteria that would be evaluated during product design decisions. Interviewees comprised of four senior managers (sales, R&D, engineering, and systems), three middle managers (service, service development, and operations installation), and two employees (service and R&D).

The survey questionnaire consisted of three sections. The first section collected personal information such as name, gender, department, formal job rank (five levels), and tenure. Section two inquired about the employees' communication frequencies with colleagues and customers regarding the performance of *Multisorter*. Employees were asked to name the top-three formal decision-makers regarding product design decisions. The distribution of *Multisorter* customers and employees is presented in Table 1. The 46 employees and 8 customers represent the product's complete network. In the third part of the questionnaire, rating scales were used to assess (1) product design decisions, (2) the extent of concern for the decision-making criteria identified during the above-mentioned interviews, and (3) the relative performance of the current product against those of competitors.

[Insert Table 1 about here]

The group feedback session was organized to present our findings to the company. Members of management were invited to discuss the findings with us and their colleagues. This feedback session helped to (1) validate our findings regarding the structure of the communication network, as well as (2) further explain why some departments experienced difficulties in communicating with one another.

The Unit of Analysis and Data Collection

The frequency of information exchanges between actors of the network regarding customer and employee feedback on *Multisorter* is under study. As described above, data was collected via a survey questionnaire distributed via internal mail. After two email reminders and personal telephone calls, a response rate of 92.6% was achieved. Regarding the inclusion of missing employees it was assumed that if 'X' stated that s/he communicated 'x' times with the missing employee 'Y', 'Y' would have stated the same communication frequency 'x' (Borgatti and Molina, 2003). For all other employees, the number of symmetric pairs was 73.87%. Given that the measurement for communication frequency did not include directionality, if employees 'X' and 'Y' stated different frequencies of interactions, both employees were contacted to cross-validate their initial input in order to increase the number of symmetric pairs to 100%.

Measurement Properties

Communication patterns. Employees were asked to indicate how frequently they effectively interact with colleagues and customers about the current performance of *Multisorter*. Also, each employee was asked to rate (out of 10) how comprehensible the information generated during these interactions was, and whether interactions communicated important (useful) detail to them about *Multisorter*'s performance.

Based on these measures, the architecture of the communication patterns and employees regarded as the most knowledgeable are identified. This means that, based on others' reporting, each employee is given a 'knowledge creation score' and, based on his/her own saying, a 'knowledge absorption score'. If the total number of employees spoken to by an employee i is j, and the scores given by the j employees to employee i to establish how much learning happens during their interaction is 'x' Є [1;10], the 'knowledge creation score' of i is calculated as follows: $\sum_{(1 \to j)} x_i$. The 'knowledge absorption score' of employee i is simply the sum of all x’s that employee i allocated to his/her interactions with the j employees of the network s/he communicates with: $\sum_{(i)} x_{1 \to j}$. This score will help us answer RQ5 and RQ6.

To study employee involvement in information sharing we refer to degree centrality (Freeman, 1979), which is used to compare actor centrality within a single network (Ahuja, Galletta, and Carley, 2003). Actor degree centrality calculations were performed using UCINET VI software (Borgatti, Everett, and Freeman, 1999). A social network matrix is a binary matrix with senders on each row and recipients on each column. The presence of a link between two employees is represented by a '1' in that cell given that directionality was not conferred to information exchanges. With frequency of communication measured on a seven-point rating scale, our interviewees were first consulted to determine an appropriate cut-off point to assign a '1' or a '0' on each cell of the matrix. On that basis, a '1' was assigned if the communication frequency was equal or greater than once a month.

Decision makers. Each employee was asked to name the top-three formal decision-makers regarding modifications to the design of *Multisorter*. The reasons for doing so were the following: (1) to identity the functional membership of formal leaders and, thus, a departments’ formal influence in decision-making, and (2) to compare the current composition of the formal leader group against that of a group, which would reduce decision-making bias.

Product design decisions and *decision-making criteria*. The scale measuring product design decisions was based on that of Song and Montoya-Weiss (1998, p. 126). The scale 'product design decisions' (Table A-1 of the Appendix) is reflective and our findings show an alpha reliability coefficient of 0.79 (Cronbach, 1951). Employees were surveyed about hypothetical modifications to an existing product given that post hoc data regarding a product already gone through the product decision-making process could be affected by belief revision (Hogarth and Einhorn 1989). Regarding decision-making criteria, employees were asked to what extent each criterion identified during the in-depth interviews would be a factor of concern in their decision-making regarding product design modifications. Scales anchoring ranged from '1' (No, not of concern) to '5' (Yes, of very much concern). Finally, the relative performance of the current product against those of competitors was assessed. Based on the *Multisorter* catalogue and by cross-validating important product attributes (e.g., flexibility, capacity, reliability, system availability, serviceability, etc.) across department, the extent to which *Multisorter* performs 'much worse' to 'much better' than competing products is evaluated (Table A-1 of the Appendix).

ANALYSIS AND RESULTS

Research Question 1: The Nature of Product Design Decision Criteria

Analysis of the in-depth interviews establishes a taxonomy of product design decisions involving four types of criteria. First, confirming previous findings (Carbonell et al., 2004; Zahay et al. 2004), product acceptance and product-related factors are crucial to product design decisions. Says a senior operations engineering manager: “*Analyzing how the product operates in different sites is essential. For instance, what are the different misallocation rates of the sorter belt? Also, how does the product fit customer logistics?”* The product-related decision criteria we identified through the interviews were similar to Bloch's (1995) dimensions of product form: performance, ergonomics, and aesthetics. Aesthetics refer to "*product appearance […] and appeal to the senses*" (Srinivasan, Lovejoy, and Beach, 1997, p. 155). Ergonomics involve "*the matching of a product to the target users' capabilities to maximize safety, efficiency of use, and comfort*" (Bloch, 1995, p.18).

