Using Axiomatic Design for minimizing QFD application difficulties in NDP: research proposal and preliminary definition of first and second hierarchical levels

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Abstract: This paper describes a proposal of a systemic model for applying QFD, designed to reduce its application difficulties. This model is constructed based on Axiomatic Design (AD). The paper presents the steps of this on-going research project, namely: a literature analysis, a field research to collect empirical data, and the application of AD. The results from those steps made possible to establish a theoretical basis of this work. This basis enabled to initiate the application of AD to the development of the proposed systemic model for QFD application, which is described in the end. Preliminary results suggest that AD is able to set a QFD application model that might minimize its inherent difficulties and constrains when using the method.
Keywords: axiomatic design, QFD application, QFD experienced difficulties.

1. Introduction

The ability to launch new products to market quickly and successfully is fundamental to any customer driven company. One of the methods that contribute to that is QFD – Quality Function Deployment. There is no doubt that QFD is an effective method that for new product development since it identifies customer demands and translate them into product attributes.

Historically, QFD has emerged in Japan in the late 60's. In the early 80's, the QFD product development approach was adopted by American (CRISTIANO et al., 2000) and European industries, e.g. in Italy (ZUCCHELLI, 1995), in Sweden (EKDAHL & GUSTAFSSON, 1997), and in the UK (MARTINS & ASPINWALL, 2001). Later on in the 90's, it started to be used in developing countries, e.g. in Brazil (CAUCHICK MIGUEL, 2003). By adopting QFD for product development, organizations have their inherent benefits, as pointed out by a number of studies (e.g. GRIFFIN, 1992; CRISTIANO et al., 2000; 2001; MARTINS & ASPINWALL, 2001; CAUCHICK MIGUEL, 2003).

Nevertheless, the literature (CRISTIANO et al., 2000; 2001; MARTINS & ASPINWALL, 2001; CAUCHICK MIGUEL, 2003; 2005) has pointed out that companies have experienced difficulties when applying QFD. In a number of times those obstacles discourage organizations to adopt the method. For this reason, it is relevant to develop means to minimize QFD application constraints so companies can have its inherent benefits. In this sense, the purpose of this research is to use Axiomatic Design to develop a systemic QFD application model that decrease its difficulties. In this article, the first stages of this on-going research project are presented. Those stages include the results of a literature analysis of QFD difficulties, and a field research with QFD users to identify requirements for QFD application. The paper also considers the results of a past field research thought semi-structured interviews conducted in the past in companies that have applied QFD in Brazil.

2. Research methodology

This work is part of an on-going research project which the objective is to develop a systemic model for QFD application. This model aims at eliminating or minimizing QFD difficulties when applying the method. This work can then be categorized as a theoretical-based research since its purpose is to develop such a conceptual model. The model is based on the use of Axiomatic Design (AD), developed by SUH (1990) in the late 70's. Its underlying hypothesis is that there are fundamental principles that govern good design practice (SUH, 2001); AD key components are domains, axioms, hierarchies, and zigzagging (GONÇALVES-COELHO, 2005), described further ahead in this paper.

In order to develop the model, a preliminary work had to be done, based on the following stages: 1) Review of the literature on QFD difficulties and a subsequent data organization by using affinity diagram as well as tree diagram; 2) Identification of difficulties, requirements when applying QFD based on

empirical data; 3) Develop a theoretical model based on previous stages by adopting AD as a framework. The objective of the present paper is to present stages (1) and (2) and outline some aspects of stage (3), developed so far. Table 1 shows the stages and methods used for data gathering and analysis, followed by their description.

2.1. Literature review

The literature review was conducted by applying four steps suggested by MARCONI & LAKATOS (2002): identification, location, gathering, and record. To identify the sources various data base were used, such as Blackwell, Cambridge University Press, Emerald, Gale, IEEE, Oxford University Press, Science Direct On-line, and others. In addition, the Internet was also accessed as well as Libraries (physically and electronically). More recent publications were considered, ranging from 2000 to 2006, resulting in 157 articles individually recorded in MS Excel® spreadsheets.

