A reference model to promote performance development by focusing on capability improvement

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Abstract: Business process capability can be understood as the ability of the process to maintain its repeatability in different instances. While maturity models determine the evolutionary improvement of a business process as a whole and are usually known as staged models, the concept of capability implies analyzing the process to define areas that can become the object of local improvement actions. This concept is more appropriate to the implementation of continuous improvement, and from the business point of view, it is a powerful concept since process improvement can be aligned with opportunities for improvement determined by the market in which the company acts. A new product development (NPD) reference model was designed whereby improvement actions are based on process areas and their levels of capability. The application of this model enabled us to realize that reference models can promote performance development by focusing on activities which increase process areas capabilities.

Keywords: product development, process capability, improvements.

1. Introduction

New product development (NPD) is a business process that is, to a large extent, responsible for customer satisfaction. It is one of the most important business competences. Because NPD is a business process, its activities transcend departmental barriers, taking place throughout a value chain ranging from requirements to production specifications. Discussions on product development are found in engineering, operations management, business and marketing literature. Several reference models exist for managing NPD. These models are structured maps to guide the NPD process through functions, helping to remind people of the company's business orientation.

The capability maturity model integration (CMMI), which is based on a process improvement approach, is one of the most important reference models built to guide NPD. This model, which looks into product development as a process composed of process areas, is based on the capability maturity model (CMM), the main standardized process for software development. In CMMI, software and systems engineering are harmoniously integrated.

The product development process can be improved in CMMI if the process areas involved are managed in a continuous or staged form. This evolution can be monitored by analyzing the capability or the maturity of NPD process areas. Despite this, authors who advocate models like CMMI have not presented data by which a clear relation between the improvements based on their models and increases in process area capabilities is proven. Does improved capability enhance the performance of product development? Is a more capable NPD better than another less capable one?

This paper presents a research involving measurements of performance indices after improvements of NPD capabilities based on a reference model. The reference model application took place over a 2-year period during which the researcher was engaged in action research involving all the people associated with product development in a company that designs mechatronic products. After the model application, the NPD performance was evaluated and some factors were found to have improved in comparison to the previous situation. The measurements were based on interviews and express the interviewees' perceptions of improvement, since the company does not have a structured system for measuring performance indices. The interviewees were product design engineers, functional managers and assembly workers. The questions followed a general closed format, but open-ended ones helped to clarify why some indicators were perceived to be better than others.

This paper summarizes the reference model, presents the company, briefly explains the model's applications, and discusses performance results and the capability driver profile.

2. Product development and process areas

The majority of product development reference models are based on a stage-gate type representation, as described in the works of Pahl and Beitz (1996), Pugh (1990), Wheelwright and Clark (1992), Clark and Fujimoto (1991), Ulrich and Eppinger (1995), Nonaka and Takeuschi (1995), Cooper (1993), and Creveling et al. (2003). These representations insert decision points and sets of operational activities. Cooper et al. (1998) has demonstrated how gates should be employed to ensure that the product developed in the various stages meets the company's business objectives.

CMMI (capability maturity model integration), a reference model that differs from the stage-gate models, evolved from the CMM (capability and maturity model) proposed by the Software Engineering Institute (SEI) to evaluate the ability of a software firm to develop information systems. CMM was initially adopted by the US Department of Defense (DoD) to manage its software suppliers, and its use was later massified in different industrial sectors.

Chrissis et al. (2006) presents CMMI as a proposal to integrate software and hardware development through a model that "...emphasizes both, systems engineering and software engineering, as well as the integration necessary for designing and maintaining the product".

CMMI, according to the authors, consists of best practices organized in process areas that address the development and maintenance of products and services covering the product life cycle from conception to delivery and maintenance. A process area can be understood as "...a cluster of related best practices in an area that, when implemented collectively, satisfies a set of goals considered important for achieving significant improvement in that area".

As CMMI suggests, the NPD process areas are not specifically delimited by new product development boundaries. This framework's goal is to map and to redefine some NPD activities to allow an integrated approach for business process improvement. As a consequence, into the CMMI framework, activities related to the design-build-test cycle are less detailed than in other reference models as in Pahl and Beitz (1996) or Creveling et al. (2003). Besides, activities related to the organizational background considered as success factors for a high performance NPD are better described than by the others.

CMMI process areas sum up 25 processes. As the company analyzes was a small one, the CMMI approach was used as guidance for process improvement, but not for process mapping. Moreover, in CMMI, instead of a phased structure, the NPD was presented as a structure of process areas. However, at no point do Chrissis et al. (2006) discuss the differences between these two ways of understanding the NPD and this imposes difficulties to understand how CMMI approach can be fitted to stage-gate processes.