Second, service acceptance or service-related criteria were also identified as relevant in establishing reasons for adapting, refining, or enhancing product design. Service aspects relate to product serviceability and service reliability. As stated by one service employee: *"Service needs to be easy. It is simply too difficult right now since we do not understand the error messages [...] and it needs to be reliable. That's all our customers are asking for, but we need to reconsider the product's design to improve this [...]. This is a key issue of concern!"* Our findings complement those of Zahay et al. (2004) referring to 'customer needs and wants', which also include service aspects. These views were shared by all departments *a priori* showing no influence of functional membership during the in-depth interviews. In fact, past research found product design to influence both the amount of service support required and the way it can be delivered (Goffin, 2000).

Market-related reasons are also considered to be essential product design decision criteria. Previous studies found significant support for market-related criteria such as 'market share' and 'sales revenues' in the later stages of NPD (Carbonell et al, 2004; Zahay et al., 2004). However, seven of the interviewees contended that these criteria were also evaluated before implementing the fourth phase of NPD. Observes the sales manager: "*We know the product and how it performs in terms of market share. Before we even think of altering it, we think about how these changes will affect market share and sales revenues. I mean, what will be the marginal gain on sales revenues on a five year period?"* The system manager's reflections point in the same direction: "*We sell many products, and the mere fact that we seriously consider a product for re-design means that we have at least established its future sales revenues to some extent."*

Finally, the costs and the ability of design modifications are taken into consideration. The interviewees confirm the importance of feasibility-related aspects. The sales and the R&D manager concur in their assessment: "*The bottom line is also an essential concern*!" The costs of design modifications relate to the ability constraints involved with the change of the product. Previous studies identified the importance of the cost of modifying the product, as well as the company's ability (resources) to do so (Sahay and Riley, 2003).

We validated this four part taxonomy in the quantitative phase of our study. Using factor analysis, varimax rotation method with Kaiser Normalization (Kaiser, 1958), on the full network sample, the number of factors and the loadings of measured indicator variables corroborate the findings from the in-depth interviews (Table 2).

[Insert Table 2 about here]

Research Question 2: Functional Influence on Product Design Decision-Making

To answer *RQ 2(a)* and *RQ 2(b)*, Table 3 presents the descriptive statistics relating to the concern for decision-making criteria and product design decisions. The current relative product performance, as perceived by the company respondents, is 2.92 (σ = .42) measured on the five-point rating scale. Performance was assessed on a broad spectrum of product-related customer benefits (e.g., solution flexibility, capacity, system availability, serviceability, etc). The low relative performance confirmed our ex ante expectations about the setting of the case study. The management perceptions suggest that the *Multisorter* is a product in need of change.

[Insert Table 3 about here]

Given the nature of a network study within a single field site, the number of observations in some subsamples is bound to be limited. Only the service, engineering, and R&D departments have a headcount of at least 10 employees. Non-parametric Mann-Whitney U-tests were performed in order to compare the concern for product design decision-making criteria between these three departments and the rest of the company (Howell, 2002). The perceptions of current product performance did not differ significantly among the groups. The important question then becomes: *do functionally different groups invoke different criteria to support product design modifications?* Again, the readers must be reminded that this concerns a limited sample of respondents in a single field site.

- R&D employees are significantly less in favor of proceeding with product design modifications than other employees are ($Z = -1.835$; $p < 0.05$). In addition, they seem less likely to be motivated to proceed with design modifications because of service-related issues than are employees from the service department ($Z = -1.908$; $p < 0.05$) and engineering ($Z = -1.759$; $p < 0.05$). In fact R&D employees are significantly less concerned with the service-related criterion ($Z = -2.103$; $p < 0.05$) and the market-related criterion ($Z = -1.648$; $p < 0.05$) than are other employees. Service employees, on the other hand, are significantly more concerned with the service-related criterion ($Z = -1.951$; $p < 0.05$) and (borderline) significantly less concerned with the market-related criterion (*Z*= -1.505; $p < 0.10$) than other employees are.

Based on these findings, it is observed that functional membership *does* have an influence on concerns for product design criteria in the decision to proceed with on-going product design. In this manufacturing company, a global industrial player, the differences in concern appear especially for service- and market-related criteria, and pertain particularly to the R&D and service function.

As a final observation, the concern for product design decision-making criteria does not significantly vary with formal job rank. Thus, apart from the functional belonging of employees (‘horizontal’ differentiation), the formal organization had no impact on the concern for product design decision-making criteria (‘vertical’ differentiation).

Research Question 3: Communication Network Degree Centrality

In order to have a holistic understanding of the communication setting, Figure 2 presents the Gower Metric Scaling communication graph. This method plots closely together employees who engage in intense information exchanges, either directly or through other employees (Verspagen and Werker, 2004). The overall communication network density is .13. Since the data is binary, this implies that 13% of all possible ties are represented. There is a great deal of variation between ties given that the standard deviation (.34) is almost three times as high as the density measure. This involves a rather sparse network (Verspagen and Werker, 2004) with substantive inequalities of informal patterns of communication.