Affinity diagram and tree diagram were use to group the following data by similarity and hierarchically: paper scope, QFD conceptual definition, experienced difficulties when using the method, usage benefits and, finally, recommendations for QFD application, resulting in an individual diagram for each group of data.

2.2. Field research

Firstly, data from a previous research (CARNEVALLI & CAUCHICK MIGUEL, 2003) were used. That work consisted of interviewing company representatives (in the past) who have been identified as benchmarks as QFD users in Brazil. Four companies involved in various ranges of industries were investigated. Semi-structured, tape-recorded interviews with individuals involved with product development were the main technique employed to gather the data *in loco*. Other methods for gathering data such as non-participant observation and document analysis were also employed. A ten-question interview protocol check-list was adopted on which notes and annotations were made as the interview progressed. The interviews lasted about two hours, ranging from one hour to 2.5 hours. The aggregation of results was done *a posteriori*. In this phase raw data were assessed once again to be used in the present study. The purpose was to extract difficulties in QFD usage.

Secondly, a field research was conducted by sending a questionnaire to 21 companies that participated in a previous survey (CAUCHICK MIGUEL, 2003). Most of those companies belong to the top 500 companies operating in Brazil (based on annual sales) and can be considered as mature organizations in terms of QFD application. The companies were previously contacted and the questionnaire was sent by surface and electronic mail. However, before sending the questionnaires, two pilot tests were carried out to enhance the instrument in both form and contents. From the pilots, some questions were changed to improve their understanding and new questions were introduced resulting in a 17-question instrument. Multiple questions were recorded at MS Excel® spreadsheets and open-ended questions were coded for further analysis. Similarly to the previous phase, data were used to extract difficulties in QFD usage and requirements of its application.

2.3. Axiomatic Design

As mentioned before, Axiomatic Design is used to develop a model of QFD application. Under the AD point of view, the design outputs pertain to four distinct domains (SUH, 1990; GONÇALVES-COELHO, 2005): the customer domain, the functional domain, the physical domain, and the process domain. The design process initiates with the customer domain with the identification of customer needs, i.e. the characteristics that customers are looking for in the 'design object', be it a product, a process, or any other tangible or intangible system (GONÇALVES-COELHO, 2005). Mapping between the customer and conceptual domains is then used to find out the functional requirements (FRs) of the design object (SUH, 1990; GONÇALVES-COELHO, 2005). Once this is done, another mapping makes the translation of the FRs into design parameters (DPs), which are the set of properties that describe the object in the physical domain. At last, mapping from the physical domain to the process domain leads to the process variables (PVs), which outline how to make the design object.

In the case of this on-going project, it is necessary to collect customer characteristics, requirements and

Table 1. Summary of research methodology.

Stages	Methods for data gathering	Methods for data organization and analysis	Main results
1) Literature review	Bibliography search on QFD (referred journal papers)	Bibliography records, affinity diagram; tree diagram	Literature mapping on QFD difficulties
2) Empirical data	Company interviews (data from previous work); questionnaire	Interview transcription and content analysis	List of difficulties and requirements when applying QFD
3) Theoretical development	Stages (1) and (2) and theoretical development	Axiomatic Design	Theoretical systemic model for QFD application

expectations to construct the customer domain. The 'customer' here correspond to QFD users, represented by QFD team members, project leaders, functional managers, and top managers. Therefore, the first step is to gather their requirements and expectations. In order to do so, two main sources were used: QFD literature and empirical data, respectively, stages 1 and 2 in the research methodology (Table 1). The findings from those sources are described next.

3. Findings

Preliminary results are presented according to the three steps showed earlier in the research methodology session.