As the authors would like to use the concept of phases to recognize and communicate the limitations of NPD in an approached company, this lack was dealt with by using another important NPD reference model. Analyzing the IEEE 1220:1998 standard described on INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (1998), a framework for representing the concept of systems engineering in complex products design, some complementarities between phased structures and process areas were revealed. According to this standard, systems engineering must be implemented along a system life cycle (Figure 1).

As presented in the figure, a system has a life cycle beginning in its primary definition, being divided into subsystems and components and ending in production and after sales activities. In all of these phases, the systems engineering process must be followed to attend customer specifications.

The process presented in Institute of Electrical and Electronics Engineers (1998) means each NPD phase might be carried out throughout a process in which specific phase requirements are identified, their relations are clarified using a functional analysis approach and a systematic verification are performed. However, for each NPD phase, the proposal prescribes the same set of activities identified as part of the systems engineering. It was just possible in a narrow NPD viewpoint in which no marketing, logistics or manufacturing activities are focused on, but only engineering. A whole NPD framework must present process areas along its phases, but not involving the same set of activities, because it differs in function from the maturity of the solutions developed in engineering, marketing and manufacturing.

3. Improvement in new product development

In Clark and Fujimoto (1991) the automotive industry of the 80s is analyzed. It was the first major study of NPD focusing on performance indicators. These authors treated "…NPD performance as a reflection of the company's long-

Sistems definition	Subsistem definition			Production / Service
	Preliminar design	Detail design	Manufacture assembly integration and test	

Figure 1. A common system life cycle. (Reference: IEEE 1220, 1998, p. 18).

term capacities". Total product quality (TPQ), lead-time and productivity were the NPD performance indicators used by the authors.

In Cooper et al. (1998) there is an entire argument about the connection needed between gates and portfolio reviews based on the use of performance indicators, whose three basic functions are: 1) to verify the alignment between the company's strategy and the results of the design of each product; 2) to check the portfolio's balance; and 3) to ascertain the maximization of the portfolio's value. To this end, the author suggests a set of non-financial indicators such as probability of commercial success, probability of technical success, adaptation to sales channels, and adaptation of the product to the company's development capacity.

Although the authors criticize the indiscriminate use and simplification of portfolio analysis based on the use of individual financial indicators, they advocate the use of the net present value (NPV), the internal return rate (IRR) and, especially, the expected commercial value (ECV) as financial measures to be used in each project of the company's NPD portfolio.

Within the reference established by Chrissis et al. (2006), NPD performance indicators can be "basic" or "derived". The basic measures are obtained directly from management data, while derived measures are combinations of the former. The main basic measures include: number of document pages, number of working-hours, number of defects, and design lead-time. The derived measures include the added value (AV), schedule performance index (SPI), average time between failures, percentage of high-severity defects, etc. Generally speaking, CMMI requires the use of the concept of process capability to analyze the results of each indicator. In short, the indicators must be planned based on predefined goals; and the higher process capability, the lower the standard deviation of the measure in relation to the goal.

Some studies try to understand NPD drivers in relation to new product success. Table 1 states NPD drivers and success metrics used in this kind of study.

The kind of study presented in Table 1 is based on the following rationing: if some aspects were discovered by which a company could improve its product development outcomes, it will be possible to create some cause-effect relations. For example, if the company wants to focus on time performance, it could better manage its process performing market test earlier (ROBERTS; BELOTTI, 2002) or assigning a strong champion to drive the project (COOPER; KLEINSCHMIDT, 1995). Beyond drivers and performance indicators, Kahn et al. (2006) state that studies as those in Table 1 are delineated across new product dimensions. Adams-Bigelow (2006) emphasizes the need that each company develops its own metrics, because they will depend on business objectives.

Analyzing the differences between research departments in comparison with the development, Chiesa and Frattini (2007) found different profiles of performance measurement between them. Research groups are more measured by the quality and impact of their outcomes than by their compliance to cost and schedule plans. Engineering departments are commonly measured by time, cost and productivity aspects as percentage of correct drawings delivered, number of components built/week etc. Authors also identify that research measurements are more subjective and qualitative, and engineers are measured in a more quantitative profile even when using subjective evaluation.

Toledo et al. (2007) survey a number of small Brazilian high technology firms trying to understand what their drivers for new product success are. The results comply with international researches when identify the importance of a strong and detailed up-front homework and management

Table 1. NPD performance drivers and product success metrics.

