EFFECTIVENESS EVALUATION IN PRODUCT DESIGN AND DEVELOPMENT

Paes, Rodrigo Barros, rodrigobpaes@yahoo.com.br
Caminada Netto, Adherbal, adherbal@usp.br
University of São Paulo
Engineering College
Department of Mechanical Engineering
Av. Prof. Mello Moraes, 2231
São Paulo - SP - Cidade Universitaria
05508-900 - Brazil

Abstract. *This work approaches the subject of product design process evaluation from the designer`s point of view. In so doing, the authors hope to develop a more "friendly" method of evaluating the quality of the product design process and which may actually be considered useful by design organizations. It is also pointed out that the work involves two phases: the preliminary qualitative survey and the final quantitative survey. For the first phase, it is used a methodology combining SERVQUAL and the critical incident technique (CIT). The central concept of effectiveness factor is introduced and its relationship with satisfaction items and SERVQUAL dimensions is established. Based on the results of the preliminary phase, a coherent questionnaire is selected and submitted to a group of designers from a global company in the train manufacturing industry. Data provided by the answers are compiled, presented and discussed. An analysis is then carried out in order to identify management actions that are considered the most important ones, for both assuring and evaluating the effectiveness of the product design and development process. These actions are classified as assurance and evaluation management actions. Finally, based on the evaluation management actions, indicators are defined and a single and flexible effectiveness index is proposed, which can be calculated using both company and industry data for evaluation and benchmark purposes.*

Keywords*: Continual Improvement; Effectiveness; Product Design; Product Development; Train Manufacturing.*

1. INTRODUCTION

1.1. Objective

In present day competitive markets consumers are individually fought for by companies. Several similar products are available at a time and consumers, having an ample selection of goods and services to choose from, will carefully decide based on a balance of price and quality at the time of purchase.

Any product while being manufactured goes through a series of steps or phases. However, within its whole life cycle the D+D process may as well be considered a crucial step in determining whether it will result in success or failure as far as company interests are concerned. It is therefore advisable to propose ways to ensure the effectiveness of this process.

With such a concern in mind, it is necessary to devise and use reliable methods to evaluate the product design and development process that take into consideration the fairness of the adopted criteria, since any evaluation will have a bearing on interested parties: employees, suppliers, partners and others.

Whenever individuals are involved, the evaluation process will certainly influence their future behaviour, either boosting or crippling both confidence and motivation. Thus, it is the authors" opinion, that any evaluation method should depart from the professionals' point of view and proceed to solutions that could actually be employed in their day to day activities. In other words, that may be friendly enough to be considered of value to the ordinary person.

This paper intends to approach the subject of effectiveness evaluation from the designer's point of view, in order to identify those factors which are important when a company desires to evaluate and assure its capacity to continually improve the effectiveness of the design and development process. Then, to translate such factors into effectiveness evaluation and assurance management actions.

In so doing the authors hope to come up with a more 'friendly' method of evaluating the process of product design, and one that may be actually useful for designers and design organizations in the train manufacturing industry.

1.2. Motivation

It might be argued why designers? The answer is simple: Firstly they are the witnesses to the largest part, if not to the whole, of the project process. Secondly because, unlike clients and other interested parties, quality standards do not require that the designers' point of view be formally taken into account. For instance, a company which wishes to comply with requirements presented by ISO 9001 standard (ISO, 2008) is already confronted with the following: "as one of the measurements of the performance of the quality management system, the organization shall monitor information relating to customer perception as to whether the organization has met customer requirements". Thirdly, when listening to what designers have to say one avoids an important evaluation drawback as pointed out by Frye and Bauer (1996): "Also, the lack of formal measures of satisfaction with the appraisal process at any level in the organization adds to the difficulty of evaluating the process".

2. INDUSTRY AND METHOD

The work described in this paper refers to the train manufacturing industry. More specifically, it was carried out in a French multinational company operating in Brazil for more than fifty years and recognized for its capacity of innovation and expertise in the transportation field all over the World. Its units in Brazil employ some 2000 employees and supply products both for the local and foreign markets. The Brazilian engineering team plays an important role within the Company´s global structure and includes numbers in excess of 30 design engineers and 50 technical designers.

