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# Quality Problems in Complex Systems even Considering the Application of Quality Initiatives during Product Development

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**Abstract.** This paper aims to present the importance to create a new and lean process for identifying potential failures during development of complex products. It has been identified in the literature and in companies the lack of knowledge to select the most appropriate quality tools in order to solve and or prevent the potential problems that might appear during the prototype development and launching phases of complex products. Literature about quality tools are easily found, therefore there is much questioning on the appropriate quality tools to be selected and how, where and when they should be applied. Based on this, this article aims to provide the understanding of the quality tools during program development and direct their application (Design for Six Sigma, Design FMEA, QFD, TRIZ, Robust Engineering, DFM and DFA). It is noticeable that even applying quality tools during all phases of complex products the failures still exist and, therefore, still cause a lot of problems to the companies that can be letal (example: at aerospace, automotive, metallurgical, medical and others companies) (CANCIGLIERI, OKIMURA, 2015) [1]. Besides all this, this paper will provide the evidence that something in addition to quality tools application should be done to guarantee design robustness of complex products. Two case studies provide evidences that only performing quality tools analysis like Design FMEA, DFSS, DFM, DFA and others is not enough to achieve the objectives of quality, as well as competitiveness, that large companies are looking for. A new and lean process is necessary to evaluate and identify the failures in a robust and definitive scenario. The new processes is based on the concept of Lean System Engineering as well as Lean Engineering Principles and propose to create a dual process to the systems engineering process mitigating the risks of failing what should be done as planned in the product and its life cycle processes.

**Keywords:** Lean System Engineering, Lean Engineering Principles, Mitigating the risks of failing.

## Introduction

This work is designed to emphasize the importance of the application of quality tools in the development process of complex products (PDP) and highlight the need to have something additional to this process for quality improvement, since, even with the effective implementation of quality plan, failures continue to be weakness points of product.

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The identification and failures analysis should be done throughout the product development process from the beginning of the project conception until the design release phase in order to make the product robust against failures that also matches with customer satisfaction in innovative products (D. CHANG, C.H. CHEN, 2014) [2].

It will be shown, through case studies analysis, that quality problems in systems and/or complex products remain relevant even with the favorable scenario for analyzing and identifying potential failures through quality tools at the right time of program development, that is, since the beginning of conceptual phase of the project.

One of the major problems currently found in the PDP is to define the correct application of Quality Tools (what and when) to the solution and or prevention of potential problems that may occur in the phases of prototypes and even after the launch of the product on the market (BERTELLI, 2006) [3].

It is easily found in the literature the information about the Quality Tools, but there is a big gap in the orientation of their correct application as well as the outcomes if, after their application, the quality results match with the objectives of the stakeholders of organization. According to Griffin (2010) [4] faults still exist even considering that all procedures were done by the company.

This paper shows, through case studies analysis, that failures in systems and/or complex products remain relevant, even with the favorable scenario performed since the beginning of the design phase relative to the application of quality tools in both case studies that will be described.

The purpose of this work is, at the same time, illustrate the importance of the application of quality tools, but also emphasize the need to map (R.C. BECKETT, 2015) [5] a new process that supports this application in order to make the development of systems and/or complex products robustness against failures, once, there are opportunities for improvement in the identification and analysis of potential failures during the development of complex products.

## 1. Problem Search

Currently there is a strong focus on developing and implementing the DFMEA (Design Failure Mode Effects and Analysis) [6] in various situations. ISO [7] and QS [8] standards show this direction. However, it is important to verify and analyze whether DFMEA application is appropriate for the specific situation that is being analyzed.

The identification and failure analysis are performed later during the product development phase, since this analysis is made, in most cases, when the architecture phase is already defined. There are contrary situations, that is, the analysis and fault identification follows the appropriate process at the correct development phase time, but the quality problems still affecting the product performance.

It is recognized that failure is a common occurrence at the projects and that the project's success is often a result of the reaction to faults (LOUTHAN, 2010) [9].

The effective application of DFMEA is recommended for the vast majority of cases, while in other scenarios, it is necessary to combinations and applications of other quality initiatives tools and, also, there are situations where the application of DFMEA does not add high value in the development of that particular project (BERTELLI, 2006) [3].

So, it becomes important the need to guide the implementation of Quality Tools for different situations of project and verify that the application reached the organization's goals.

## 2. Definitions of Quality Tools

For understanding the integrative character of Quality Tools, the comprehension of each initiative is necessary. Follow are shown - in brief - the tools that are identified as the most suitable and Known to be applied during the PDP process focusing, specially, on quality; but they are not limited to those defined herein.

