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DEVELOPMENT OF A MODEL FOR ASSESSMENT OF DESIGN PROCESS PERFORMANCE

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Abstract

The efficiency of business processes and the methods to measure them are considered the best way to improve a company's success. This article shows a model for measuring the performance of design process. Such process has been applied successfully in the new product development at the NeDIP (Integrate Product Development Nucleus) at the Mechanical Engineering Department of the Federal University of Santa Catarina (UFSC). The research methodology was a multiple case study in two companies and the results of a questionnaire sent to design specialists. The results are presented by a critical analysis of the proposed model.

Key words: performance metrics; performance management; product development

1 Introduction

A company's success is strictly related to the efficiency of its processes which strengthen the marketability of its products. Control is part of efforts to have a very effective process, hence, performance measurement plays an extremely important role on planning and controlling any company. The efficiency of any control strategy depends, among other things, on the suitability of the performance measurement that has been developed, as well as a well-structured Performance Measurement System (PMS). Initially, performance measurement was based on traditional managerial accounting systems that were coherent to mass production paradigm. However, when one considers some processes that have played fundamental role in the organizations nowadays - as, for instance, the Product Development Process (PDP) - they no longer offer any relevant information for the controlling and improving the performance. The PDP involves several departments such as marketing, design, manufacturing, logistic, sales and supplies, which becomes it multidisciplinary, with singular characteristics and hard to assessment. This article deals with the modelling of a PMS applied to the design process.

The proposed model for assessing the design process performance was developed from a literature review on design process and PDP performance measurement, a case study carried out in two Brazilian companies and a questionnaire sent to design process experts.

2 Literature Review

The literature review consists of two parts. The first approaches the design process that was used as the basis for the development of the PMS. The second presents a brief literature review of the performance measurement and guidelines for the PMS development.

2.1 Design Process

As seen earlier, the PDP is multidisciplinary process based on the product life cycle as shown on figure1. One important stage is the design process - the focus of this paper. The *Núcleo de Desenvolvimento Integrado de Produtos* – NeDIP (Integrate Product Development Nucleus) which is part of Mechanical Engineering Department of the Federal University of Santa Catarina (UFSC) has been dealing with design during the last 20 years. The design process has been the main focus of all the studies carried out in nucleus based on the models proposed by Back[1], Pahl & Beitz [2], Hubka & Eder [3] and Ullman [4]. Its greatest influences come from the first two models and their representation is show on figure 2. It is composed by four phases: informational design; conceptual design; preliminary design and detailed design. Each phase is deployed in activities and tasks. Each phase delivers a well-defined result, which will be the input for the following. Between the phases some points of evaluation of the product's technical results are considered (figure 2). As the result is approved, a next phase begins otherwise returns to the previous phase for corrections. This occurs until the end of the design, when the final product documentation is delivered. Accordingly to concurrent engineering principles, the phases can be realized in parallel, considering activities that will not depend on the results of previous phases.

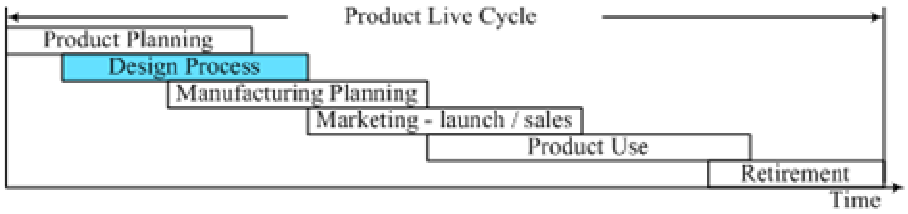

Figure 1 - Product Live Cycle.