[Insert Figure 2 about here]

The average degree centrality of employees is fairly high (μ: 7.07). The standard deviation (σ: 4.90) shows that the population is quite heterogeneous in structural positions during on-going product design decisions. The coefficient of variation in communication patterns shows high heterogeneity: $(\sigma / \mu) * 100 = 69.27$. Our findings demonstrate differences between the degree centrality of engineering and service employees compared to other employees: engineering employees are significantly more central than are other employees (Z= -2.262; $p < 0.05$), while service employees are significantly less central (Z= -1.645; $p < 0.05$).

Individual positional advantages are unequally distributed. The top 10% of central employees consists of an employee and a middle manager from R&D, two middle managers and a technician from engineering, and the general manager from sales. In this company, apparently, the central employees tend to operate in the back-office (n=24), and have a technical background. In fact, based on a clique analysis with a minimum set size of five employees (Bron and Kerbosch, 1973), eight cliques are identified; six of which are solely formed by R&D and engineering employees. This confirms previous findings on the higher frequency of communication behavior within engineering subcultures (Tushman, 1979), as well as the high standard deviation of the overall network density.

Interestingly, there is no significant difference between the frequency of customer communication between the front- and back-offices (Z= -.200; $p > 0.05$). This suggests that, in this manufacturing setting, the front- and back-offices are, in fact, equally important in collecting customer feedback information.

Research Questions 4-6: Knowledge Structures and Product Design Decisions

Presented in Table 4 are the top-six formal decision-makers identified according to the frequency of citation by company network actors in the 'decision makers' question of the questionnaire (Table A-1)[i]. This table regroups individuals identified according to three different grouping criteria: (a) the *formal* decision-making *power* (columns 1 & 2), (b) *knowledge*-derived scores (columns 3 & 4), and (c) degree centrality (column 5). The analysis of the knowledge creation and knowledge absorption measures in Table 4 suggests that a significant amount of knowledge is generated by R&D employees, and absorbed by engineering employees. Four of the top-five knowledge creators – as perceived by the employees - are from R&D. Regarding knowledge absorbers, three are from engineering, one is from R&D, and one is from service. The *most knowledgeable* individuals (columns 3 and 4) are, in fact, *under-represented* in the formal decision-making group (columns 1 and 2). *Those who know most have a limited impact on on-going product design decisions.*

[Insert Table 4 about here]

First, only two employees among the top-five knowledge absorbers and one of the top-five knowledge creators are formal decision-makers in the organization. Second, comparing the six most frequently cited decision-makers to the top-six central employees, it is observed that these groups share only a third of the employees. Observe that the service department is completely absent from the list of most frequently cited decision-makers. However, internally it was viewed was one of the four key business units in the company's annual report. These findings show a strong discrepancy between the service division's actual influence and its assumed network position. Within the customer contact front office, the service division is important as a network link, but not as a decision-making authority.

Influences of Degree Centrality and Experimental Learning on Product Design Decisions (*RQ 4 to 6)*

In assessing the relationship between network centrality, learning and product design decisions, Partial Least Squares was used to estimate the structural equation model (PLS-Graph Version 3.0; Chin, 2001). To ensure that our sample size was adequate for the analysis, a power test was conducted, as proposed by Cohen (1988), for the *F*-test, relating R^2 for the endogenous constructs. Assuming a large effect size ($f^2 = 0.35$; $R^2 = 0.26$) for three predictors, a significance level (α) of 0.05, and a desired power ($1 - \beta$) of 0.80 for our analysis requires a sample size of 35. This figure is within the bounds of the sample size obtained for the network analysis. Figure 3 displays that:

- On-going product design decisions are a linear function of the degree centrality (*ß* = .359, $p < 0.10$, $R^2 = 0.79$) (*RQ 4*) and an inverted U-shaped function of the amount of knowledge absorbed about current product performance (*ß* of the quadratic term = .482, $p < 0.05$, $R^2 = 0.79$) (*RQ 6*);
- Learning is a function of degree centrality (*ß* = .637, $p < 0.05$, $R^2 = 0.41$) (*RQ 5*).

[Insert Figure 3 about here]

Our data demonstrate face validity. Other studies have proven the impact of centrality on learning (e.g., Levin and Cross, 2004). Also, the frequency of customer contact is significantly associated with the amount of learning, thereby confirming the value of customer information for organizational learning (e.g., Maltz and Kohli, 1996).

Second, our findings confirm the dual impact of degree centrality: a *situational opportunity* to make modifications to the existing product and a *cognitive opportunity* influencing the decision to modify product design following an inverted U-shaped function. According to the calculation of this function's optimum, the optimum *Z*-

score for the amount of knowledge is 0.18. This means that ($X_{optimal}$ – 86.32) / 47.89 = 0.18, where 86.32 and 47.89 are the mean and standard deviation of original scores for knowledge absorption respectively. Thus, employees most inclined to make modifications to the existing product are those with total 'quantities' of knowledge absorption equal to $X_{optimal}$ = 95 (where values range between 23 and 272). If employees learn to their fullest during each individual interaction (10/10), they will be most favorable to product design decisions if they interact with nine actors in the network. If they learn at the fullest with more actors, information overload seems to affect the willingness to alter the design of the existing product.

Where does that leave the formal organization? Again, only functional differentiation was important. Job rank does not have a significant effect on on-going product design decisions. Counter to popular belief, the level one occupies in the organization does not significantly influence the inclination to engage for a different course in product development.

