Using Functional Analysis Diagrams for Production Cost Optimization

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Abstract

This paper presents a methodology combining Failure Mode and Effects Analysis (FMEA) and Value Engineering (VE), assisted by a set of hierarchical Functional Analysis Diagram (FAD) models, and its pilot introduction in a UK-based manufacturing Small Medium Enterprise (SME). The proposed methodology suggests the parallel execution of both processes, using a combination of FAD models and the FMEA tabular tool to yield results for both FMEA and VE. The resulting Risk Priority Number (RPN) is used to identify and prioritize not only the high-risk components requiring improvements (highest RPN values), but also the potentially superfluous components (lowest RPN values) that could be safely downgraded to reduce unnecessary costs.

Key words: Function-based design, Functional Analysis Diagram, Value Engineering, FMEA, Lean manufacturing

Introduction

Many large manufacturing organizations around the globe have employed Quality Management and design methods such as Six Sigma, Failure Mode and Effects Analysis (FMEA) and Value Engineering (VE) to add value to their products [1, 2]. Being by nature cross-disciplinary processes, FMEA and VE require the collaboration of a number of different disciplines such as Marketing/ Sales, Quality, Design and Manufacturing [3, 4]. As these methods mainly involve the analysis and evaluation of product functions, the users' functional understanding and ability to abstract are essential for the effectiveness and efficiency of these methods [4-6]. The Functional Analysis Diagram (FAD) approach is a functional modelling technique developed, in part, to assist methodologies such as VE and FMEA, and a number of case studies report excellent results on assisting functional understanding within cross-functional teams [7-10]. However, the investments required for the implementation of these methods are often seen as prohibitively high for smaller organizations which often adhere to traditional design methods [11, 12].

This paper presents the process and the outcomes of a pilot introduction of a methodology combining FMEA and VE assisted by a set hierarchical FAD models.

Aims and objectives

To develop a resource- efficient methodology combining FMEA and Value Analysis, and evaluate its efficiency in a manufacturing Small-Medium Enterprise (SME).

Background

FMEA

FMEA was first used by the US military in the 1940's and further developed by automotive and aerospace industries to improve product reliability during the product design stages [13]. Generally, FMEA processes can be divided in three main phases:

a) Identification and *function-based* criticality (severity) evaluation of the potential failure modes of the system/sub-system in question.
b) Risk evaluation (Risk Priority Number- RPN) of each component's potential failure mode based on its severity, occurrence and ease of detection.
c) Plan, monitor and evaluate corrective actions according to the resulting RPNs

The method is extensively used within a range of industries and is included in the "toolbox" of the major Quality Management Systems. Most of the documented shortcomings of the FMEA method appear to be related to the lack of a structured method for selecting the key failure modes [9, 14, 15] which in turn results in two major issues:
a) the process fails to capture all key failure modes and
b) the process can be long and tedious, discouraging companies and individuals from performing the process frequently.

Value Engineering

Value Engineering [4, 16, 17] is a quantitative approach defining product Value (V) as the ratio of a product's function (usefulness to the user) to cost (Value = Function/ Cost). According to this theory, Value can be increased either by improving the product desirable functions (technical, aesthetic, social, etc.) or by reducing its cost. However, the innovativeness of the solutions yielded of this process lies in the users' ability to identify a system's functions at higher orders of abstraction [6]. As with FMEA, Value Analysis requires a cross-functional team representing the customer, the design and operations functions of an organization. To enhance the ability to abstract and cross-functional communication, the Value Analysis method aims to represent each function simply by the combination of an *active verb* and a *measurable noun*. The *'active verb'* represents the **action** performed, and the *'measurable noun'* represents the **object** upon which such action impacts [5, 18].

Functional Modelling

The demand for immediate technological advance and the rise of systems engineering and computer programming, were some of the reasons dictating the development and use of a method allowing us to understand and control complex systems [18]. The *active verb - measurable noun* taxonomy introduced by Miles [16] was later adapted by the majority of Functional Modelling methods. Generally, Functional modelling methods are visual representations of decomposed systems, providing the space and a set of simple rules to perform functional analyses on systems. Unlike the majority of the functional modelling methods such as Function Tree, Function –Structure and FAST [19], FAD is a form-dependent functional modelling method [18], better assisting the functional analysis of existing systems [9].