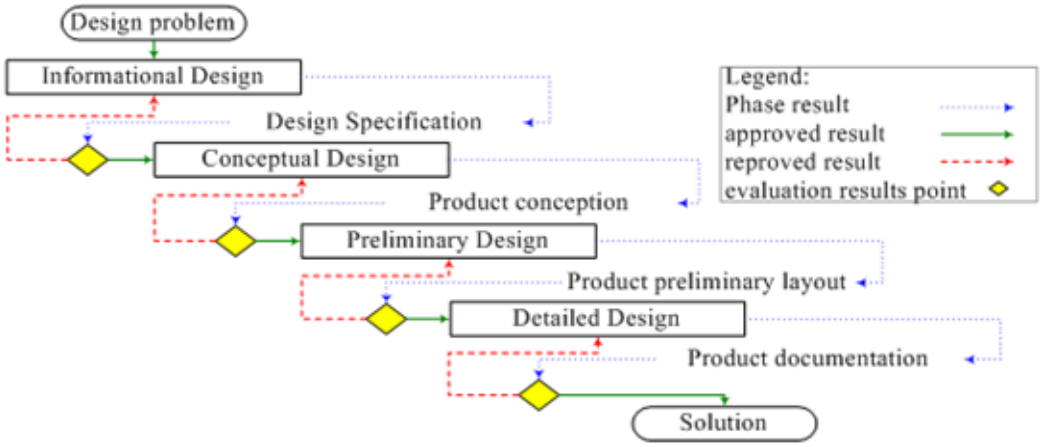

Figure 2 - Phases of the design process.

The collection of information about the stakeholders' needs is the start point in the informational design phase (figure3). In such phase, the collected information is transformed in design requirement. The core of this phase is the processing of information in order to create a hierarchy among the design specifications. In the conceptual design phase the resulting information of the previous phase (design specification) is treated to generate a product concept that complies with the client's requirements. During this phase, creativity activities, functional decomposition, concept selection, and other, are performed. In the preliminary design phase, the designer starts from the selected concept, aiming the

materialization through the establishment of initial shape, the selection of materials and manufacturing processes. At the end of this phase, is the designer comes up with a definitive layout. In the detailed design phase, the definitive layout of the previous phase is detailed according to the design specifications, generating the product final documentation.

The result of each phase passes is evaluated based on technical and cost requirements of the product – represented on figure 2. However, the efficiency and effectiveness of the design process are not considered formally. It important to highlight that the measurement of performance is fundamental for the appropriate management of the design process. It is imperative to optimize the design process performance in terms of cost, time and quality in order to become competitive in a global economy. Hence, the assessment of the design process performance is very important regarding the management of such process.

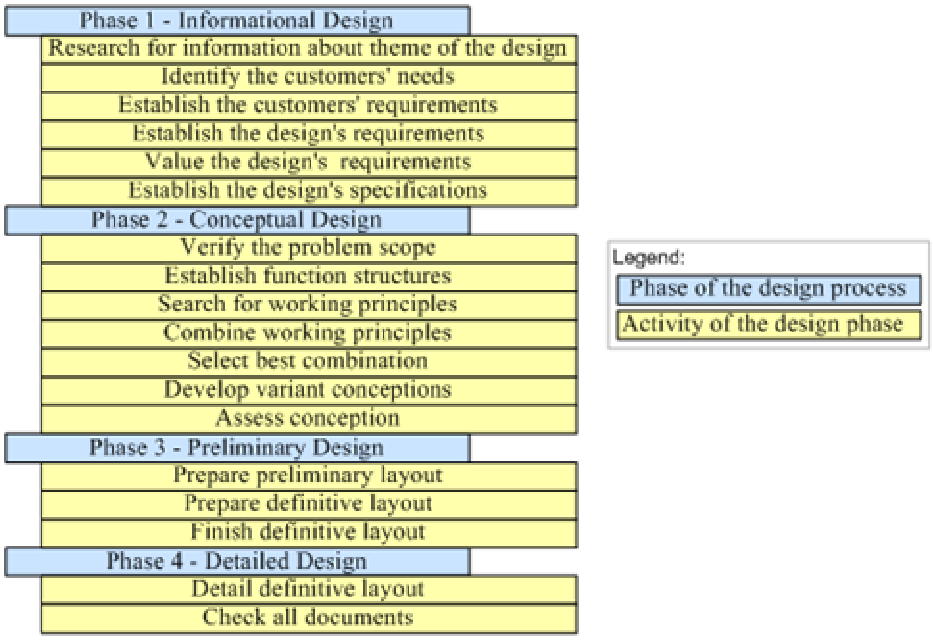

Figure 3 - Deployed the design phases.

