ROBUST DESIGN METHODOLOGY AT THE BACK-END OF PRODUCT DEVELOPMENT PROCESS: AN ATTEMPT TOWARDS SUSTAINABLE DEVELOPMENT

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Abstract

Purpose – This paper aims to apply robust design methodology (RDM) principles at the back-end of a product development process as a way to create greater customer satisfaction and support a sustainable product development.

Methodology/approach – Based on the literature, a framework combining RDM principles with exploratory data analysis (EDA) is proposed. This framework is used to analyze customer warranty claim data of a Swedish manufacturing company.

Findings – From a theoretical standpoint, we found useful connections between RDM principles and EDA principles, thus contributing to a new framework for data analysis. From a practical standpoint, the framework has led to revelation of valuable improvement ideas for the company in the areas of practices supporting customer focus, robustness, and sustainability.

Research limitations/implications – The research data are limited to the organization's claim data recorded during the last 5 years (2006-2010). Investigation of the interrelationships between various departments of the company with respect to the claim database was not included in the context of this project.

Originality/value – The proposed framework combining robust design principles and exploratory data analysis serves as a tool for data analysis in quality improvement projects in general. The findings from the claim data analysis show the usefulness of robust design thinking at the back-end of product development process in creating higher level of customer satisfaction and contributing to sustainable development.

Keywords – Robust Design Methodology, Exploratory Data Analysis, quality improvement, customer focus, sustainable development.

1. Introduction

Creating benefit to the present society without compromising the future has become increasingly important topic in the last decade. Focusing only on economic benefit of product development is no longer sufficient. Social and environmental benefit of product development process should also be considered. Various ways to achieve these benefits include, amongst others, continuous improvement (de Ron, 1998), policy and principles for sustainable production (O'Brien, 1999, Veleva and Ellenbecker, 2001), eco-design (Luttropp and Lagerstedt, 2006, Ben-gal et al., 2008), design for sustainability (Spangenberg et al., 2010), and product life cycle assessments (Kaebernick et al., 2003, Vinodh and Rathod, 2010).

Genichi Taguchi, who is known as the pioneer of robust design, defines quality as the losses a product imparts to the society resulting mainly from product failure after sale (Taguchi and Clausing, 1990). This appears to have a strong connection to sustainable development since quality is also defined by those who do not necessarily use or purchase the product. Research on the broader applications of robust design has identified three principles, namely, awareness of variation, insensitivity to noise factors, and continuous applicability (Arvidsson and Gremyr, 2008). Those robust design principles are in fact applicable in almost any design process, not only in the statistical design of experiment. In line with the application of statistical thinking beyond the science itself, Hoerl and Snee (2010, p.123) wrote that "…*in the twenty-first century it seems that society needs statistics to be primarily an engineering discipline, with a secondary focus on statistics as a pure science*". They gave a specific example of how statistical engineering, instead of statistical science, is needed today than ever before "…*we feel strongly that at this time new strategies to better utilize control charts for maximum benefit in health care, finance and other service industries are needed even more than additional research on the mathematical properties of control charts*" (Hoerl and Snee, 2009, p.517). A practical application of robust design methodology in solving real-world problem can be seen as one example of statistical engineering.

Practices of robust design methodology have widespread emphasis on the front-end of product development process in past years (Hasenkamp et al., 2009). Unfortunately, there is not enough emphasis on its relevance at back-end of product development process. The third principle of robust design methodology (RDM) is about continuous applicability, which says that robust design principles should be applicable in all stages of product development process. This paper aims to apply robust design methodology principles at the back-end of a product development process as a way to create greater customer satisfaction and support a sustainable product development. Specifically, a new theoretical framework combining RDM principles with exploratory data analysis (EDA) is proposed and used to analyze the warranty claim data of a Swedish manufacturing company.

This paper is structured as follows. Section 2 provides the theoretical background in the related areas. The methodology of the research is described in Section 3. The results and the analysis are presented in Section 4. Section 5 provides some discussions on the findings and its practical implications. The conclusion of the study and further research is presented in Section 6.

2. Theoretical Background

In early literature, sustainable production was defined as the ultimate result of a continuous improvement of industrial activities with respect to cost and time efficiency, product and process quality and effectiveness. Life Cycle Assessment methodologies are widely recognized as a suitable tool in the assessment of environmental impacts of manufactured products and its processes (Kaebernick et al., 2003, Vinodh and Rathod, 2010). End of life product information feedback, or sharing, helps to close up the flow of information and knowledge into a product design stage in order to consider the environmental implications of a design (Lee et al., 2006). In accordance to this, warranty claim analysis and result may be used as an approach to sustainable product development. One main cause of environmental damage is unsustainable production and consumption. Achieving sustainable production will require changes in industrial processes of the products produced (Nowosielski et al., 2007).