More detailed information about the these as well as others quality tools initiatives can be found in several references including those mentioned in this work.

The definition of the quality tools initiatives done by theirs respectives authors have the goals to be collaborative (BORSATO, PERUZZINI, 2015) [10] with the industry and with the improvement of the world.

### *2.1. DFSS (Design For Six Sigma) [11]*

The method Design for Six Sigma (DFSS) became widespread and applied in 1970 by Motorola and, in the 90s, by General Electric. Similarly, the concept of quality itself has several definitions associated with the DFSS method. Therefore, the following definition is the result of experience obtained in specifics “Case Studies”.

The DFSS is defined as follows: "Design for Six Sigma is a method used in creating products and processes that reach a level of quality desired by the customer through the identification and optimization of critical parameters of the project”. DFSS should be assimilated as a new manner to work in the process of product development.

The DFSS goals is to become possible to engineering technical area to reduce and optimize their costs and design a product into Six Sigma levels once all current business in the world is governed by the following equation:

$$PROFIT = REVENUE - COSTS \quad (1)$$

As "PROFIT" is a matter of survival in the highly competitive market in which profit operate companies, the variable "REVENUE" is no longer controlled by companies and was controlled by the volatile market, that imposes it as subtle way, but decisive. So the only variable on which companies can still exercise control to increase your profits is just the "COST".

From the perspective of variable cost, DFSS can be defined as a tool that seeks to find the ideal balance point in the project between consumer satisfaction and the development and production costs of the product, also called "Risk Consumer x Producer".

By drawing a comparison between Six Sigma and DFSS, specifically for product development inside the industry, there are five distinct stages in a project:

a. research
b. development
c. tests and prototypes

d. production
e. sales and after sales.

Considering these steps, Six Sigma efforts are applied only in the last two steps - production, sales and after sales - in which, both the product and the process already exist. Therefore, it can be said that defects are easy to be seen, but the costs to correct the defects are very high. On the other hand, DFSS is applied in the initial two steps, that is, research and development. Opposed to Six Sigma, defects are hard to be seen during DFSS application, but correction costs are low.

Note that the defects are hard to be found by DFSS and, because of that, is very important applies others engineering methods to support its analysis like: CAE simulation, prediction methods to anticipate results of project performance as well as provide estimation about design behavior during its life cycle once there is no actual data. The task of carrying out this correlation is the great challenge of DFSS.

The DFSS is to be understood as a way to:

- Identify critical functions affecting the quality level required by the customer;
- Create specific engineering measurements for these functions;
- Understanding the system level functionality;
- Identify the nominal requirements and its variation for project parameters;
- Predict and optimize rather than correct;
- Analyze "intelligently" the best "Quality Tool" to be used to optimize a project, resulting in a more reliable product to the end consumer.

By DFSS application, the projects will be designed taking in consideration a clear customer needs that will be translated in technical language through system requirements descriptions. DFSS will also generate more robust and effective development process characterized by no sensitivity of variation of the manufacturing process as well as by their users or any other possible change in the environment.

### *2.2. QFD (Quality Function Deployment) [12]*

Developed in Japan in 1966 by Dr. Yoji Akao, Professor of Industrial Engineering in Tokyo.

In 1972, QFD was used in the shipyards of Mitsubishi in Kobe (super tanker manufacturing that are products that have requirements clearly defined by their users).

In 1974, was created the Committee of the Foundation for the QFD within the JSQC (Japonese Society For Quality Control). From 1977 to 1984 began the use of QFD in the automotive industry (Toyota). In 1983, QFD is introduced in the US by Dr. Akao through an article in Quality Progress magazine. In 1985, QFD was first time applied in US by Ford and General Electric.

QFD is a tool that translates customer requirements into business requirements along the phase of the product development cycle since the initial activities of research until distribution phase.

Follow some principles of QFD:

- Customer focus is the key. Satisfied customers keep business growing. It is essential to have a deep understanding of their needs,
- Development of the product in proactive basis is more effective than in reactive base,

- It is a methodology for teamwork (Concurrent Engineering and or concurrent), enabling the participation of more people, with a greater degree of involvement and focus.

QFD is developed in four phases (or arrays):

- Phase (Matrix) 1: Product Planning. At this stage are determined customer requirements & company requirements

  Objectives:

  1. Identify customer requirements (Voice of Customer),
  2. Determine overall requirements of product performance,
  3. Determine goals for product requirements,
  4. Determine items for further studies.

- Phase (Matrix) 2: Deployment of the Project. At this stage are determined requirements company & features parts.

  Objectives:

  1. Select the best design concept,
  2. Identify critical parts,
  3. Identify critical features of the parts,
  4. Determine goals for the characteristics of the parts.