2.2 Performance Measurement

The performance measurement plays a fundamental role in providing information for planning and controlling purposes. According to Neely [5], it allows informed decisions to be made and action to be taken based on the evaluation of past actions. The field of performance measurement has faced a revolution since the 1990's after the realization of inadequacy of traditional performance measurement based on financial indicators such as ROI (return on investment), labor cost, processes cost and materials cost, as Martins [6]pointed out. Financial performance indicators are useful but they do not consider the drivers of financial performance like time-to-market, customer satisfaction, conformance quality, product quality, employees' satisfaction, and so on.

The performance measurement revolution can be explained by the evolution of the industry, the increase of worldwide competition, and the evolution of the customer needs that becomes more demanding. In this period, the need to evaluate non-financial aspects began to gain importance. Among researchers that study the subject, one of the most cited in publications, Neely [5], studies the business performance evaluation, proposing the construction of a model to evaluate its performance. Another influent researcher is Kaplan [7]. He proposes a PMS

model (Balance Scorecard) that emphasizes a connection of the metrics to the company's strategy. Unfortunately, a large number of the researchers have focused on business the performance measurement as a whole, where product development process is one of all company's business processes. However, each process has specific characteristics which demands special efforts in developing performance measurement frameworks for such processes.

Within this context, it is important the development of models for assessing the PDP performance because it has unique characteristics. Indeed, the PDP contributes a lots for the company's performance as a whole. Some authors are studying PDP performance measurement as a whole. Among the most quoted, we can point out: Clark [8] has studied the relationship between the project scope and the project performance and its effects on the automobile industry PDP; Griffin [9] and [10] has related the effects of the project's characteristics and PDP with its development cycle time; De Toni [11] proposes a PMS model adequate to process's management that provides the necessary organizational changes to reach a lean production – one of those processes is PDP. The characteristics of such proposal are global performance measures (time, quality and cost), performance measures to processes and related activities. The author proposes metrics for three processes: development of new products, production/assembly and logistic. Pawar [12] and Driva [13] have evaluated the evolution of the PDP's performance under the company's perspectives and proposed a framework and a workbook to generate performance measures to evaluate the PDP performance.

In short, literature reports on some aspects that can be used as guidelines for a PMS, among them:

- ✓ The measures should reflect the company strategy;
- ✓ There has to be a balance between financial and non-financial measures;
- ✓ Have specific measures for each of the design phases;
- ✓ The information should be spread to the organization within actual time;
- ✓ Be dynamic and adaptable to new measures;
- ✓ Indicate progresses;
- ✓ Be of easy implantation;
- ✓ Provide an understanding of the relation between cause and effect between measures; and
- ✓ Don't obstruct the design process.

These guidelines can be applied in developing performance measurement system for product development process. In spite that performance measurement has been applied on PDP, few studies deal with the design process, although it has a fundamental role inside PDP.

3 Research Methodology

The research methodology applied to gather empirical information, for the development of the model, was a combination of qualitative and quantitative methods. Firstly, literature research was carried out to capture the state of art about the subject. During this period, an interchange was carried out between the Federal University of São Carlos (UFSCar) and UFSC, to exchange information about the subject and to plan an empiric study to be conducted at two high technology companies. A semi-structured questionnaire was sent by e-mail to design

methodology specialists in order to collect relevant information about the aspects regarding performance measurement of design process. The research methodology is exhibited in figure 4.