References	NPD drivers	Product success metrics
Paladino (2007) Cooper and Kleinschmidt (1995) Griffin and Page (1996) Terwiesch et al. (1998) Roberts and Belotti (2002) Kahn et al. (2006) Silva et al. (2007) Toledo et al. (2007) Chiesa and Frantini (2007)	Product strategy decisions Strategic resource orientation Product marketing orientation Personally involved champion Hierarchical level of resource provider Service and technical support advantage Early, sharp product definition Customer test / field trial of product Product technical content Team-oriented project organization Communication and collaboration into new product projects Early market test Total quality management techniques	Financial performance Product quality Customer value Percentage sales by new products Technical success rate Financial impact on the firm Cycle time On-schedule project Market growth Innovation rate Break-even time Stakeholders satisfaction

skills associated with team-based design as drivers, but the authors identify that the activity of "providing project documentation" is a driver too. Silva et al. (2007) presents a complementary work in which technology firms from medical and industrial automation are compared. Automation companies present success projects strongly related to superior technical performance against competitors, and medical companies rely on interpretation of consumer needs and generation of product ideas. Moreover the authors identify that the homologation activities are well related to product success, a novelty in this kind of study when comparing to international literature.

In this paper framework, NPD dimensions are the MRM process areas as stated on the section 4.2, the main driver of new product success is proposed to be the capability level of each MRM process areas as described in section 4.3, and the performance indicators are specifically designed for the company's NPD being presented in section 7.

4. Reference model built

The reference model used to make improvements in a company's NPD utilizes a framework that represents NPD as a phased process, based on which a process area classification and a step-by-step framework for continuous improvement are built. The model reflects best practices in mechatronic product development, and has been dubbed a mechatronic reference model (MRM) because, from the technical standpoint, it involves products that integrate electronics, mechanics and software.

4.1. Stage-gate structure of the model developed

Figure 2 gives an overall view of the proposed reference model. The phases of the MRM are defined as a function of the results they generate. Results are documents and represent the concept of "information of value" discussed by Clark and Fujimoto (1991).

The phases of the MRM can be described as follows: 1) strategy: definition of the strategic objectives to be pursued in each product line (PL); 2) portfolio: definition of the portfolio of each PL; 3) specifications: definition of the specifications of each product; 4) project planning: definition of the project plan for each product; 5) conception: definition of the main components and solution principles for the main functions of the mechatronic product; 6) technical planning: detailing of the project plan based on the previous defined conception; 7) technical design: technical solutions for the main functions of the product; 8) optimization: detailing and testing of solutions for the product's secondary functions and analyses required to increase the product's robustness and reliability; 9) homologation: homologation (approval) of the product's manufacturing and assembly process; 10) validation: product validation and certification; 11) launch: launching of the product in the market; 12) monitoring: monitoring of the results attained with the product and management of the modifications made in the initial production configuration.

Each phase is separated by a decision point and four different types of gates were developed. The gates, illustrated by (1), represent moments in which the decisions are made for a given set of products. In the strategy phase, the set comprises all the products of the company, while in the portfolio phase, the products all belong to a given PL. Gates represented as (2) are business-oriented decisions made on the basis of design performance indicators. The gates illustrated as (3) are technical decisions made through peer review meetings, and a gate (4) represents the closing of a given development project after product ramp-up.

4.2. MRM process areas

The MRM was built to be used in small and medium companies. For this reason, it did not utilize CMMI process areas. Anyway, some aspects of CMMI were summarized using a different approach more suitable for mechatronic technology and small firms. Figure 3 illustrates the MRM process areas distributed along the aforementioned phases, whose distribution is indicated by the horizontal bars. Although all the bars end only in the product-monitoring phase, the beginning of each one is highly illustrative of its function in the NPD.

The strategy deployment process area is based on the proposal of Cooper et al. (1998) concerning the integration between portfolio decisions and gate decisions. As can be seen in Figure 3, it covers all MRM phases. At the beginning it deals with strategy definition, at the middle it organizes

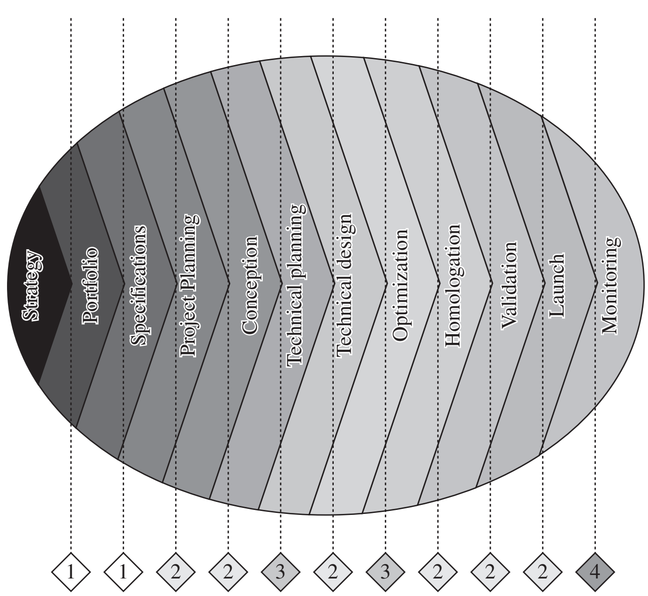


Figure 2. Phases and decisions of the MRM.