DISCUSSION AND MANAGERIAL IMPLICATIONS

The Impact of Functional Membership on Decision-Making

Functional membership with service, sales, or R&D sub-cultures can be distinguished within most organizations (Bloor and Dawson, 1994). A professional sub-culture grows out of the characteristics and skills of the people in the profession. Broadly speaking, Sirmon and Lane (2004, p. 311) state that a professional culture *"exists when a group of people employed in a functionally similar occupation share a set of norms, values, and beliefs related to that occupation.*"

Our findings in this exploratory study demonstrate that functional membership significantly bias the concern for product design decision-making criteria, especially for service- and market-related concerns. As such, this would be less of a problem if each organization would involve at least one individual from each functional area in product design decision-making. However, in a formal or informal manner, some departments achieve a dominant position in the communication network. This dominance engenders, or is engendered by, a specific corporate culture, which is defined as "*the personality of the organization that is comprised of assumptions, values, norms, and tangible signs of organizational members and their behaviors*" (Schein, 2004, p. 6).

In our field site, some departments (i.e., engineering, R&D, and systems) were formally more dominant than others (columns 1 – 2 in Table 4). Informally, engineering is in a dominant position (column 5 in Table 4). Due to the frequent communications between engineering and R&D, these departments establish *de facto* the dominant values, norms, and practices of this manufacturing organization. It is essential for every organization to identify where the formal and informal powers reside.

R&D employees are significantly less in favor of modifying the existing product than is the rest of the company. This could be explained by the fact that R&D employees may perceive the current product as 'perfect' regardless of what the customer wants (Shaw and Shaw, 1998). However, our findings suggest a second explanation. R&D employees are (1) not significantly more central than other employees and, at the same time, (2) still reach high levels of knowledge absorption due to the nature of their relationship with the engineering department. Both these factors could explain R&D's significantly lower willingness to modify the current product's design.

Integrating Sales and Service Employees in Product Design Decisions

Bridging the gap between engineering profiles and business profiles is critical for organizations (Johnston, 1989). We do not suggest complicating the decision-making process. It is likely that engineering and R&D departments will be central in the majority of manufacturing companies due to the nature of their core activities. However, our findings demonstrate the importance of acknowledging and understanding the consequences for decision-making processes. Prior to this study, the company we studied perceived the front-office as being well integrated in its internal communication and product decision-making. Yet, our results demonstrated that sales and service are under-represented in the formal and informal decision-making process. This is a key finding given that the R&D department appeared significantly less concerned with service- and market-related issues.

During the feedback session, it became apparent that several members of this organization were not satisfied with the timeliness and the jargon at the sales/R&D interface. Jargon has been identified as a barrier to communication (Griffin and Hauser, 1996). This was clearly the case regarding the *Multisorter* project: "*Our people need to understand fully what they are selling and I must admit that it is not always the case for Multisorter. It is a complex product and some sales people do not understand all the technicalities because they are not clearly communicated to us by R&D"* (General manager, Sales). Challenged with this information during the group feedback session, the R&D top manager pointed out the second communication barrier between R&D and sales: "*We always send you documents regarding the products. We send them to you and we are ready to explain them to you but you never have time when we offer to help. Then, a few weeks later, you ask for them again, and again, and again"*. These frank observations suggest a disparity between R&D's and sales' time-orientations or an understaffing of sales people in a technical company. Regarding time orientation, R&D has a long-term horizon (Griffin and Hauser, 1996), while sales requires on-time information when they are in the process of selling a product. This in turn is problematic for manufacturers given that sales people need to make sure that the sold product fits customers' logistics since this will affect product installation and serviceability. Also, sales people can be a valuable source of information regarding customer needs and wants for R&D engineers. Both parties can benefit from each other. Therefore, manufacturing companies are advised to shed light on the R&D/sales communication patterns; especially for manufacturers of complex products. To effectively manage R&D/sales relationships, manufacturers must create an atmosphere for communication. This is rarely accomplished by means of a quick fix (Patterson et al., 2005); interfunctional socialization efforts may provide an organizational method to accomplish this. It fosters goal congruence and process transparency across functionally different subgroups in the innovation process (Harris and Mossholder, 1996). Practically, simply making sure that product information is accessible online for the sales department is already an easy way to reduce timeliness problems.

Several authors have highlighted the importance of service inputs for the organization (e.g., Voss et al., 2004). Past research found product design to influence both the amount of service support required and the way it can be delivered (Goffin, 2000). Our empirical results reinforce the role service employees should play in manufacturing companies. Optimizing pre- and post-sales service integration does not only require gathering customer information, but also disseminating and using it (Maltz and Kohli, 1996). Therefore, manufacturers should make sure to include a service employee in product design decision-making teams. His/her role should be to share customer information with the rest of the decision-making team, and ensure that back-office decision-makers - especially those from R&D - do not underestimate the importance of the service-related criterion. Our study shows, however, that, at the departmental level, engineering employees had more frequent customer contact than service employees. This could be due to the complexity of the product under study. However, overall, there is no difference in the frequency of customer contact between the front- and the back-offices. These findings show that the front- and back-offices are equally important regarding the possession of customer information.

Third, it is important to establish, within each department, single points of contacts which should manage the information shared with other departments. Each department should have a gatekeeper (Tichy et al., 1979) for product development communication. A gatekeeper is an individual "*who links the social unit with external domains*" (Opt. cit., p. 508). This reduces the professional culture bias and the information overload because gatekeepers collect and manage information that can be shared intelligently with other sub-units.