Methodology

This work is a result of a 5 year participatory action research program [20] in a UK-based manufacturing SME. In addition to the efficiency issues of the FMEA process published by a number of researchers [14, 15, 21], the lack of communication between different organizational functions was identified by the authors as a considerable constraint on the efficiency of processes such as FMEA and VE. For SMEs, such processes can be often prohibitively resource intensive.

The methodology proposed in this paper was based on the FAD-FMEA methodology [see 9], initially developed to optimize the first phase of FMEA by assisting cross-functional teams in the understanding of product functions. As both FMEA and Value Analysis methods involve the analysis of product functions and their criticality to the end-user, we proposed a single process that serves both (Figure 1).

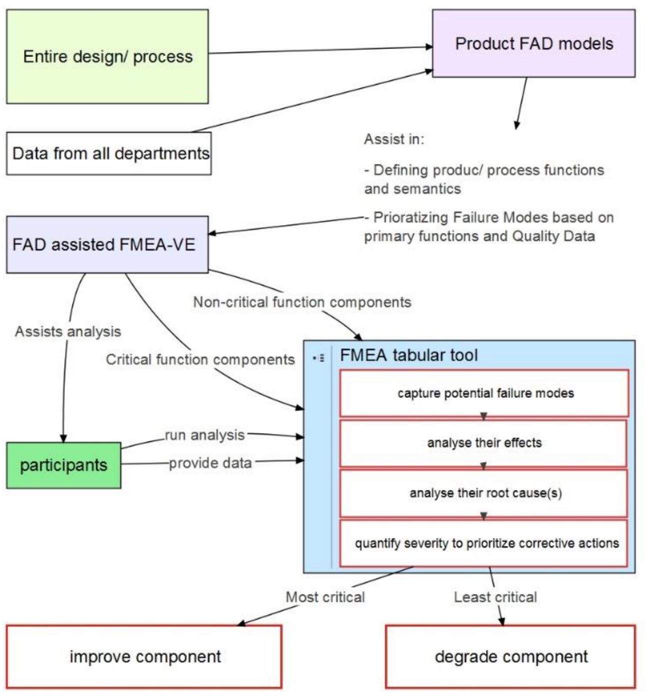

Figure 1- FAD assisted FMEA-VE process

In detail, the proposed process involved the following steps:

1. Prior to the sessions, develop FAD models of the product at top (figure 2- top) and sub-assembly (figure 2- bottom). The models can be developed by a team or an individual
2. During the first session, use the top-level FAD to define and evaluate its primary product functions (e.g. light bulb: a) emits light, b) emits heat)
3. Next, examine the sub-assembly/system level FAD and discuss any questions or comments. The sub-assembly level FAD model is completed using the input of all participants. Based on the primary function(s) evaluation from step 2, list any known and anticipated Quality issues, to identify the most critical sub-assemblies/systems and use the FMEA tabular tool to evaluate their criticality (determine RPN)
4. Repeat step 3 for the least critical functions (VE) and associated components to evaluate and prioritize by their lack of criticality.
5. Develop FAD models at part-level (Figure 3) for the sub-assemblies/systems prioritized by steps 3 and 4 to analyze their criticality (or lack of it) at part level.

While the parts with the highest RPN were to be considered for redesign or increasing quality controls, the ones scoring the lowest RPN, could be considered for downgrading their quality (i.e. removing superfluous features, downgrading materials, using wider manufacturing tolerances, etc.). The number of sessions required is dependent to the complexity of the system in question and the number of new sub-systems employed by it.

Measurable criteria

The measurable outcomes of this work were defined to be:

Quantitative:

a. The resource efficiency of the process was to be measured and compared against any previously conducted FMEA and VE sessions.
b. The potential cost savings from "downgrading" any identified "over-engineered" components in the system
c. The potential compensation and reputation savings from the early identification of any critical design flaws

Qualitative: The effectiveness of the proposed methodology was to be assessed through a questionnaire (Table 1) and interviews in terms of a) assistance in functional understanding, b) intuitiveness/ compatibility with cross-functional teams, c) time efficiency and d) user/participant satisfaction.

Case Study

The case study described in this paper involves the application of the proposed methodology on a UK-based gas spring and damper manufacturing SME, aiming to optimize the reliability and production costs of a newly developed product. The process involved six participants from Sales (steps 2-4 only), Design, Operations and Quality departments. The principal researcher and facilitator of this study was leading the Design team at the time. Excluding the researcher, none of the participants had experience with Value Engineering techniques, while their experience on the FMEA process was limited to two previously conducted sessions; one using the traditional FMEA and one the FAD-FMEA process [9].