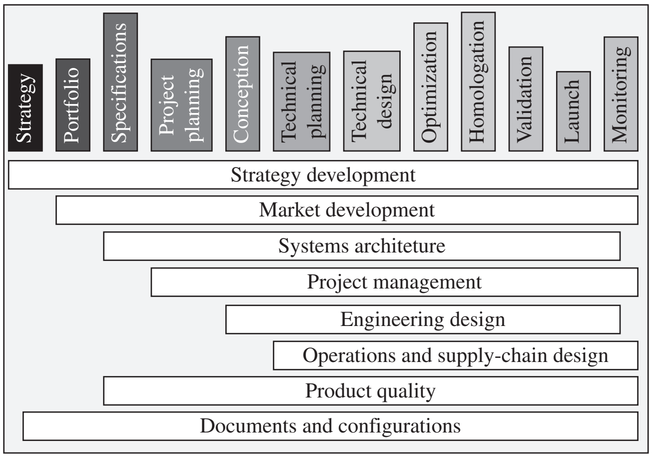


Figure 3. MRM process areas.

and runs gate decisions, and at the end it monitors the market figures.

Market development is a proposal of the authors and consists of the activities developed by a considerable number of organizational units whose objective is to ensure the product meets the existing market needs. It starts only after strategy definition and evolves in works related to deeply know the consumers' needs and the ways of product utilization along its life cycle. As customer and user needs are taken care of along the time, market people must re-feed design specifications in form so each gate can be checked against the last customer discoveries. Then, market personnel develop a market attack plan before and along the product launch phase and monitor it making the necessary changes.

Systems architecture is based on the concept of systems engineering with emphasis on the activities involved in the development of product requirements and technical documentation, as discussed in the IEEE 1220 STD standard. However, it is complemented by the analysis of software requirements, as proposed in Pressman (2001) and Bradley et al. (2000). While the market development area is responsible for identifying potential clients for the product and surveying their needs, systems architecture transforms those needs into technical requirements to be delivered to design teams. When solutions meet technical requirements, the system architecture process area can document final solutions relating them to customer requirements. Systems architecture starts after the new product project has been chosen and finishes after product launch.

Project management follows the concept defined by Project Management Institute (2005) concerning scope, time, cost, procurement and supply-chain management along the project. However, it is understood that, as the design solutions become robust, the acquisition processes become more closely related to the design of the production and to supply structure than to the development of engineering solutions. The planning-execution-control-closure cycle defined by Project Management Institute (2005) is implemented through this process area. This process area was planned to initiate when product specifications have already been written down and a project manager has been assigned to the project. After the product launch, a project management process must take place when major changes are necessary. MRM suggests an original team member must be assigned as project leader to manage the product continuous improvement.

Engineering design consists of the activities proposed by Pugh (1990) and Pahl and Beitz (1996). Based on the proposal of these authors, we suppressed only the activities relating to the phases of specification Pugh (1990) and task clarification Pahl and Beitz (1996). The contributions of authors of mechatronics and of electronic, mechanical and software engineering, such as Bradley (1991) were added to this process area. Operations and supply-chain design consists of the activities described by Clark and Fujimoto (1991) as "process engineering" and the activities of manufacturing structure design required for introducing the product into the company's production line, as proposed by Slack (1999). The activities related to engineering design run since conceptual design phase and those from operations and supply-chain design since technical planning phase where the first make or buy decisions are making.

Product quality consists of the activities related to analyses to predict failures in products, assurance of product reliability, and guarantee that they do not present safety risks to users and operators (JURAN 1992). The activities of identification and analysis of customer requirements - which some authors affirm belong to quality management - have been subdivided in order to reflect the origin of the needs they express. Thus, the identification of customer needs is related to the market development process area, while the normative requirements have been associated with product quality forecasting, since they result from accumulated knowledge which is consolidated in quality standards for different product typologies. Consequently, product quality activities are carried out before product specifications have been finished in the third phase of MRM. In this occasion, a normative search should be carried out to guide project managers in planning activities and to help designers in conceptual design phase. At the technical planning phase the normative analysis is reviewed to comply with technology requirements stated into the chosen concept.

The area of documentation and configuration is advocated by systems engineering standards, as exemplified by the IEEE 1220 STD, and is expressed explicitly in quality standards such as ISO 9001:2000. However, it has chosen to treat this subject independently from the other process areas, as proposed in the standards like European

Cooperation for Space Standardization (1996). As a result, inside MRM framework in each phase were placed some activities related to codifying, identifying and making control of every document developed. While system engineering process area develops the document content, document control and management are responsibilities for document and configuration process area.