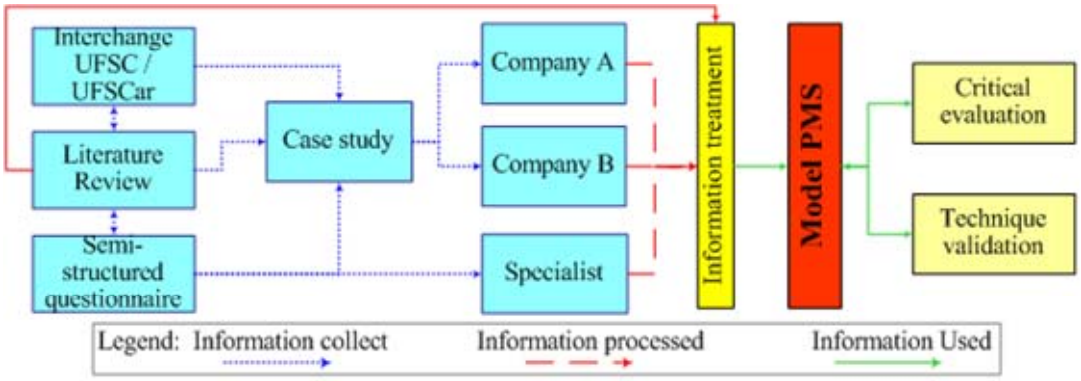

Figure 4 - Research methodology.

The validation of the model will be done in two stages. Firstly it will be judged through an analytical evaluation. Later, it will be empirically validated through application in selected companies. Nevertheless, due to the time demanded in validating the model empirically, this article will present only the analytical evaluation.

4 Case Study

The objective was to carry out an empiric exploratory study in two multinational companies in order to gather data about the performance measurement of the design process. People directly involved in the product design from different hierarchical levels (managerial, tactical and operational) were interviewed. A semi-structured questionnaire was applied to guide the interviews. The open questions helped to capture the practitioners' perspectives on the issues involved in the research. The goal was to characterize the performance measurement used in the company instead of paying attention to the specific numerical results. The focus was the methods employed in obtaining those results.

The unit of analysis in the company A was the technology development center which develops products of high complexity, high added value and high technology, competing in the global aerospace market. Company A does not have a formal and structured PMS to the design process. The performance indicators used are mainly financial and time indicators. A single person determined subjectively of the performance indicators. They are ultimately connected to the company's strategy and the purpose of measuring are only to control and planning of future designs. The approach is not well structured and doesn't emphasize the checking of design activities, being only applied in phase reviews that refer to the checking of the product's technical results. The interviewee has reported the design performance measurement does not efficiently satisfy their requirements. Other important factor that validates the lack of efficiency of the company's design performance measurement is the non-formalization of the company's PDP, what makes the measurement process a lot more difficult. The interviewed people have manifested interest in owing a formal and adequate PMS crafted to PDP.

The company B is a manufacturing company that develops products with high added value, complexity and technology, and competes mainly in the national petroleum extraction market. The company has a well-established PMS applied to the whole business. This system

encompasses the project as a whole, using time, cost and quality as main performance indicators. However, the system is not deployed until the design process. The design performance measurement is restricted to cost and time issues. There is much emphasis on the subjective aspects of performance what doesn't reflect reality. The company's PDP isn't totally formalized. Although it already has a PMS, the Company B showed interest to improve the current PMS in order to establish a better relationship between the performance information and the business strategy.

The empirical findings from the case study show that:

- ✓ Companies are concerned with both the design process performance and the measurement of such process;
- ✓ The lack of a formalized process affects directly the establishment of formal design process performance measurement system;
- ✓ The indicators are primarily determined subjectively;
- ✓ There is a lack of performance information at the activities level in the design process;
- ✓ There is lack of non-financial indicators; and
- ✓ The interviewed people has claimed a formal and well-structured design PMS There's in order to have information at the right time to take corrective action, and not only to register and control for future projects.