The method employed is essentially based on the work by Caminada Netto (2006) and comprises the following steps:

- Preliminary exploratory research;
- Structured research based on factors previously identified;
- Data analysis;
- Definition of management actions;
- Establishment of effectiveness indices;
- Conclusions.

3. QUALITATIVE PRELIMINARY RESEARCH

A preliminary exploratory research was carried out involving 20 designers in order to identify what is actually relevant in the product design and development process, according to the designers' point of view in the train manufacturing industry.

Based on the Critical Incident Technique (FLANAGAN, 1954 and HAYES, 1998), a questionnaire was used that requires a list of up to 10 "important" and 10 "unimportant aspects", in each designer's opinion, as regards the product design and development process effectiveness. It should be noted that although CIT is nowadays widely used to evaluate clients' satisfaction with goods and services, it was originally conceived to gather the opinions of pilots directly involved in combats during WWII, that is, those directly responsible for the tasks performed, as contemplated in this work.

Respondents willingly provided 230 "critical incidents", which were grouped by similarity and then classified into **satisfaction items**. The latter were made to refer both to product design and development needs and to the well known SERVQUAL dimensions proposed by Parasuraman, A., Zeithaml, V. A. and Berry, L. (1990) as shown in Tables 1 and 2.

Table 1. Description of consolidated dimensions.

DIMENSION	DESCRIPTION
TANGIBLES	Appearance of physical facilities, equipment, personnel, printed and visual materials.
RELIABILITY	Ability to perform promised service dependably and accurately.
RESPONSIVENESS	Willingness to help customers to provide prompt service
ASSURANCE	Possession of required knowledge, courtesy, trustworthiness and believability of contact personnel.
EMPATHY	Careful and personal attention given to clients.

Source: Adapted from Parasuraman, Zeithaml and Berry (1990).

Table 2. Design satisfaction items.

DIMENSION	SATISFACTION ITEMS
TANGIBLES	Documents Resources
RELIABILITY	Fundamentals Realization Results
RESPONSIVENESS	Plans Budget
ASSURANCE	Competence Experience Information
EMPATHY	Communication Motivation

Source: Adapted from Caminada Netto (2006).

The reason for establishing the aforementioned connection between product design satisfaction items and SERVQUAL dimensions is that although containing a high amount of software, and sometimes varying amounts of other product categories, design is basically a service supplied to either internal or external customers.

Once the preceding steps had been completed, the affinity diagram technique (Dellaretti Filho, 1996; Nayatani et al., 1994; Mizuno 1988) was used in order to translate the previous satisfaction items into the following six **effectiveness factors** capable of representing the effectiveness needs in the product design and development process as exemplified in Fig. 1:

1. Design preparation;
2. Organizational environment;
3. Information and knowledge;
4. Technical personnel;
5. Design realization;
6. Product success.