Many design and development implications can be derived from this framework. However, their exploration is out of this article scope. The following section presents the method by which MRM process areas are used to improve a company specific NPD.

4.3. MRM application method using the CMMI capability concept

Each activity of each NPD phase has different possibilities to be complied to, depending on the capability of its process area. Because a process area is a set of activities, its capability was modeled as the sum of each activity capability. For example, if a process area has 20 activities, each of which is considered as a level 1 capability, that area will be designated as level 1.

The application of the model consists of diagnosing the level of capability of each NPD activity modeled in the company and of defining the type of improvement to be applied to each one. Thus, the application is based on the development of a capability diagnosis questionnaire that reflects the MRM process areas described in the previous section. To evaluate the capability of each activity of the process areas, one uses the scale depicted in Figure 4, whose definition of each level of capability, based on CMMI, is:

- "DOES NOT DO" – capability level "incomplete" or 0 (zero). The company does not carry out the activity prescribed by the model;
- "DOES" – capability level "performed" or 1 (one). The company carries out the activity, but there is no process standard or previous planning for its execution;
- "PLAN" – capability level "managed" or 2 (two). The activity is carried out according to previous planning;
- "METHOD" – capability level "defined" or 3 (three). The activity is carried out as planned, based on a well-defined method and a set of standards and templates;

Activity	Capabilty						How is done
	Does not Do "0"	Does "1"	Plan "2"	Method "3"	Measures "4"	Optimizes "5"	

Figure 4. Gauge scale of the capability of the NPD process areas.

- "MEASURES" – capability level "quantitatively managed" or 4 (four). The activity is carried out, based on planning and a method, and its results are measured in order to compare different instances of its execution; and
- "OPTIMIZES" – capability level "optimized" or 5 (five). The activity is continually improved through the identification and elimination of the causes of variability of its results.

After the questionnaire has been completed, its analysis consists of calculating the capability level of each process area, based on the scale of the six values mentioned above. The proposals for NPD improvement are then defined based on the diagnosis of capability. Note that if the increase in the capability level targeted for the process area – according to the concept of targeted profile (CHRISSIS et al., 2006) – is higher than "1", it may lead to implementation problems resulting from the lack of maturity of the company's NPD; therefore, a level "1" of capability increment is always preferable.

Obviously, when calculating the average of the improvement degrees of the activities of a process area, there may be results expressed in real and fractioned numbers, such as 1.2 or 1.7. These results demonstrate that the final levels of maturity would be 1 in both cases. However, they also show that the process area with a result of 1.7 is closer to a level 2.0 capability than the former. Such differentiations will be taken into account in this work, since the aim is to identify the highest capability levels and their impact on performance indicators.

After the initial capability level of the process areas has been identified, one analyzes the possibility of introducing improvements in the company's NPD. To this end, the MRM offers tools for capability level transitions from 0 (zero) to 1 (one), from 1 (one) to 2 (two), and from 2 (two) to 3 (three). The application by capability level basically follows these rules:

- If the capability level of a given process area is "0", one uses the MRM activities as a checklist of what must be done to increase the area's capability to "1";
- If the capability level is "1", the activities should be planned so that the intermediary information/documents can be generated systematically. This must be done using the templates of documents allocated to each activity of the model. This procedure will increase the capability to "2"; and
- If the capability level is "2", the model foresees several methods that can be transformed into process standards to be applied to increase the capability to "3".

5. Applications of the mechatronics reference model in the company and practical results

The company where the MRM was applied was founded in 1985. Its history began in USP São Carlos (University of

São Paulo at São Carlos), and it was constituted of researchers and technicians of the university's Institute of Physics. The company's current portfolio consists of products for the areas of coatings and industrial laser applications, as well as for defense and aerospace applications. Its product line includes medical/ophthalmological instrumentation. Today, the company employs about 300 people at its headquarters in Southeastern Brazil and its branches in the South and Northeast. It also has an office in Miami and representatives in Europe, Asia and Oceania.

Improvements were made over a 2-year period. During that time, the company developed medical and aerospace products. The actions performed to improve the NPD focused on company objectives such as product certification, project planning, ISO certification, etc.

Table 2 shows the number of activities of each process area that was analyzed based on the form illustrated in Figure 4.

Some methods for product strategy planning were applied in the strategy phase. This improvement was extended to the portfolio phase. Some activities for improving product specification outputs were carried out in the specification phase. Project planning was improved through the introduction of schedules and work breakdown structures (WBS) as part of the planning procedures.