- Phase (Matrix 3): Process Planning. This stage determines the parts characteristics & process operations

  Objectives:

  1. Determining the best combination between process and design,
  2. Identify the critical process parameters,
  3. Set goals for the process parameters,
  4. Select items for subsequent development.

- Phase (Matrix 4): Production Planning. This phase determines the process control & requirements controls.

  Objectives:

  5. Translate the provisions of previous phases in terms of operating activities, so that all people involved in the QFD process understand what need to be controlled to meet with key points of the Voice of the Customer.

The intention to perform the deployment in arrays is to define the actions and tasks on that are really important.

Benefits of QFD:

- reduction of development cycle time (30 to 50%),
- less problems in the implementation of the product,
- reduce costs since the beginning of production phase,

- reduction of field problems,
- own knowledge base,
- documentation,
- integration between functions

*2.3. FMEA (Failure Mode Effects and Analysis) [6]*

Originated at NASA in 1960, was included in Military Standard number 1629 (American Military Standard). Soon after, Ford Motors adapted the theory and initiated using FMEA in the development of their automobile vehicles.

The FMEA is based on preventing potential field failures. It takes part of its study to analyze the index RPN (Risk Priority Number) which is the result of multiplying three other indexes:

- Severity,
- Occurrence,
- Detection.

These indexes vary numerically from 1 to 10. The numerical value of RPN index is purely subjective.

RPN index indicates that a preventive action needs to be taken to prevent potential problem does not occur. The numerical value of this index varies among the companies. There is no policy or procedure, which determines the lowest value for this index.

Companies generally stipulate the value of the RPN index equal to 125. This number is derived by multiplying the severity, occurrence and detection indexes. In case those 3 indexes – severity, occurrence and detection - be equal to 5 (5 middle of full range – 10 is the maximum index), the product between them results in 125.

It is adopted when this ratio is the value of or higher than 125 a preventive action should be taken to avoid that potential problem does not occur. The goal is to reduce this index rate to understandable range below than 125.

The DFMEA analysis applies to product design as well as at manufacturing process. For this reason, DFMEA is called as Design FMEA and PFMEA is called as Process FMEA.

*2.4. Robust Engineering (Taguchi Methods) [13]*

This method was developed by Genichi Taguchi as of 1950. It is a method used for designing products and processes in order that they suffer minimal impact of external factors such as manufacturing conditions, environment and use by the consumer. This is achieved using the principles of the Energy Transformation in order to optimize performance for the designated product instead of attempting to control the undesirable symptoms or problems presented by it (product).

Application of Robust Design enables to:

- Develop products and processes that behave consistently (reliability) under a wide range of conditions of use throughout their life cycle (durability),
- Maximize robustness - improve the function required of the product, developing and increasing their insensitivity to factors that tend to degrade performance.

- Develop or modify parameters of products and processes to achieve the desired performance at the lowest cost.

Following will be defined the TRIZ. It should be relevant to describe that even TRIZ not being a quality initiative tool, it has a very noticeable application with regard to technological innovation.

*2.5. TRIZ (Theory of Inventive Problem Solving) [14]*

Russian theory developed by Genrikn Altshuller for the development and creation of new ideas that can contribute to the project improvement.

The TRIZ is based on:

- be a method to get innovation in a systematically manner,
- be a method to, consciously, help the growing of the technologic systems,
- a tools to eliminate engineering conflicts without making "Trade-off",
- a way to dramatically increase the knowledge and creativity ,
- a way to share the experience of the brilliant inventors in any time,
- in fact the great majority of the basic problems which are faced today by the engineers have been solved in the past, typically in a completely different industry and in a totally disconnected scenario, often using a different technology .
- using it, there is no more necessity to wait for a "new inspiration" or analyze them through known methods of "trial and error".
- Basically, the TRIZ study provides:
- an effective way to explore an extensive "knowledge base",
- cover numerous physical, chemical and geometrical effects,
- in tuning with the experience of different industries and elements of science and technology,
- increases the engineer's capacity for rapid development of innovative solutions to their toughest technical problems.

*2.6. DFM / A (Design for Manufacture / Assembly) [15]*

The project focused on manufacturing aims to integrate the planning of the manufacturing process with the product development. The use of these techniques requires the systematic involvement of the product development teams and manufacturing process teams, which promotes an efficient feedback of requirements to accommodate industrial needs during conceptual phase of product development. This integration helps to reduce development time by eliminating rework cycles, usually made to facilitate the assembly line process and possible delays arise when the current resource production are not considered in product development time.