Experimental Learning: Impact on On-going Product Design Decisions

Our results demonstrate that the relationship between the amount of experimental learning and the decision to modify the existing product follows an inverted U-shaped function. There are two reasons for that. First, too large an amount of learning regarding problems with a product could lead to the perception that radical design modifications instead of incremental design modifications are needed. This engendered much resistance within the R&D department: *"We are not completely changing this product. Before finding all sorts of faults people should read the manuals.*" Second, information overload will reduce on-going product design decisions. Information overload is the state of an individual (or a system) in which not all communication inputs can be processed and utilized, leading to breakdown (Rogers and Agarwala-Rogers, 1975). Information overload is due to the fact that (a) too many messages are delivered and it appears impossible to respond to them adequately; or (b) incoming messages are not sufficiently organized to be easily recognized (Jones et al., 2004). In this study, it is shown that communicating with nine *very knowledgeable* people in the network leads to the highest inclination to support product design modifications.

The fact that our findings do not allow us to identify which of the individuals, or groups of individuals, are right or not regarding *Multisorter* must be acknowledged. Indeed, more central employees are more in favor of product modifications; *rightly so*? R&D is less concerned with service-related product design decision criteria; *rightly so*? When passing a threshold for the quantity of knowledge, employees become less willing to modify product design; *rightly so*? These questions cannot be answered since we are studying a hypothetical modification to an existing product and do not know how *Multisorter* would perform on the market if altered. At this stage, however, our findings can help manufacturers calibrate decision-making teams.

How to Assign Decision-Makers for On-going Product Design?

First, rather than managers and employees, experts and non-experts must be present in decision-making teams. Second, team members should originate from different departments. Past research advocates that teams with members of similar profiles may facilitate knowledge transfer, simplify coordination, and avoid potential conflicts (Borgatti and Foster, 2003). On the other hand, limiting communication between dissimilar others prevents a group from reaping the benefits of diversity (Borgatti and

Foster, 2003). Based on our results, it is shown that team member similarity can lead to decision bias. Finally, there should be team members from both the front- and back-offices. This finding is derived from the social network analysis, which demonstrates that the front-office was given significantly less importance than the back-office in the communication network although the front-office communicated as intensively with the customer. In Table 5 product-team composition guidelines are proposed to reduce potential product design decision-making bias. The current formal decision-making team (Table 4, Column 1) did not fulfill criteria 1, 3, or 4 and partially fulfilled criterion 2.

[Insert Table 5 about here]

RESEARCH LIMITATIONS AND FURTHER RESEARCH

As in most research, this study has certain limitations that affect the generalizability of the results, while at the same time suggesting directions for further research. The first limitation pertains to the study of product design decision criteria in-between two stages of NPD. Only two exploratory studies have examined this issue, and the relevance of these decision criteria therefore needed to be re-examined for the purposes of our study. Without altering the relevance of our findings, one should, however, acknowledge that other manufacturing companies may have additional product design decision-making concerns.

Second, our study was conducted within a network of 54 actors, and differences in concerns for product design decision-making criteria and also the decision outcome were established based on rather small groups of employees. Eventual differences could not be tested for other, smaller departments such as installation, systems, and sales. Despite this, given that significant results between rather small groups are observed, we foresee that effects should remain for larger departments, especially because employees from similar departments were quite consistent in their answers.

Third, this study was carried out for a single project in one manufacturing firm. However, individuals' informal patterns of communication and decision-making may depend on the nature and complexity of the product under study (Adler, 1995) and the context a company is operating in. Therefore, a replication of this study could establish external validity of our findings across contingencies.

Finally, the validity of the research could be strengthened by triangulation. Even if many documents on the performance of the *Multisorter* were consulted in order to establish its current performance, documents in order to verify whether, in the past, product design decisions had differed between different departments could have been gathered through archival research efforts. For instance, these documents could have been functional reports on product performance and suggestions for product design improvements. Common method variance, which may have inflated some of the relationships, is considered a limitation of this research (Lindell and Whitney, 2001)

With regards to further research, first, it is expected that functional membership and informal patterns of communication will influence product design decisions between other stages of NPD. We suggest that research should study patterns of communication in order to unravel informal influences during the idea development stage. Indeed, it may be that degree centrality hinders the potential to generate innovative product ideas (Hansen, 1999). Therefore, the influence of the situational advantage on on-going product design decisions could, in fact, be different in nature on decision outcomes in this stage of NPD.

Second, research should evaluate the relative dominance of functional employees for different types of products. Our study tackles the communication network of an industrial product that is relatively complex. This may partly explain why service employees were significantly less central than operations engineers in the informal communication network. Replications of our study for different types of incremental product modification projects will bring more insights in how central service employees are in other settings.

Finally, our findings suggest the necessity to study the R&D/sales interface more in-depth. Establishing how manufacturing firms can better manage this interface is essential given that selling a complex product, which does not fully fit customer logistics, may lead to important problems during product installation, service reliability and overall quality.