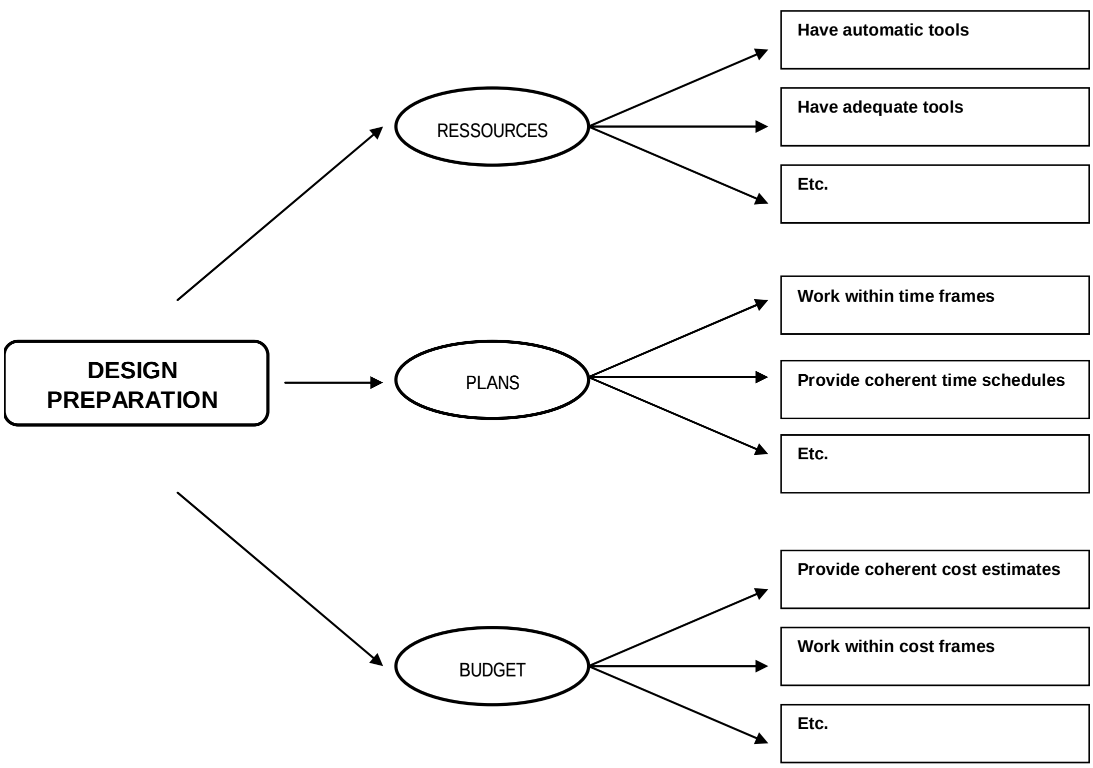

Figure 1. Effectiveness factors, satisfaction items and critical incidents

It should be noted that **effectiveness factors** constitute an important concept that allows one to link the opinion of a designer – a central actor of the socio-technical network (Latour, 1994) of product realization – to the formal activities of effectiveness evaluation of the product design and development process. The way they interrelate with SERVQUAL dimensions and satisfaction factors is shown in the affinity diagram of Table 3.

Table 3. Dimensions, satisfaction items and effectiveness factors.

EFFECTIVENESS FACTORS ▸ ▾ DIMENSIONS	DESIGN PREPARATION	WORK ENVIRONMENT	INFORMATION AND KNOWLEDGE	TECHNICAL STAFF	DESIGN REALIZATION	PRODUCT SUCCESS
TANGIBLES	RESOURCES				DOCUMENTS	
RELIABILITY			FUNDAMENTALS		REALIZATION	RESULTS
RESPONSIVENESS	PLANS BUDGET					
ASSURANCE			INFORMATION	COMPETENCE EXPERIENCE		
EMPATHY		COMUNICATION MOTIVATION				

4. QUANTITATIVE RESEARCH

4.1 Questionnaire

The first step required to go from effectiveness factors to the product design and development process evaluation in the second phase of the research work was to draw up a comprehensive questionnaire, and then to submit it to a selected group of 25 designers in the Brazilian operation of the above mentioned French train manufacturer, that had kindly agreed to cooperate with the authors´ research. Bearing in mind the similarities between the present work and that carried out by Caminada Netto (2006), it was decided to use the same in-depth questionnaire whose contents are shown in Table 4.

Table 4. Questionnaire Contents.

SECTION	EVALUATION OF ASPECTS RELATING TO
INTRODUCTION	Purpose and Instructions
DESIGN PREPARATION	Resources, Plans and Budget
WORK ENVIRONMENT	Communication and Motivation
INFORMATION AND KNOWLEDGE	Foundation and Information
TECHNICAL STAFF	Competence and Experience
DESIGN REALIZATION	Documents and Realization
PRODUCT SUCCESS	Results
THE WORD IS YOURS	Opinions and comments
PERSONAL DATA	Demographic Information

As can be seen, in addition to three complementary sections, the questionnaire is composed of six sections relating to each one of the effectiveness factors. Each section comprises 10 statements whose importance must be evaluated by the respondent from vital (6) to very small (1).

4.2. Results

Not one of the six sections showed an average value less than 4,80, which reveals a very good degree of adherence with the result of the previous phase, that is, with the critical incidents provided during the qualitative research. In other words, all the 60 statements were considered by the respondent designers as relevant to the product design and development process. This can be further verified by the following figures:

- Not one statement showed an average value less than 4,00;
- 53 statements showed an average value equal to or greater than 4,50;
- 30 statements showed an average value equal to or greater than 5,00.