3.1. Results from QFD literature review

After organizing all data from the 157 articles by using affinity diagram and tree diagram, the following results can be emphasized:

QFD definition: large proportion of authors (more than 33%) are still defining QFD as a synonym of house of quality or its aims. Only half of publications present a comprehensive QFD definition as stated by AKAO (1998).

QFD benefits: 253 benefits were cited in the papers that were organized as non-tangibles and tangibles. After organizing them, almost 80% were related to the former and the remaining corresponded to the latter, which were not as frequent as one would expect. Both tangibles and non-tangibles were further grouped into benefits 'within the QFD project' and 'outside QFD project'. For instance, a tangible benefit within the QFD project can be 'reduced lead time' (BOUCHEREAU & ROWLANDS, 2000) and an outside QFD project can be 'increased revenue' (KARSAK et al., 2002). On the other hand, a non-tangible benefit within the QFD project can be 'improved teamwork communication' (JUSEL & ATHERTON, 2000) and an outside QFD project can be 'increased customer satisfaction' (GONZÁLEZ et al., 2004). In summary, the results indicated that benefits within the project are more frequently cited.

QFD main pre-requisite for its application: 56 citations were identified. The most frequent are 'top management support' and 'personnel and other resources to the QFD team'.

Obstacles for QFD general usage: 56 citations concerning 'external' difficulties when using QFD were identified (i.e., difficulties that are nor directly related to the QFD application itself). When organizing these data by affinity and hierarchically, the following difficulties emerged: lack of 'top management support' (GINN & ZAIRI, 2005), 'limited resources' (KENGPLO, 2004), and (lack of) 'knowledge about the method' (MARTINS & ASPINWALL, 2001).

Obstacles for QFD specific application: 113 citations concerning specific QFD application difficulties when using QFD were identified. The most cited was 'difficulties due to the size of matrix' (BOUCHEREAU & ROWLANDS, 2000). After organizing data using an affinity diagram and a tree diagram, the main methodological QFD difficulties were raised. More than 78% are related to the development of the quality matrix, associated with: 'interpret customer voice' (GINN & ZAIRI, 2005), 'unclear relations between customer requirements and quality characteristics' (CHAN & WU, 2005; FUNG et al., 2006). Therefore, reduce methodological QFD difficulties when developing the quality matrix is a key factor to motivate and increase QFD usage.

Recommendations for QFD usage: 194 were identified. By organizing data through affinity and tree diagrams, the main groups are related to recommendations to apply QFD and also associated to the development of the quality matrix (customer requirements versus quality characteristics). Recommended solutions are diverse. For example to assist in the voice of customer, the recommendation is the use of Kano model (SHEN et al., 2000); to define level of importance is the application of triangular fuzzy numbers (CHAN & WU, 2005); to translate customer requirements into quality characteristics is the adoption of design knowledge hierarchy (YAN et al., 2005), and others. A trend have emerged recently: the use of fuzzy logic and AHP, together or separately within the matrices.

3.2. Results from field research – Revisiting previous collected data

An earlier data gathering (CARNEVALLI & CAUCHICK MIGUEL, 2003) indicated the following user expectations concerning QFD application: 'to support new product development', 'interpret customer requirements', 'become leader in new product development', and 'develop a product that can embrace various markets'. A re-analysis of raw data has revealed other user expectations that were not identified previously: 'to understand relationship between quality characteristics with manufacturing process parameters', 'QFD contribution to assure product quality', and 'QFD contribution to minimize project risks'. It can be verified that the expectations are somewhat related to the inherent method benefits. In addition, there is an obstacle to be overcome: both managers and team participants have a negative impact when seeing a matrix at the first time. According to some interviewees, people are scared with the contents in the matrix (e.g. numbers, symbols, etc.) pre-judging the method as very complicate.