5 Expert Survey

The goal of this stage was to gather information about the requirements of PMS from potential users' point of view. Questionnaires were sent to 23 experts, among researchers and professionals involved with design process areas. There was 35% of response. The results reveal that 100% of the specialists use a formalized project process and the number of people involved on informational, preliminary and detailed design phases varies from two to five. Six to ten people are involved in the conceptual design phase. Sixty per cent of the respondents revealed that the developed products have medium complexity, that is, technologies in development, and 50% develop from two to five products simultaneously. Regarding the design process, the specialists were asked about the influence of each phase on its development. In increasing order, the most influent phases, according to the specialists, are: conceptual design (35%), informational design (28%), preliminary design (21%) and detailed design (16%). Still about the design process, it was asked what performance indicators would be more appropriate for each phase. The answers are exhibited in table 1. It is possible to confirm that the conceptual design phase is the most critical one, i.e., this an important phase to establish a well-structured PMS to provide information to decision makers. The empirical findings also point out that each phase should have appropriate performance indicators. The measurement criteria – time, costs, quality, and flexibility – assume different importance positions for each phase according to the exposed on table 1.

Table 1 - Importance of each phase and measurement criteria score.

Phase of the design process	Importance in PMS	Measurement criteria score in each phase			
		1°	2°	3°	4°
Conceptual Design	**35 %**	**Quality**	Time	Flexibility	Cost
Informational Design	28 %	**Time**	Flexibility	Quality	Cost
Preliminary Design	21 %	**Time**	Quality	Flexibility	Cost
Detailed Design	16 %	**Time**	Cost	Quality	Flexibility

6 Measurement Model

The model was developed from literature review and empirical findings from both case study and expert survey. A major concern in the modelling of the system was a structured and formalized design process. As it has already been exposed, design is composed of four phases: informational, conceptual, preliminary and detailed. Each phase is developed through activities and tasks. The model will be developed and applied at the activity level.

Figure 5 illustrates graphically the model. The start point is the product strategy that is directly related to product planning and indirectly to design management. The strategy is the basis of choosing the set of indicators which will be applied on the design process. This choice is based on the portfolio of the system's indicators. It contains pre-established indicators and is constantly updated with new indicators from the users' interaction with the system, that makes it dynamic and up-to-date.

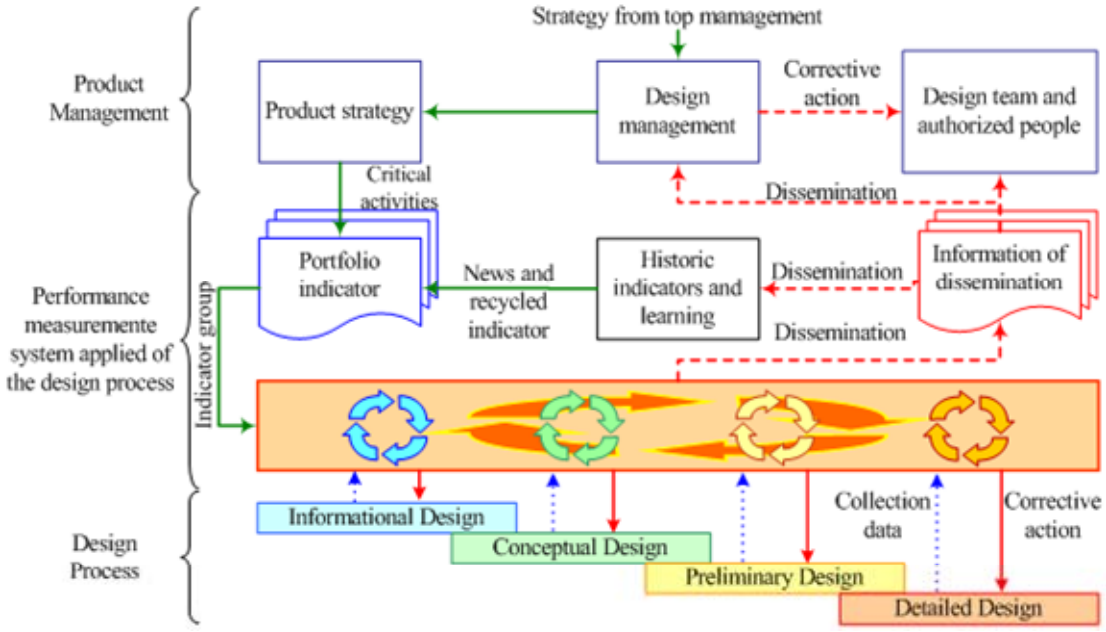

Figure 5 - Proposed of a model assessment of design process performance.