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Figure 1: Social Network Analysis between the Third and Fourth Stage of NPD

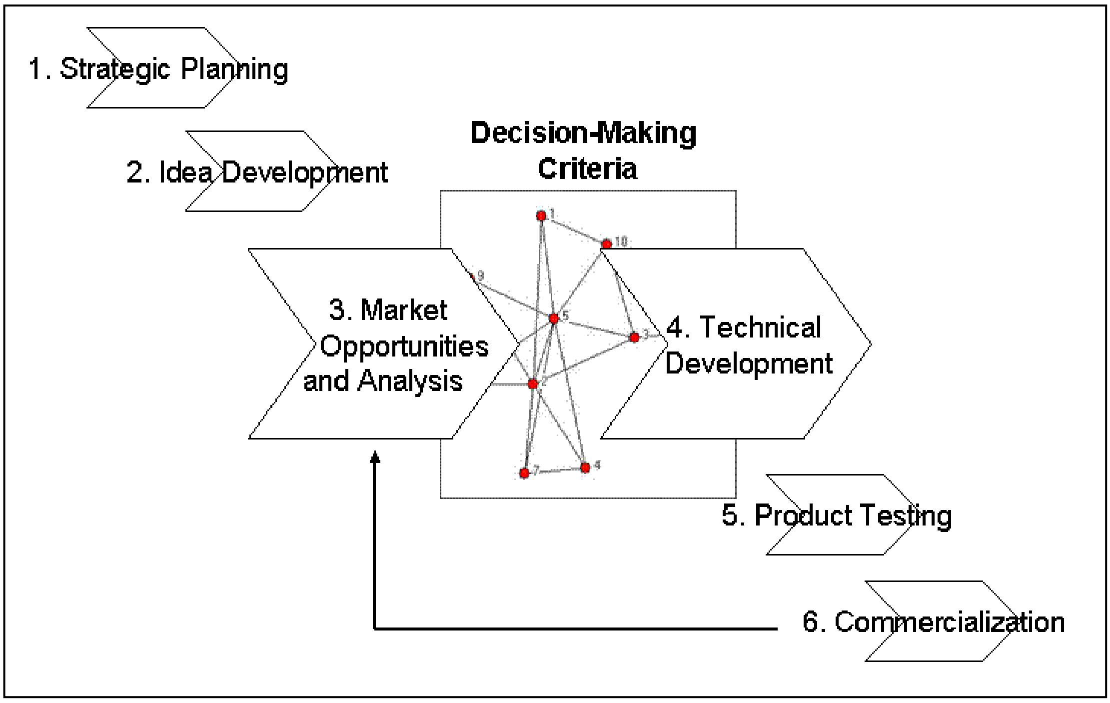
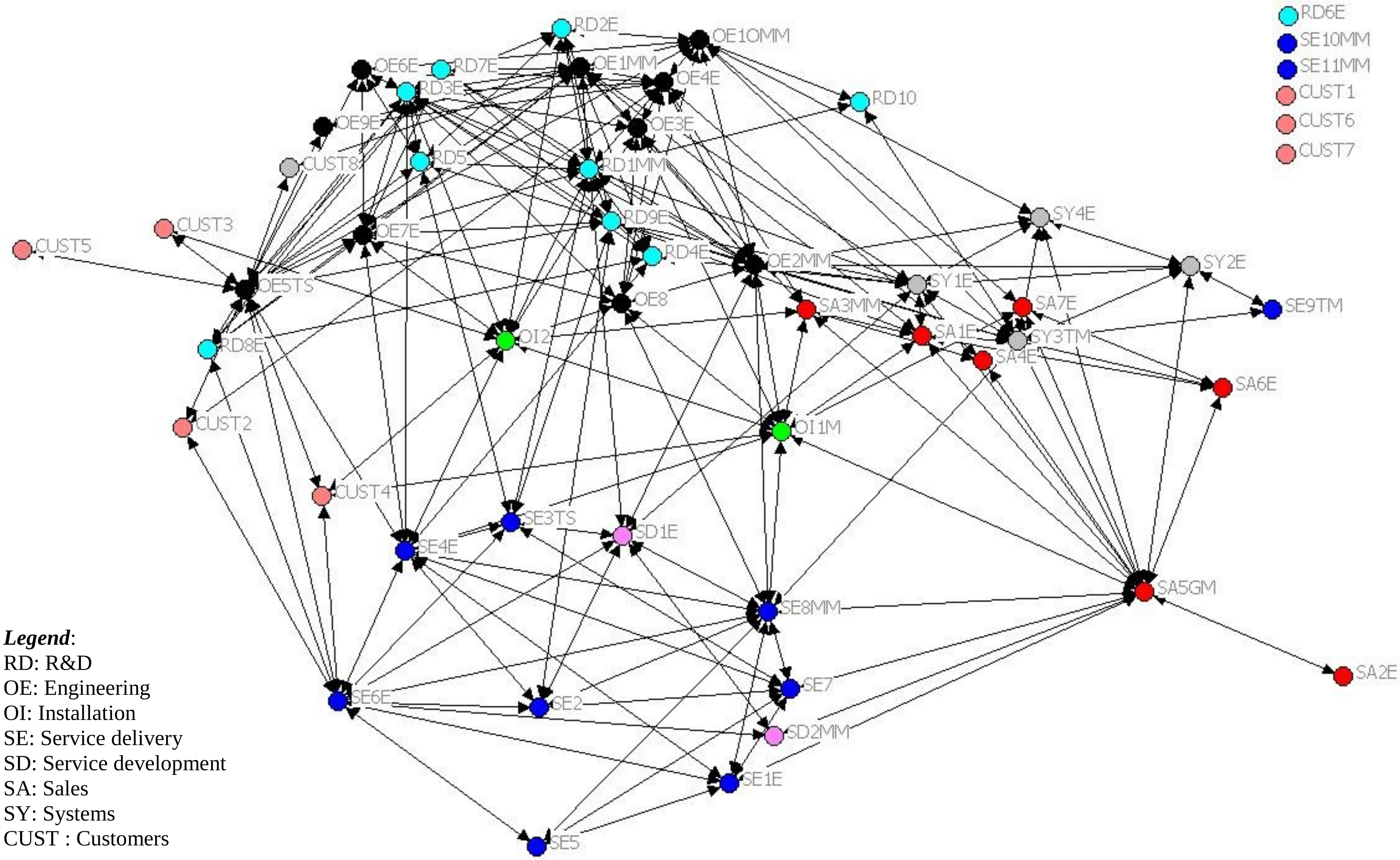
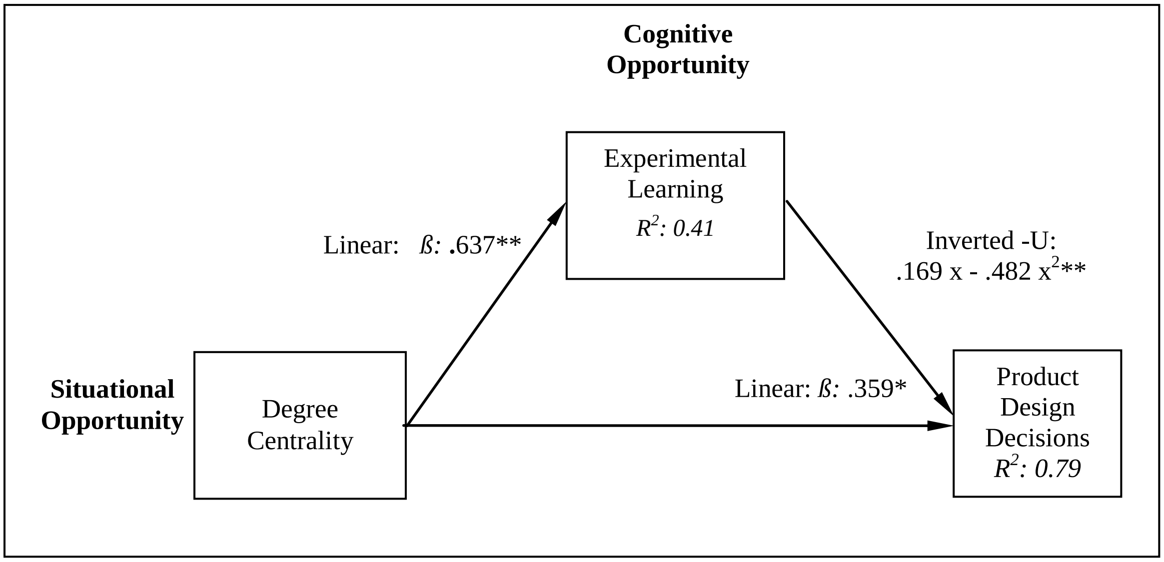