Concept modeling and selection techniques were applied in the conception phase. Technical planning was improved by the introduction of product trees and architectures. The technical design was better documented and the company began applying risk analysis through product failure mode and effect analyzes (FMEA), as well as signal-to-noise and reliability analyzes. At the end, product approval was became an activity officially expected. The company began to produce manufacturing flowcharts and to plan training courses for the shop floor personnel and with manufacturing management staff. Product validation was better structured and the results of tests with users started to be planned and well documented. Planning of the launch phase was improved. The product began to be monitored by means of a management tool shared among the sales, technical assistance, engineering and quality areas.

In terms of process areas, the application of the model emphasized "documents and configurations" and "project management", with 19 and 18 actions taken, respectively. The areas with the fewest improvements were "strategy deployment" and "market strategy", where 3 and 7 actions, respectively, were taken. These numbers are related to those in Table 1. It means, for instance, that 19 up to 23 activities from "documents and configurations" were improved.

A series of practical results were achieved directly through the application of the model, such as ISO 9001:2000 certification of the company's engineering area, the registering of two electromedical devices at the ANVISA (Brazilian National Agency for Sanitary Vigilance) and the FDA (Food and Drugs Administration), which involved aligning the products with the requirements of the CE mark. In addition, the company managed successfully an alignment of its development process to the contractual requisites of the Brazilian aerospace agency.

6. Capability improvement

The capability levels were identified through interviews with activity supervisors and validated by the participant observation.

Figure 5 shows the company's NPD capability level in the beginning of the MRM application (Nci), at the end (Ncf) and the ratio between them, named improvement grade (Δc). The numbers presented in each process area represent the average capability of the activities of each area, evaluated as depicted in Figure 4.

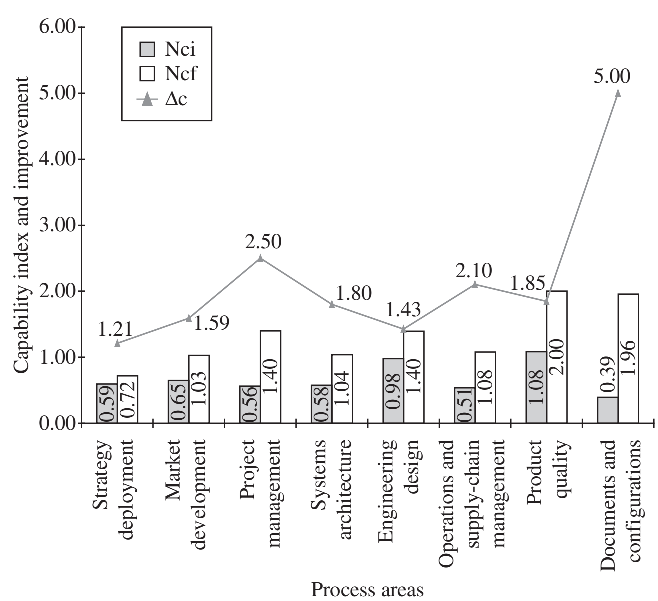


Figure 5. Capability level of the process areas before MRM application (Nci), after MRM application (Ncf) and improvement grade (Δc).

Table 2. Number of NPD activities analyzed in each process area of the MRM

Process area	Number of activities	Process area	Number of activities
Strategy deployment	32	Engineering design	46
Market development	34	Operations and supply-chain design	39
Project management	25	Product quality	12
Systems architecture	27	Documents and configurations	23

In the beginning the average of capability level of the process areas was about 0.5 (incomplete level). Generally speaking, the capability graph in Figure 5 indicates that most of the process areas contain actions that were not being carried out when the MRM was initially applied. This means that, in general, the applications should follow an improvement strategy based on the execution of these actions. This strategy would result in an advance from the "DOES NOT DO" to the "DOES" level.

The process areas with the highest capability were engineering design and product quality, which scored about 1.0 (performed level). The lowest capability was in the area of "documentation and configurations" and can be understood as being strongly related to difficulties involving the NPD organization. Moreover, this area is considered to be closely linked to that of "project management", based on the interviewees' statements.

As can be seen from Ncf values in Figure 5, the average capability increased, although there was a greater standard deviation between the capability levels at the end than at the beginning of the work. The area with the highest capability was still "product quality", closely followed by the area of "documentation and configurations", both showing level 2 capability. The areas of "project management" and "engineering design" showed a capability of around 1.4. The capabilities of the "market development, "systems architecture" and "operations and supply-chain design" areas were close to 1. The lowest capability detected upon conclusion of this work was in the area of "strategy deployment".