3.3. Results from field research – Data gathered recently

Seven leading QFD companies have answered the questionnaire, from which users of the method within the organizations were considered as 'QFD customers' (team

members, functional managers, and top managers). Among the respondents, the majority of users were team members or team leaders. In addition, some people provided QFD training or were QFD facilitators. Hence, it was possible to get different perspectives on QFD usage.

Concerning the introduction of QFD in the company, half of respondents considered that QFD is difficult to implement but they expected to achieve its benefits. Overall, the method did not have resistance to be introduced but they did consider it complex and time consuming at the beginning. Moreover, some reported that the barriers of some functional areas were associated with not having a top-down decision and the need of having a experienced facilitator to support implementation.

The respondents were asked to report their expectations after QFD has been implemented, i.e. when the method had been part of the day-to-day activities. They expected QFD to have a certain degree of difficulty to be used routinely, to achieve its benefits, and to be applied it in various projects. One respondent was quite skeptic about QFD. The expected benefits from the method agreed to those suggested in the literature under the point of view of team members, team leaders, and functional managers. Not all companies were aware about expectations from top managers concerning the method either in terms of its benefits or the required resources.

In summary, almost all respondents had expectations that the method is rather complex and the level of difficult was somewhat associated with the support of the functional areas involved with the project. Despite the difficulties, tangible and non-tangible benefits were pointed out by the respondents. Moreover, they were satisfied with the results from QFD usage. Unanimously, the respondents recognized that there is a need to facilitate QFD implementation and day-to-day application. Therefore, data analysis confirmed that the reduction of QFD difficulties is part of customer requirements (customers here as QFD users) then justify the development of the model based on Axiomatic Design.

3.4. Model development by Axiomatic Design

Subsequently to the analysis of the literature and empirical data (previous sessions) a customer attributes (CA) should be generated. After identifying the CA, the first level of functional requirements (FR) should be developed. Next, is necessary to deploy FR_1 and DP_1 in various sub-items hierarchically. This deployment follows a zig-zagging process (called hierarchical decomposition). The design process should be developed in a top-bottom manner until the design object can be defined with sufficient level. This process is oriented according to the axiom 1 (the independence axiom that states that the independence of functional requirements must always be maintained). The developed tables (QFD experienced difficulties; QFD pre-requisites; and QFD recommendations) are used to deploy FRs and DPs. DPs will be developed based on axiom 1. The highest-level FRs in the hierarchy's highest level can be represented by the matrix:

$$\begin{bmatrix} FR_1 \\ FR_2 \end{bmatrix} = \begin{bmatrix} x & 0 \\ 0 & x \end{bmatrix} x \begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix} \quad (1)$$

To define the customer domain, in fact, there are different 'QFD customers': direct and indirect ones. Direct QFD customers are the users, i.e. QFD team members, functional areas managers and top management. Indirect customers are company clients that receive products (developed with QFD) in the market. Then, customer attributes are (extracted from previous research steps):

Team members: $CA_{1\,user}$: 'less difficulty to introduce QFD in the organization'; $CA_{2\,user}$: 'QFD as an effective method to develop new products'; $CA_{3\,user}$: 'use QFD to register and spread out knowledge of new product development'; $CA_{4\,user}$: 'less difficulty to use QFD in day-to-day activities'.

Managers involved with QFD: $CA_{1\,manager}$: 'QFD as an effective method to support product concept and planning' and $CA_{2\,manager}$: 'generate better results with QFD compared to the current way of working'.

Top management: $CA_{1\,top\,management}$: 'achieve operational improvements with QFD' and $CA_{2\,top\,management}$: 'QFD generates return of investment (prevention quality costs)'.

Company clients: $CA_{1\,Co.\,client}$: 'receive a product that fulfil theirs needs'.

After identifying customer attributes, those should be met through the choice of functional requirements. Since it is very difficult to fulfil all customer requirements, the most important ones are chosen. So, $CA_{4\,users}$ ('less difficulty to use QFD in day-to-day activities') was chosen because this CA consider partially the remaining customer attributes ($CA_{1\,user}$, $CA_{2\,user}$, $CA_{1\,manager}$, $CA_{2\,manager}$, $CA_{1\,top\,management}$, and $CA_{1\,Co.\,client}$.