Figure 2: Social Network Analysis of Informal Patterns of Communication Regarding *Multisorter*



Legend:
RD: R&D
OE: Engineering
OI: Installation
SE: Service delivery
SD: Service development
SA: Sales
SY: Systems
CUST : Customers

Figure 3: The Influences of Degree Centrality on Product Design Decisions



* $p < 0.1$.
** $p < 0.05$

Table 1: Sample of Interviewees Involved with *Multisorter*

Customers & Departments	Frequency	Percentage
Customers	8	14.8
Systems	4	7.4
Engineering	10	18.5
Installation	2	3.7
R&D	10	18.5
Sales	7	13
Service delivery	11	20.4
Service development	2	3.7
Total	**54**	**100**

Table 2: Factor Analysis of Decision-Making Criteria

	Decision-Making Criteria			
	Feasibility	*Service*	*Market*	*Product*
Sales revenues	-.011	.191	**.675**	.350
Market share	-.121	.171	**.966**	.145
Product serviceability	-.159	**.922**	.170	.101
Service reliability	-.238	**.760**	.106	.045
Product performance/capacity	.116	.346	.004	**.930**
Product aesthetics	-.124	-.059	.288	**.556**
Product ergonomics	-.110	-.039	.324	**.581**
Cost of change for the company	**.786**	-.276	-.154	-.031
Difficulty/resources of change for the company	**.987**	-.135	-.004	-.076

Table 3: Descriptive Statistics for Decision-Making Criteria Concerns, Current Product Performance (CPP), and On-going Product Design Decisions (PDD) across Functions

Department	Product	Service	Market	Feasibility*	CPP	PDD
Sales	1.73 (.43)	3.60 (.89)	3.50 (.77)	2.50 (1.05)	3.15 (.77)	3.90 (.62)
Service	2.17 (.96)	4.06 (1.18)	2.21 (1.15)	2.00 (.83)	2.71 (.34)	3.98 (.51)
Service Dvlp	1.33 (.00)	**4.75** (.35)	3.25 (1.06)	2.25 (1.77)	3.00 (.00)	3.71 (.40)
R&D	2.00 (.64)	2.69 (1.46)	2.29 (1.11)	2.11 (.65)	3.05 (.19)	3.21 (.82)
Installation	1.67 (---)	4.00 (---)	3.00 (---)	2.50 (.71)	3.10 (.14)	4.21 (.30)
Systems	**2.33** (.33)	3.37 (1.38)	**4.00** (1.15)	**1.88** (.85)	2.68 (.22)	4.11 (.32)
Engineering	2.30 (1.25)	3.80 (1.00)	3.35 (1.60)	2.15 (.94)	2.78 (.32)	3.97 (.61)
Average	*2.06 (.87)*	*3.62 (1.22)*	*3.01 (1.30)*	*2.15 (.85)*	*2.92 (.42)*	*3.87 (.53)*

* Regarding feasibility, the lower the concern the better.