The portfolio contains specific and general performance indicators. They are arranged in forms containing information such as: the indicator's name, its description, phase in which it is applied, evaluated level, goals, type, information collection effort, unit, evaluation method, possible support tools, measuring frequency and comments. For its efficiency, the system should have two types of indicators – specific and general. The specific indicators will gather performance information in each phase, for example, on the informational phase, the specific indicator gathers information regarding the construction of the house of quality (QFD). The general indicators are those applied in all the activities, for example the lead time of each activity. Therefore, the PMS makes possible to gather information during the design, generating an information network that can be used during a phase and as a record for future designs. With relation to the number of indicators, recommends keeping the number low. It can vary from six to ten. As the system is used, new indicators can be added to the initial ones.

Inside the system's nucleus (figure 6), the information are acquired, analyzed, interpreted and made ready for dissemination. These activities are performed during all the phases and

activities, and they make the system dynamic. In the acquiring activity, reports generated the information needed on basis of each indicators delivered to the design manager.

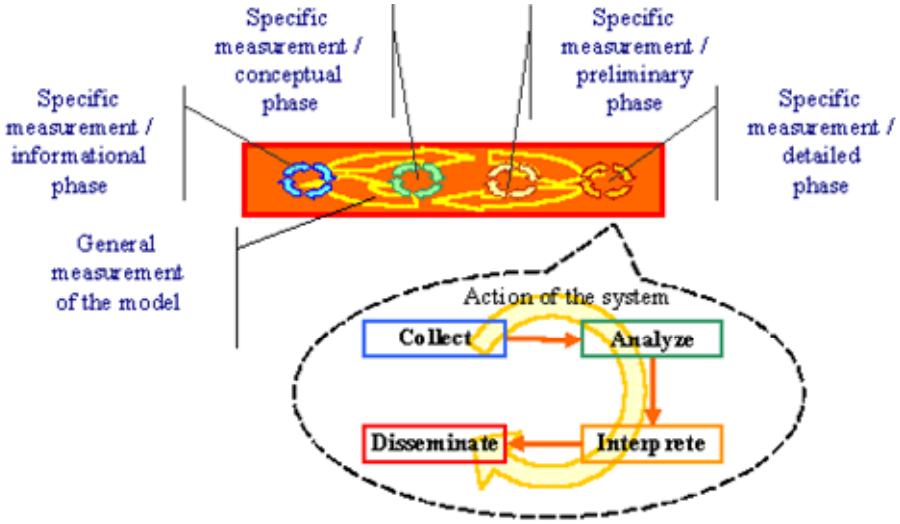

Figure 6 - Nucleus of the model.

In the analyzes activity, the information is processed according to the metrics contained in the form and interpreted. One of the results can be a corrective action if non-conformity is detected. The available information is disseminated to the design team and authorized personnel. The circle shaped arrows (figure 6) represent the system's dynamics, which has to gather information and relate them during the development of each phase. So it is possible to take corrective actions as the phases progress. The small circle-arrows represent the specific indicators of each phase and the bigger ones represent the system's general performance indicators. They are conveyed according to criterion of time, cost, quality and flexibility. The information gathered is applied to check the actual design situation, besides generating new indicators. The arrows that join the PMS to the design process represent the exchange of information during the design progress. Each phase has feedbacks to its activities that makes possible the figure out the mistakes and take corrective actions during the design phase before the end of it. At the end, the reports produced during the design phase with information about the design process performance are presented as a report with all the gathered information. They will be stored and can support the planning of new designs. It could also be applied in establishing new indicators when the system will be updated. The table 2 shows an example of a set of indicators applied on design. As seen earlier, this choice is based on the portfolio of the system's indicators.

Table 2 - Set of indicators applied in process design.