The lined graph in Figure 5 shows the degree of improvement of the capability level of the process areas (Δc), i.e. the ratio between the final and initial capability level (Ncf/Nci) of each process area. Note that the improvement in the capability level of all the process areas was higher than "1". Also one can see that the process area with the highest degree of improvement, "documentation and configurations", was also the one with the largest number of MRM applications and that the area with the lowest Δc was also the one with the fewest MRM-based interventions.

Statements were taken from the people involved in the company's NPD in order to better understand the degrees of improvement detected. These findings enabled us to conclude that improvements in "project management" are closely related to the company's growth, while improvements in "documentation and configurations" result from market and regulation pressures, especially concerning exports. In terms of "operations and supply-chain", one considers that the documentation generated in the final stages of a project have allowed for a reduction of the learning curve by the shop floor operators.

7. Improvement of NPD performance indicators

Because the company had no active performance measuring system, it was decided to find out what the engineering, manufacturing and sales employees perceived as improvements. In addition to aspects of cost, delivery times and quality, some indicators to evaluate the degree of improvement achieved through documentation and configuration control efforts were used. The performance indicators used were: correctness of time planning, cost monitoring and control, improvement of time control, easy access to project data, easy designer integration, level of requirement changes, and reduction of manufacturing and user complaints.

The group of participants of the company's NPD, from which the people who had filled out the diagnostic questionnaire analyzed in previous section were excluded, responded based on a scale of agreement or disagreement about whether there had been an improvement of these performance indicators. Table 3 presents the functional departments and the organizational roles of people involved in interviews about performance improvement.

As performance indicators were diagnosed in a subjective way, the Figure 6 is presented to demonstrate how different each group perception is from the general view. The scale is traceable to the one used in the agreement/disagreement questionnaire (+2,+1,0,-1,-2). The overall media of agreement resulted at 0.27 and all of the groups are ranked on the positive agreement side except when

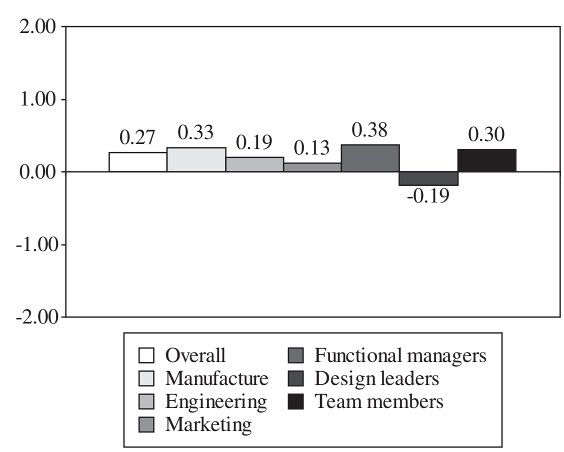


Figure 6. Improvement average as recognized by extratified groups.

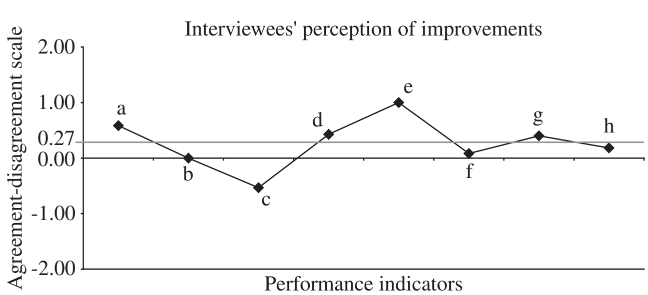
Table 3. Interviewers who evaluate the perception of performance improvement

Total	Engeneering	Manufacture	Marketing	Functional managers	Design leaders	Team members
17	13	3	1	6	4	7

considering only design leaders responses. No research tool was developed to understand this behaviour, but it is probably related to the stress on design leaders who need to deal with quality and time trade-offs and the resulting interdepartmental pressure. Moreover, even being the main responsible for design outputs, design leaders have not any hierarchical power into the company organization.

Figure 7 gives an overall view of the interviewees regarding the degree of improvement of the NPD performance indicators. The average distribution shown in the graph is 0.27 and its standard deviation is 0.45 as can be calculated using the figures from Figure 6. Note that the performance indicator considered the most positive in the evolution of the company's NPD within the time frame of this research was the "capacity to integrate new designers into the projects", which was the only one above the limit represented by the average added to the standard deviation. This improvement suggests a positive correlation to the area of "documentation and configurations", since the documentation generated along projects serves as the basis for the allocation of new hirings or for the reallocation of staff according to the technical state of a project. We also consider that there is a relation between more efficient "access at information generated along the project" and this facility for "integrating new designers".