Table 4: Willingness to Proceed with Product Modifications According to Three Different Grouping Criteria*

Formal based (5)	**Formal weighted (5)+**	**Knowledge absorber (5)**	**Knowledge creator (5)**	**Centrality based (6)**
RD10	RD10	OE10MM	RD1MM	RD3E
OE2MM	OE2MM	OE5E	RD3E	OE5TS
SY3TM	SY3TM	OE3E	RD9E	RD1MM
RD1MM	RD1MM	RD1MM	RD5	OE2MM
OE8E	OE8E	SE6E	SE3TS	OE1MM
OE10MM	OE10MM			SA5GM
------------	------------	------------	------------	------------
4.23 (.39)	4.28	4.06 (.54)	3.43 (.48)	4.14 (.59)
Range: *3.71 – 4.71*	Range: *3.71 – 4.71*	Range: *3.71 – 5.00*	Range: *2.86 – 4.00*	Range: *3.57 – 5.00*

* The first two letters stand for the department: RD: R&D; OE: Operations Engineering; SA: Sales; SY: Systems; and SE: Service delivery. The two final letters informs whether the individual is an employee (E), a technician (TS), a middle manager (MM), a senior manager (TM), or the general maneger (GM). An absence of letter is due to a missing value. However, the post-hoc group feedback enabled us to identify RD10 as a senior manager, and RD5 as a middle manager.

+ In order to calculate the weighted effect, we multiplied the product design decisions of each formal decision-maker by the frequency of citation by other employees in the network.

Table 5: Ideal Product-Team Composition

Product-Team Composition Guidelines	**Reasons**
1. Experts & non-experts *rather than* employees & managers	Effects of learning quantity *rather than* functional job rank (lack of) influence
2. Different functional areas	Centrality, functional membership influence
3. Front- and back-office personnel	Centrality, functional membership influence, frequency of customer communication
4. Keeping track of team members' communications	Inverted-U effects on product design decisions

APPENDIX

Table A-1: Measurement Instruments

COMMUNICATION PATTERNS (Internal)

Please indicate how frequently you **interact about work-related matters** with the following colleagues about the *MULTISORTER* product / solution.

Please also indicate in the last column on a scale from 1 to 10 how much you learn about *MULTISORTER* 's performance by interacting with each of the colleagues. This score indicates: how clear the information is and whether it communicates important details to you.

The first three lines are presented as an example. If you do not interact effectively with a person, do not fill out anything on that line (just as exemplified in line 2).

	List of Colleagues	*Less than once a year*	*1-3 times a year*	*4-6 times a year*	*1-3 times a month*	*1-3 times a week*	*4-5 times a week*	*Several times a day*	*How much do you learn?*
1	Name 1		X						8
2	Name 2								
3	Name 3				X				4

COMMUNICATION PATTERNS (With customers)

Customers	*Never*	*Less than once a year*	*1-3 times a year*	*4-6 times a year*	*1-3 times a month*	*1-3 times a week*	*4-5 times a week*	*Several times a day*
[NAME OF CUSTOMERS]								

DECISION-MAKERS

Please name the three most important (formal) decision-makers when it comes down to deciding whether [Name of the Firm] is going to alter *MULTISORTER*? Of course, one of the three persons could be you. Please fill in your name if it is the case.

PRODUCT DESIGN DECISIONS

Please state to what extent you agree with the following statements that refer to the current *MULTISORTER*::

I think that:	*Completely Disagree*				*Completely Agree*
Enhancing *MULTISORTER* 's design would be good.	1	2	3	4	5
Making some changes to *MULTISORTER* 's engineering could be beneficial.	1	2	3	4	5
Adapting *MULTISORTER* could lead to some improvements to the products.	1	2	3	4	5
Adapting *MULTISORTER* could lead to some improvements to the process.	1	2	3	4	5
Refining some aspects/elements of	1	2	3	4	5

MULTISORTER would be advisable.					
Refining the product and process is something we should consider for *MULTISORTER*	1	2	3	4	5
MULTISORTER is perfect as it is; no changes could improve it.	1	2	3	4	5

DECISION-MAKING CRITERIA

If you have indicated above that you would like to see some changes (adaptations, refinements, or enhancements) to *MULTISORTER*, note your support for the following concerns/reasons:

	No, not of concern		*Somewhat a concern*		*Of very much concern*
Sales revenues	1	2	3	4	5
Market share	1	2	3	4	5
Product serviceability	1	2	3	4	5
Service reliability	1	2	3	4	5
Product performance/capacity	1	2	3	4	5
Product aesthetics for customers (shape, size, frame, side covers, weight, etc.)	1	2	3	4	5
Product ergonomics for customers (installation & ease of use)	1	2	3	4	5
Cost of change for the company	1	2	3	4	5
Difficulty/resources of change for the company	1	2	3	4	5

RELATIVE PRODUCT PERFORMANCE

In comparison to the best competing products on the market, how does *MULTISORTER* perform on the following dimensions?

	Much worse	*Worse*	*Identically*	*Better*	*Much better*
Solution flexibility	1	2	3	4	5
Material handling quality	1	2	3	4	5
Capacity	1	2	3	4	5
Conveyability	1	2	3	4	5
Information Interface (visualization)	1	2	3	4	5
Reliability	1	2	3	4	5
System availability	1	2	3	4	5
Operating costs	1	2	3	4	5
Design flexibility	1	2	3	4	5
Serviceability	1	2	3	4	5

[i] Note that 6 employees are identified according to their degree centrality and formal decision-making power due to, respectively, ex aequo degree centrality scores and frequency of citation by members of the communication network.