It can be seen that such a biased result, with a significant frequency concentration on higher values, can only be due to a questionnaire made on purpose to adjust to results obtained in the preliminary quantitative research.

In order to clearly show those statements that are relatively more important among all others, they were classified in a decreasing sequence according to the respective average values.

5. CONTINUAL IMPROVEMENT OF THE PRODUCT DESIGN AND DEVELOPMENT PROCESS

5.1. Research results

The flowchart shown in Figure 2 presents a comprehensive view of the method herein employed.

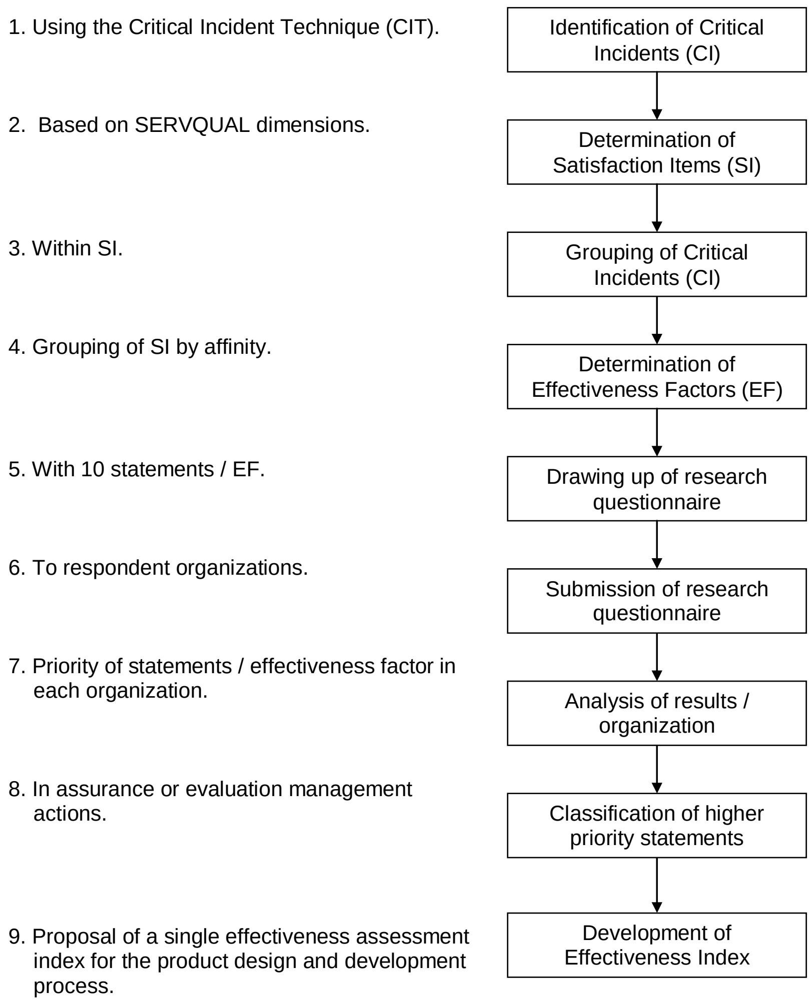

Figure 2. Work flowchart.

Research results actually supply two kinds of information, both important as far as the continual improvement of the product design and development process is concerned, namely:

- Information relative to management actions for effectiveness **assurance**;
- Information relative to management actions for effectiveness **evaluation**.

5.2. Assurance and evaluation management actions

A criterion for management actions classification was established according to concepts contained in the ISO 9000 (ISO, 2005) standard for quality management systems. Assurance actions are those indispensable to assure the efficiency of the design and development process, that is, to assure the best possible use of the available resources. Evaluation actions on the other hand are those aimed at verifying whether the desired objectives are being attained or not. In other words, whether the design and development process is effective or not.

As shown in Table 5 for questionnaire sections I to VI, the ranking of statements allows one to establish priorities when taking assurance management actions, or considering evaluation management actions to compose indicators and arrive at indexes capable of translating designers' concerns and opinions into figures needed to assess the effectiveness of the product design and development process.

Table 5. Selected statements for the adoption of management actions.