These are the Quality Tools, which will be the focus of the next section that will address the issue of Determination of the Oriented Application of Quality Tools in Product Development through comparative table.

## 3. Methodology

As initially described, it will be shown below through a matrix "i, j" a combination of alternatives which facilitate the determination of which quality toll should be applied vs. the project configuration.

All studies should be initiated during the conceptual design phase. The analysis of possible failures evaluated from this stage contributes to the development of design improvement, reducing rework as well as structural cost organization. Examples of these costs are: hours spent on project development of a non-robust design and additional budget to be invested in a design that will be changed due to wrong decisions done during conceptual design phase.

So, as it is important that all studies began in conceptual design phase is important for them to be finalized before the final release of the project - final format design of the project. Any changes arising from the failure analysis which are done through DFMEA, DFA, DFSS studies, etc should be implemented at the design release phase. The proper conduct of this procedure prevents project delays, increases the possibility of investment earnings and increases the "know how" for future projects.

### *3.1. Determination of the Oriented Application of Quality Tools in Product Development Through Comparison Table*

The proposal written is based on the thesis “Determination of the Oriented Application of Quality Tools (BERTELLI, 2006) [3].

This proposal is applied for more than 8 years in a big engineering company, specifically the product development area.

As result, it can be confirmed that is being achieved continuously high rework reduction rates as well as reduction time of program development. Lower engineering change and increased customer satisfaction in relation the final product are also observed.

All learning gotten by experts during years of execution of these activities helped to elaborate the following matrix (BERTELLI, 2006) [3], (F. ELGH, 2015) [16].

The first column identifies key points that should be used as base to define the best quality tools to be applied (DFSS, QFD, DFMEA, RE, TRIZ, DFM and DFA).

**Table 1.** Matrix "i, j" for determining the Quality Tool.

| | DFSS | QFD | DFMEA | RE | TRIZ | DFM | DFA |
|---|---|---|---|---|---|---|---|
| Understand requirements Customer | | X | | | | | |
| Innovate Technologically | | | | | X | | |
| Using new technology which is locally known but applied in other companies by supplier | | | X | X | | | |
| Using new technology which is applied locally on another platform with good performance (Warranty Data ) | | | X | | | 0 | |
| Using new technology which is applied locally on another platform with medium or low performance (Warranty Data) | | | X | X | | | |
| Using new technology which is locally known | X | | | | | | |

| | DFSS | QFD | DFMEA | RE | TRIZ | DFM | DFA |
|---|---|---|---|---|---|---|---|
| Check Manufacturability of Component | | | | | | X | |
| Check Assembly Component / System | | X | | | | | |
| Check interference and or Mount Conditions | | | | | X | | |
| Check tubes, hoses, harnesses , roots, … | | | X | X | | | |
| Analyze functions and components / systems | | | X | | | | |
| Analyze function of failed components and or systems | | | X | | | | |
| Analyze security items | | | X | | | | |
| Improve system performance | | | X | X | | | |
| Solve problems with root cause unknown | X | | | X | | | |
| Solve problems with root cause known but no evidence of effectiveness of the solution through confirmatory tests | | | X | X | | X | X |
| Analyze design changes | | | X | | | X | X |
| Analyze application of resin | | | X | | | | |
| Solve problems with root cause known however with the solution proven efficacy through confirmatory tests | | | X | | | X | X |
| Analyze assemblies tampering, sealing & manufacturability of metal parts (BIW) | | | | | | X | X |
| Analyze functions of metallic hardware (BIW). Example: breaks, Resistance welding, cracks, sealing, … | | | X | | | | |
| Analyze performance/ result of new metal parts (BIW) | | | X | | | X | X |
| Analyze functions of plastic parts | | | X | | | | |
| Analyze assembly / manufacturability of plastic parts | | | | | | X | X |
| Analyze re- use of parts / systems / components in different environments | | | X | | | | X |
| Analyze software configuration | | | X | | | | |
| Analyze electronic circuits | | | X | | | | |
| Analyze fabrics and/ or foams | | | X | | | | |

Legend: BIW: Body in White (metal part without finishing).

## 4. The Relevance of Comparative Table of Application

The consumer since the beginning of the century is more demanding, known so better their rights, make more accuracy analyzes about the alternatives to make a decision based on data on which product is more reliably.

The elaboration and preparation of a quality plan implemented during the product development adds value during design, prototyping and post launch phases.

This analysis can be made, for example to select an airline for travel, the purchase of a TV set that has better reception, image and sound transmission, the acquisition of a more practical electrical equipment appliance to be used by the user and even in selection of a more robust car and therefore high immune to maintenance and breaks during and after the warranty period.