FAD model development

The model shown in Figure 2 was developed by the facilitator of this study, using the freely available "DesignVue" software package [22]. The part-level models such as the one shown in Figure 3 where developed during the sessions using the same software.

Session 1

During the second step of the proposed methodology,

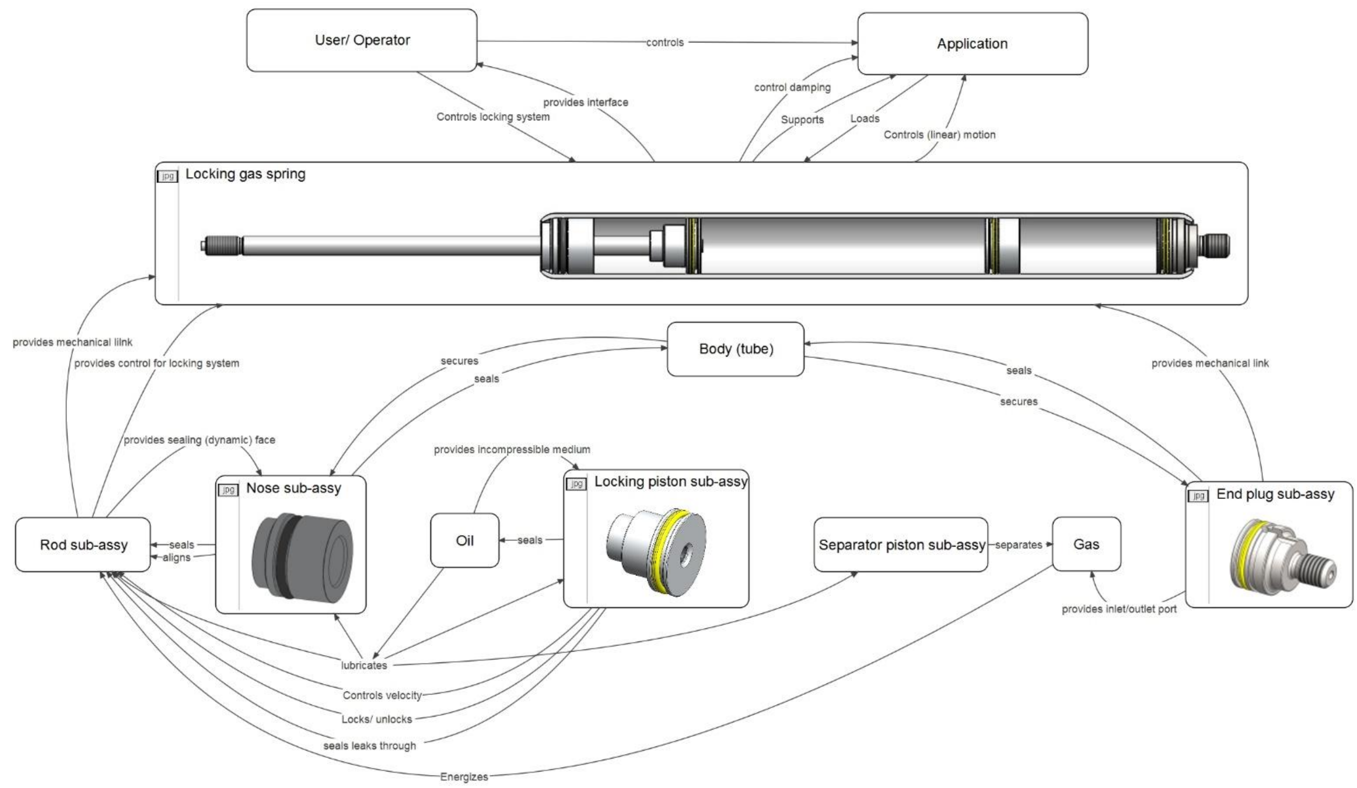

Figure 2- Top and sub-assembly level FAD of a lockable gas spring

the product's primary functions were analyzed using the FAD model (Figure 2). At this stage, the input of the Sales representative was essential, as he provided an insight of the customers' expectations from the product.

During step 3, all participants carefully examined the sub-assembly level FAD model (Figure 2- bottom) and most of them contributed by adding or improving some function descriptions. Having identified the most critical sub-assemblies, the FMEA spreadsheet tool was used to evaluate their criticality based on the input of all participants.