SECTION	STATEMENT	MA
I. Design preparation	1. Consultation with other involved areas for setting up time schedule.	A
	2. Compliance with time schedule for each design phase.	E
	6. Compliance with planned design budget.	A
II. Work environment	6. Feeling that one's contribution is important for the design process.	E
	8. Working conditions that assure concentration on design realization	E
	10. Mutual trust between company and employees.	E
III. Information and knowledge	1. Assessment of product market viability in the face of competition.	A
	4. Identification of potential design risks.	A
	5. Consideration of product quality as perceived by clients.	E
IV. Technical staff	2. Presence of members with practical experience in the team.	A
	4. Presence of members with prior design experience in the team.	A
	5. Concern with the maintenance of technical capacity.	A
V. Design realization	1. Records of the whole design history.	A
	3. Standardization of all that can be standardized (calculations, drawings etc.).	A
	10. Programming of design activities.	A
VI. Product success	5. Definition of a supplier base committed to product development.	A
	6. Assessment of adequacy of information for suppliers.	E
	7. Assessment of ease of product fabrication / construction.	E

MA – management action: A – assurance; E – evaluation.

5.3. Effectiveness indicators

Based on evaluation management action statements presented in Table 5 and considered as most important by the group of interviewed designers, selected indicators are shown in Table 6.

Tabela 6. Selected indicators.

Section - Statement	INDICATOR	Index
I.2	Compliance with time schedule for each design phase	I_1
II.6	Perception that individual contribution is important	I_2
II.8	Degree of concentration on design	I_3
II.10	Degree of mutual trust between company and employees	I_4
III.5	Product quality as perceived by clients	I_5
VI.6	Adequacy of information for suppliers	I_6
VI.7	Ease of product fabrication / construction	I_7

The selected industry indicators are also shown in Figure 3, where Roman digits inside rectangles correspond to questionnaire sections or **effectiveness factors**, while Arabic digits correspond to the respective statement of interest. Indexes outside rectangles, that is, I_1 to I_7, express the mathematical content of the respective indicators.

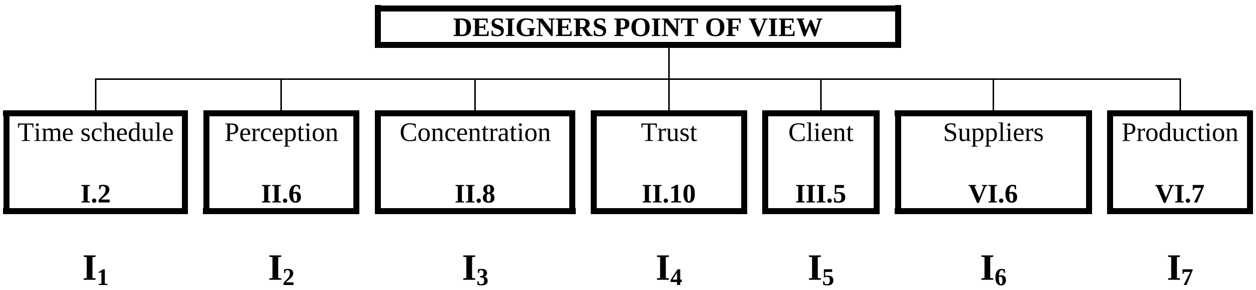

Figure 3. Structure of the effectiveness indicators for the design process in the train manufacture industry.

5.4. Effectiveness index

The structure of Figure 3 includes indices (I_1 to I_7) relating to those indicators that reflect the common or "industry" perception of all interviewed designers. Such indices can be combined to provide a single index of continual improvement, which can be denominated Effectiveness Index (**I_E**), and that, according to the overall approach followed by this work, will simply be equal to:

$$I_E = \frac{\sum_{i=1}^{n} I_i}{n} \qquad (1)$$

where:
- I_i = index relating to industry indicator "i";
- i = 1, 2 , 3 ... n;
- In the present case, n = 7.

It should be noted that expression (1) is sufficiently general to allow anyone responsible for effectiveness evaluation in a particular organizational context to choose those formulations considered more adequate to arrive at values for I_1 to I_6 (providing that all obtained values are expressed consistently, for instance from 0 to 100).

Furthermore, it is also possible to add indices from other data sources — if this actually increases the level of information contained in **I_E** — as well as to use **I_E** in combination with broader indicator structures. What distinguishes **I_E** is not its form, but rather its essence, that is, the fact that it reflects the designers' opinion through the selection of the indicators that originate it.