Considering currently the level of industrial competition is increasing, it is extremely necessary to the existence of a framework that makes the difference between the similar products offered by various competitors.

The table could be filled in with an infinite of items. For items that are not included in the table, it is believed that an analysis by the specialist on the component or system associated with understanding of the table vs. quality tools initiatives will assist in defining the best quality tool to be applied.

The table analysis should be done considering 3(three) different product parameters:

1. focus on project / design,
2. focus on manufacture,
3. focus on assembly and disassembly (services).

In most cases, can be considered the tools noted in the table as primary applications. Secondary tools, may also be added in the analysis.

To notice that there are cases where the application of DFMEA can be omitted taking into account the application of another tool. The inclusion of this evidence is one of the objectives of this article.

It must be emphasized that the multi- functional team has to be part of all studies to ensure a good quality of discussion and decision making.

## 5. Case Study

Many illustrative examples could be shown in this article as "Case Studies". For better understanding, were selected two case studies taking into account the metrics in "warranty claims and warranty cost". The term warranty cost should be understood as all money invested to correct determined issue in a product that has already been industrialized, that is, in production.

### *5.1. Case Study # 1*

This case study is relative to the headlamp which is a component used in a determined vehicle "X" (part used in the automotive industry).

During the development of a new vehicle, there was failure analysis identification performed by DFMEA. All analyzes were evaluated and the DFMEA was completed.

In addition to the DMEA, other quality tools like DFA and DFM were applied according to table 1 definition.

### *5.2. Case Study # 2*

As a second case study, will be cited the DFMEA study of a fan which is a part used in the automotive industry. In this analysis were assessed the environment conditions applied to the fan into the engine compartment and were taken the improvement actions during the product development phase of the specific vehicle.

The work team members developed the critical failures analysis and after developing some meetings, the failure analysis was concluded.

The quality tools defined to be applied in this subject were in accordance with table 1 presented at section 3.

### *5.3. Field data of case studies*

At case study # 1, after initiating the production of automobiles (A. KATZENBACH, 2015) [17], there were field complaints relating to water ingress inside the lens causing problems of burning lamps. Furthermore, there was a headlamp poor appearance due to water infiltration.

To fix the problem, it was necessary to exchange headlamps because the stickers (adhesives) initially designed to attend the requirements of the lens of headlamp to avoid water penetration were incorrect.

After changing of bonding adhesive, the problem was solved.

Regarding the 2nd case study, after starting of production, there was some records relating fan malfunctioning causing damage and, per consequence, poor operation of the system. After replacing the part (fan), the system returned to work.

After experimental tests carried out at fan by the work team, it was identified a failure during attachment of the wire harness connector at fan plug region that, after sometime, started to detach causing increasing of electrical current and, therefore, burn at fan connector region.

The problem was solved, eliminating the customer problem (D. CHANG, C.H. CHEN, 2014) [2] and, consequently, additional fault report

When analyzing the DFMEA, the failure mode of connector detachment that could cause potential electrical problem was not identified allowing, in this way, the occurrence of the failure.

Examples such as these 2 models depicted, constantly repeat in projects regardless of the branch of industry, that is, aerospace, automotive, chemical, metallurgical and others.

## 6. Conclusion and final thoughts

As previously mentioned, the focus of this paper is the application of quality tools in engineering design environment and make evidences that, even with effective quality tools initiatives implementation, design problems still occurring which impact directly to the organization's goals .

It is a fact that the application of quality tools initiatives brings significant gains to the organization.

However, it is shown in the case studies that even with the elaboration and application of a quality plan, completion of DFMEA and other analysis; problems that cause project redesign, rework, issues with maintenance, increasing of warranty costs as well as the company's image reputation continue existing. Those issues confirm there is a need to propose a new lean process based on weak points of the traditional process focusing on strengthen the analysis.

The time of product development becomes less and less, which requires that quality problems be prevented as soon as possible, at the right time, in a proactively manner throughout the development process and right since the first time. This should occur for companies to maintain their competitiveness, which is essential for their survival in the market.

It is extremely important to emphasize the implementation of the Quality Plan remains essential and the purpose of this article is to show that something new must be developd to solve this dilemma.

A new agile (A. McLAY, 2014) [18] process to analyze and identify failures focused on systems engineering concepts (BIAHMOU, 2015) [19] and lean development of complex products [14] are the concepts used to create the new process.

Future articles will be developed focusing on the proposal for a new and lean system engineering process (OPPENHEIM, 2011) [20] of identification and analysis of failures of complex products. The purpose is to create a dual process of engineering process mitigating the risks of failing what should be planned in the product and its life cycle processes. It will be more detailed in future articles.

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