Since the CA to be satisfied is chosen, the first FR to meet $CA_{4\,user}$ ('less difficulty to use QFD in day-to-day activities') 'less difficult for applying QFD in a day-to-day company activities'. In order to make this CA occurs, the inherent difficulties when QFD is applied should be minimized.

After identifying the CA, the first level of functional requirements (FR) should be developed. So, FR_1 can be: 'minimize difficulties when applying QFD'. This FR_1 can be met by the following design parameter (DP_1): 'QFD application model to minimize QFD usage difficulties'.

Then, other levels in the hierarchical decomposition are to be developed. Those are outlined next.

3.4.1. Defining the second level in the hierarchical structure

As mentioned before, after defining the first level in the hierarchical structure, FR_1 and DP_1 should be deployed. Then, the following question is raised: which difficulties when apply QFD are to be minimized be the axiomatic design model? Looking into the literature a number of issues are found out. FR_1 is then detailed in the following levels: FR_{11}: develop quality matrix; FR_{12}: integrate functional areas; FR_{13}: develop QFD conceptual model; and FR_{14}: monitor QFD application. By defining the second level of functional domain, DPs should be detailed in order to respectively meet those requirements (FRs). Those are: DP_{11}: evaluation of solutions proposed by the literature about the matrix; DP_{12}: use of cross-functional teams; DP_{13}: characterization of QFD goals; and DP_{14}: evaluation of application results. After deploying FRs and DPs, a consolidated project matrix is to be created. It aims at verifying if the relationship among FRs and DPs do not violate axiom 1. This matrix is:

$$\begin{bmatrix} FR_{11} \\ FR_{12} \\ FR_{13} \\ FR_{14} \end{bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & X & X & 0 \\ 0 & 0 & X & X \end{bmatrix} x \begin{bmatrix} DP_{11} \\ DP_{12} \\ DP_{13} \\ DP_{14} \end{bmatrix} \quad (2)$$

In matrix 2, "X" indicates a strong relation between FR and DP. This is a decoupled project matrix and hence satisfies axiom 1.

In order to determine the application sequence of the model, a flow chart that represents model structure and linking points will be developed. This chart is defined according to the results from the final consolidated project matrix (an evolution of matrix 2 in further hierarchical levels). This is a future work to be done.

4. Concluding remarks

Since the present research is not completed it cannot yet be fully conclusive. However, some concluding points can be raised. Even after many years of QFD development, once again it can be confirmed (from the literature) that the method is conceptually limited to the quality matrix (house of quality). This might influence its application since users are not able to have the full potential of the method. The literature also pointed out the necessity of searching ways to minimize constraints associated with lack of support, resources, and training. Concerning QFD benefits, tangible ones are less cited than non-tangibles either in the literature or in the practical applications (although this is limited to a few studied companies). Perhaps an useful future work could consider a more tangible demonstration of its benefit.

Regarding the field research, previous data as well as new data gathered from some mature QFD users confirmed a relevant initial expectation: the method would be difficult to implement and apply. This result pointed out one of the reason why the method is not extensively applied in various projects. It suggested to reduce QFD difficulties might be part of QFD customer requirements (presupposition of this research). Therefore, an initiative that aim at minimizing those difficulties may be useful, justifying the application of Axiomatic Design with this intent.

In order to do that, Axiomatic Design was used. As required by Axiomatic Design, customer attributes were identified, followed by functional requirements and design parameters. Them those were deployed until the second level. The preliminary results suggested that Axiomatic Design is able to set a systemic model for QFD application that might minimize its inherent difficulties and constrains when using the method. Further work will concentrate on deploying FR at more detailed levels.

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