A great advantages of **I_E** is to be a single index and very easy to arrive at. Therefore, it is hoped that it will be an attractive index for the evaluation of the product design and development process in design organizations.

Another possibility that could be investigated would be to compare results between different industries, such as the automotive, aeronautical and train manufacturing industries. In so doing it might as well be desirable to stress some indicators, being enough to attribute weights to each one of the indexes that make up $\mathbf{I_E}$. Even then $\mathbf{I_E}$ would maintain its unity and simplicity, as shown in Equation (2).

$$I_E = \frac{\sum_{i=1}^{n}(I_i.P_i)}{\sum_{i=1}^{n}P_i} \qquad (2)$$

onde:

I_i = index relating to industry indicator "i";

P_i = weight attributed to industry indicator I_i;
i = 1, 2 , 3 ... n;
In the present case, n = 7.

It should be also pointed out that effectiveness indexes calculated using industry, sister companies or individual company data can be used independently or be combined. Thus, if experience in the use of the $\mathbf{I_E}$ concept indicates the convenience of such a practice, it is possible to simultaneously have indicators in said three levels for the evaluation of the product design and development process effectiveness.

6. FINAL REMARKS

The objective of this work was basically to identify, departing from the designers' point of view, and employing well established methods in the fields of quality engineering and management, those factors that are deemed important to enable a given organization in the railway industry to assure and assess its capacity to continually improve the effectiveness of the product design and development process. It is believed that the results provided by both research phases, as well as the analysis work on the available data allow one to conclude that the intended objective has been attained.

In principle, the objective of the present work would have been attained by the identification and distinction between **assurance** and **evaluation** actions for the effectiveness of the product design and development process. However, it is believed that such identification would have limited consequences without the adoption of the proposed **effectiveness index**. The use of such an index not only allows companies to individually assess their own product design and development processes, but also provides a useful means of comparison or *benchmark* with other similar processes. It is considered that the formulation of a **single effectiveness index**, which can be useful either for internal company assessments, or for external comparison purposes across corporations or industries, may be a significant contribution of the present work.

Before closing, the authors would like to point out what they believe to be perhaps the most important contribution of the present work: the **simplicity** of the general approach used. This simplicity allows the employed method to be readily and easily used in the everyday life of railway designers, as well as all product design and development organizations, exactly as intended from the very beginning

7. ACKNOWLEDGEMENTS

The authors wish to express their deep gratitude to all of the designers who willingly and often enthusiastically contributed their answers.

8. REFERENCES

Dellaretti Filho, O., 1996, "As Sete Ferramentas do Planejamento da Qualidade". Belo Horizonte: Fundação Christiano Ottoni, 183p.

Caminada Netto, A., 2006, "Quality management in product design and development: A contribution to effectiveness evaluation", Doctorate Thesis, São Paulo, Brazil, 295p.

Flanagan, J. C. "The Critical Incident Technique". Psychological Bulletin, Washington, jul., p. 327-358, 1954.

Frye T. J.; Bauer L. T., 1996, "Performance Appraisals in Quality Award-Winning Companies: Does Practice Follow Prescription?", Quality Management Journal 4, no. 1:40-56.

Hayes, B. E. 1998. "Measuring Customer Satisfaction". Milwaukee: ASQ Quality Press.

ISO, 2008, "ISO 9001:2008. Quality management systems – Requirements", International Organization for Standardization, Geneva, Switzerland.

Latour, B., 1994, "Jamais fomos modernos" (Nous n'avons jamais été modernes, Éditions La Découverte, Paris, 1991) São Paulo: Editora 34, 1994. 149p.

Parasuraman, A., Zeithaml, V. A. and Berry, L.L., 1990, "Delivering quality service: balancing customer perceptions and expectations", Ed. Collier Macmillan, London, England, 226p.

Hayes, B. E. 1998. "Measuring Customer Satisfaction". Milwaukee: ASQ Quality Press.

Mizuno, S., 1988, "The Seven New QC Tools". Cambridge, MA, EUA: Productivity Press, 1988. 322p.

Nayatani, y et al., 1994, "The Seven New QC Tools: Practical Applications for Managers". Tokyo: 3A Corporation. 181p.

9. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.