The low degrees of capability improvement in the areas of "strategy deployment" and "market development" may explain the little agreement among the interviewees about the improvements in "design requirement changes" – which are generated by the company's marketing area –, as well as reductions in "customer complaints". A poor marketing interface can also explain the significant disagreement about improvements on time planning because the main design milestones are established by marketing people.



a Cost control; 0.58	e New designers integration; 1.00
b Time control; 0.00	f Requirements change; 0.08
c Time planning; -0.53	g Manufacture complaints; 0.40
d Access at design information; 0.43	h Customers complaints; 0.18

Figure 7. Degrees of improvement of the performance indicators investigated.

As for the reduction of "complaints from the manufacturing sectors", it was expected that, with the design now better documented (degree of capability improvement of "documentation and configurations"), the transfer of product specifications to the manufacturing and assembly sectors would have become easier. However, our data did not demonstrate this relation since the average degree of agreement about the reduction in manufacturing complaints was median, but above the overall average.

An analysis of the MRM-based improvements implemented in the area of "project management" indicated that none of them involved organizational aspects, such as the establishment of matrix structures, the formation of interdepartmental committees, of multifunctional teams, etc. In other words, improving the project's documentation does not suffice to diminish the problems involved in the engineering/manufacturing interface.

With the exception of the time planning and control indicators, all the others were considered improved in the company's NPD. Since the "project management" area presented the second highest degree of improvement, according to Figure 5, there was a greater expectation regarding improvement in terms of delivery times, especially with regard to their monitoring and control. Because the main cost element of new product projects is lead-time, the control of delivery times affects cost control. Both these indicators, figured respectively as 0.0 and +0.6, lay within the limit established by the sum and the subtraction of the standard deviation from the average, +0.8 and -0.2, respectively.

Generally speaking, these data demonstrate that the increase in capability of the company's NPD process areas was accompanied by an increase in the awareness of improvements in the majority of processes performance indicators here evaluated. The fact that one group analyzed capability while another analyzed performance indicators led us to conclude that the data were reliable.

8. Findings

The results show that the measures major closely related to process improvements were improvements in time control, easy access to design data, and easy designer integration. The process areas that received the most attention during this 2-year period were project management and configuration management. These findings suggest a link between these areas and the above mentioned performance indicators. Future research will focus on quantifying time, cost and controlled documents improvements to build more formal relationships between them and the process capability.

The project management area, whose capability increased to 2.5 (Figure 5), should, in theory, rise the project delivery time indicators significantly, considering the agree/disagree profile in Figure 7. Nevertheless, the data showed that this was not the case. This discrepancy is explained not only by the fact that there was an improvement in project management as a result of contractual aspects – a fairly recent initiative in the company, but also and principally by the existence of organizational barriers that hinder the efficiency of the matrix structures necessary to carry out good practices in project management.

Because of the large size of the "projects management" area, the results may also suggest that the capability of project cost management activities is greater than that of time management activities. This analysis goes beyond the objectives of this article, but opens a space for a specific study in which the granularity of the reference model in each process area could be analyzed, known and classified so as to better associate capability improvements with given performance indicators. It would be useful to employ a research strategy whose hypotheses are derived from these possible explanations in order to ascertain the validity of the aforementioned discrepancy.

Logic would indicate that a considerable increase in the area of "documentation and configurations" would allow complaints from customers and manufacturing to be reduced, since there would be more and better detailed design documents including aspects of manufacturing, assembly and technical assistance, which was, in fact, the case here. However, our data show that this improvement in those indicators did not occur. Although there are organizational factors that may have affected this result, we consider that the model's application strategy itself was creating difficulties in achieving overall NPD improvement. In other words, one can infer from Chrissis et al. (2006) statements that the application of a model within the continuous rather than the staged frame of reference implies focused improvements. Therefore, a hypothesis to be tested in additional studies is precisely that the considerable increase in "documentation and configurations" capability occurred because of the emphasis on this process area, and that this emphasis resulted in improvements related to performance indicators leveraged by that process area rather than in overall NPD improvement.

The relation between increased capability of process areas and improved NPD performance indicators is still a subject of little indexed theoretical study. The use of the MRM, as discussed earlier herein, revealed, that by implementing a product development reference model based on the concept of process areas, it is possible to improve the perception of NPD performance in the company. It indicates if a reference model focuses on the way of increasing capability levels of process areas as stated in section 4.3, it can specific to improve some performance indicators.

This work has evolved toward the proposition of time, cost and quality indicators to quantitatively analyze a company's NPD performance. This will enable us to collect primary data throughout the duration of the company's projects. Another action is been performed to predict the relationship between a specific activity and the performance indicators improved by focusing on its capability increment.

The overall intention is to build a predictable improvement model for NPD. One can set the improvement profile to be reached, delineate the activities, which capability must be increased, and build the correct performance indicators to evaluate the results.

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