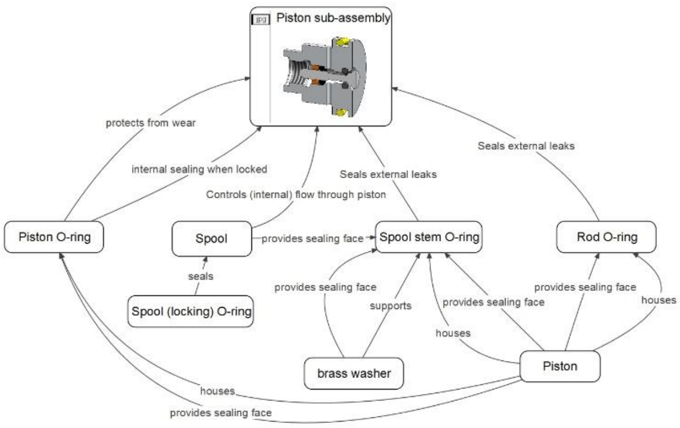

Figure 3- FAD model at part level

No noncritical sub-assemblies were identified during step 4. While the investigation for design flaws was something natural to the participants, the investigation of superfluous features initially introduced some discomfort. However during the part-level FAD model assessment (see Figure 3), a superfluous machined feature on the piston part and excessively "tight" dimensional tolerances (Quality Control) were identified on parts of two sub-assemblies.

Session 2

In this session the FMEA spreadsheet tool was used to evaluate the criticality of the sub-assemblies selected in step 3. The analysis at this (parts) level has highlighted two parts that required further attention, but also two potentially over-engineered parts.

Results and Discussion

Quantitative results

a. The process was completed in two 90-minute sessions. Considering the two hours spent to develop the models and the absence of the sales representative from the second session, the resources used were summed to 18 person-hours. The total resources used for this process were 50% higher and 25% lower than the previously conducted FAD-FMEA and traditional FMEA sessions respectively [see 9]. Taking in account the dual output of this process, it could be stated that the FAD assisted FMEA-VE process was 25% and 75% more efficient than the FAD FMEA and the traditional FMEA process respectively.
b. The capture of the superfluous feature on the piston part saved a tool change and drilling operations during machining. The over-engineered tolerances on the piston and rod parts saved machining and inspection time as well as potential scrap costs.
c. The modified part drawings and inspection procedures put in place as a result of identifying two critical part features have saved potential reputation and compensation costs.

Qualitative results

a. The vast majority of the participants (73%) agreed that the FAD models used in the sessions assisted them to identify product functions (Table 1).

b. All participants agreed that the method as intuitive and appropriate for cross-disciplinary teams. The object-action-object terminology dictated by the FAD method was instantly adapted by all participants without any preparation.

c. Some of the participants (33%) did not find the process efficient enough (Table 1). When interviewed, the Sales and Quality representatives stated that the process was still taking too long and proposed that part of step 2 could be replaced by prior participant preparation. However, the members of the Design and Operations teams found the process highly efficient. A member of the Design team stated: "*The process has helped me to focus on the function of each part and feature, allowing for potential flaws to be identified were previously missed*". Moreover, the member of the Operations team stated that "*the process has significantly assisted the team to highlights weaknesses, failure modes and on the other hand cost savings that perhaps are not identified during our everyday processes*".

d. Finally, all participants stated that they were happy to use this process in the future (Table 1).

Table 1- Survey results

FMEA-VE session survey					
	Strongly Disagree	Disagree	Neither/Nor	Agree	Strongly Agree
The FAD models used in this session have significantly assisted in the identification of the product's functions	0%	0%	16.7%	66.7%	16.7%
The FAD models and the terminology used in the session were intuitive and appropriate for cross-functional teams	0%	0%	0%	100%	0%
The process was efficient in assiting the identification of both areas for improvement and over-engineered components	0%	0%	33.3%	0%	66.7%
Would you use it again in the future?	0%	0%	0%	50.0%	50.0%

Future Work

The case study has identified areas where improvement was required and yielded two potential efficiency improvements: a) Better preparation of the participants prior to the sessions and b) Developing an FMEA results' database for commonly used parts to improve the efficiency of future sessions.

Conclusions

The results of this pilot case study suggest that the proposed methodology involving the concurrent execution of FMEA and VE assisted with FAD models, can significantly improve the efficiency and the effectiveness of both processes.

The dual output of the proposed methodology can significantly outweigh the cost of the process, and with the identified improvements in place, it could potentially fit with the tight resource constraints often seen in SMEs.

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