Indicators	Informational Design	Conceptual Design	Preliminary Design	Detailed Design
Specific	Costumers satisfaction indices	Number of conceptions variants	Number of changeovers	Rate of design correction
	Rate areas involved for activity	Rates solution principle for each function of the product	Rate of drawings production	Number of change in prototype
General	Time (rate conclusion of the activity), Cost (rate use of financial resources for activity), Quality (rate re-work) and Flexibility (time to implement change)			

7 Final Remarks

The goal of this article was to propose a design process performance measurement model that can help the decision makers involved in such process. It is important to highlight that the performance metrics applied to the design process must be carried out at the activity level. There is a risk of evaluating only the performance at the level of design process because some mistakes could not be identified as soon as possible to take corrective actions. On the other hand, if the evaluation is applied only at the activity level, there is a risk of gathering too much information which can make difficult the management job. Thus, it is recommended to apply performance measurement as far as the activity level. This recommendation could, however, be considered when one faces designs which involve a large amount of activities and tasks.

Another point to be outlined is the two design process's initial phases (informational and conceptual), where most important decisions are made, the performance evaluation should be approached with more strictness, due to the fact that a flaw in these phases could propagate all the way to the end.

Regarding the performance indicators to be applied, as exposed in the article, they should be chosen according to the phase. Because each phase has specific characteristics and goals, requiring an unambiguous indicator to better evaluate the design process phases.

The model was developed to fulfill a gap on the design process management, providing information about its performance and eliciting its critical points. Then the design team and its manager have conditions to allocate better the available resources. The model will be validated in two companies to check its feasibility. It is believed at this point the model comply with the initial requirements of a PMS, cited on the article.

The approach on how to implement and to use the model will be evaluated after the validation. The implementation of the model does not request many changes in the organization and in the PDP. The model systematizes the gathering of data in specific points, what facilitates and improves in the project management. The implementation and use of the system request training and allocation of resources. The developed model will allow the project manager to measure better the performance of design process.

References

[1] Back, N., "Metodologia de projeto de produtos industriais", Ed.Guanabara Dois, Rio de Janeiro, 1983.

[2] Pahl, G.and Beitz, W., "Engineering design: systematic approach" - 2 Rev.ed, Springer Verlag Berlin Heidelberg, New York, 1996.

[3] Hubka, V. and Eder, E. W., "Design science: Introduction to needs, scope and organization of engineering design knowledge", 2. ed. Springer - Verlag London Limited, Great Britain, 1996.

[4] Ullman, D. G. "The mechanical design process", 2 ed. McGraw-Hill Book Co, Singapore, 1992.

[5] Neely, A. (1998). "Measuring Business Performance", The Economist Books, London, 1998.

[6] Martins, R. A. "Sistema de Medição de Desempenho: um modelo para estruturação do uso", Ph.D. Thesis, Escola Politécnica, Universidade de São Paulo, 1999.

[7] Kaplan, R. S. and Norton, D. P. "A estratégia em ação: balance scorecard", 6. ed, Campus, Rio de Janeiro, 1998.

[8] Clark, K.B. "Project scope and project performance: the effect of parts strategy and supplier involvement on product development", Management Science, Vol. 35, N° 10, 1989, pp. 1247-1263.

[9] Griffin, A. "Metrics for measuring product development cycle time". Journal of Product Innovation Management ,Vol. 10, 1993, pp. 112-125.

[10] Griffin, A. "`The effect of project and process characteristics on product development cycle time", Journal of Marketing Research ,Vol. 34 N° 1, 1997, pp. 24-35.

[11] De Toni, A. and Tonchia, S. "Lean organization, management by process and performance measurement**",** International Journal of Operations & Production Management, Vol. 16, N°2, 1996, pp. 221-236.

[12] Pawar, K.; Driva, H. "Performance measurement for product design and development in a manufacturing environment", International Journal of Production Economics, 60-61 1999) 61-68.

[13] Driva, H. Pawar; K.; Menon, U. "A framework for product development performance metrics", International Journal Business Performance Management, Vol.1.No.3, 1999, pp. 312-326.

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