Robust design methodology is described as an approach to reduce performance variation in products and processes or to improve product manufacturability or product life (Andersson, 1996, Goh, 2002, Shoemaker et al., 1991). These results can be successfully achieved only if the application of robust design is widespread throughout a product life. One of the three underlying principles of robust design methodology is continuous applicability, stating that practices to achieve robustness can be applied in all stages of product development (Arvidsson and Gremyr, 2008). In order to achieve robustness of products or processes, producers and designers must create awareness of variations in the products and processes they produce or design. It is a prerequisite to create an awareness of variation to increase the understanding of robustness (Gremyr, 2005). Potential sources of variation that affect product performance are usually not possible to control by designers, and are known as noise factors (Johansson et al., 2006). Therefore, another principle of RDM is to create insensitivity to these noise factors. RDM, when applied especially based on the continuous applicability principle, functions as a continuous improvement activity.

Improvement initiatives rely on three most fundamental dimensions. They are an established quality management system, requisite quality technology comprising tools and methodologies and a capable quality information system (Goh, 1993). Quality information is defined as the know-how of product or process performances, all variability included, based on data collection. Capable quality information system could be achieved at all stages of a product, front-end or the development stage and back-end or product in-use stage. Based on previous study and application of robust design methods, emphasis have been on the design phase of products focused on reduction of variation through parameter design and design experiments (Allen et al., 2006). Robust parameter design have been much discussed in association with experimental designs and data analysis (Robinson et al., 2004). Such application shows emphasis of robust design application at the front-end and identifies a lack in research on application or practices at the back-end of a product development process. In applying the continuous applicability principle of RDM, robust design methodology is applied at the back-end of the process through analysis of warranty claim database.

Warranty claim data can be considered as the voice of the customers, but at the back-end of a product cycle. These ‘voices’, if analyzed or interpreted, using a statistical tool and/or quality concepts, will translate to product improvement ideas to be applied at an earlier stage. An opportunity is presented to organizations to create a proactive mechanism in order to react quickly to deviations in product performance through implementation of a field feedback loop (Magniez et al., 2009). Such mechanism could be designed based on the customer warranty claim database to measure actual field reliability of products and generate valuable information to be fed back into the design process (Lawless, 1998, Meeker and Hamada, 1997, Meeker and Escobar, 2004, Thomas and Rao, 1999).

Further, the development of RDM principles were associated with practices and a set of tools in an attempt to elucidate the why, what and how of RDM application (Hasenkamp et al., 2009). A gap was identified in practices needed for RDM's third principle - continuous applicability. Here, we present that warranty claim analysis as a practice of the continuous applicability principle. The framework proposed involves integration of RDM principles with the three steps of Exploratory Data Analysis (EDA), which is applied as a statistical tool in the analysis of warranty claim database.

EDA is suggested here as a systematic way of analyzing such field data. There is no shortage in availability of data in most organizations today due to computer technology. Often, at the start of solving a problem using a statistical engineering approach, one has to first understand what is going on by looking at the data. In such situation, the exploratory data analysis (EDA), which was advocated by John Tukey (Tukey, 1962), befits. The goal of EDA is to discover patterns in data through 'listening' to the data in as many ways as possible until a plausible 'story' of the data is apparent (Behrens, 1997).

More recently, De Mast and Trip (2007) proposed a framework for applying the EDA in a quality improvement project. Three steps are discerned in EDA process, namely display of data, identification of salient features and interpretation of salient features. The principles of EDA were formulated based on the purpose to parameterize a problem through framing of variations and sources of variations. A number of ways were identified in order to display the data to reveal the distribution. Identification of salient features is done through assuming a neutral reference distribution and looking for deviations from this reference. Identified salient features should then be paired with context knowledge in order to interpret them. A model of EDA was presented to exhibit idea generation through confrontation between empirical data and subject matter knowledge in de Mast and Kemper (2009). This model of EDA was re-applied in relation to the warranty claim analysis and presented in the analysis section of this paper. Based on this model, the ideas generated to improve quality and reliability of the products is used to close the feedback loop into the product development process.

3. Research Methodology

This project was initiated through collaboration with an organization as part of the Sustainable Production Initiative at Chalmers University of Technology. A total of six visits to the manufacturing facility were accomplished in order to access the claim database and conduct interviews with relevant personnel. The maintenance of the claim database in MS-Access at the organization was the responsibility of not more than 3-4 personnel. Data collection was done through accessing the database, which was followed by interviews with the responsible parties in an attempt to comprehend the input, output and analysis level of the database. The interviews were semi-structured, mostly based on questions relating to the claim process and system. Interviews and meetings were carried out by two of the authors at the premises of the organization. Notes were taken by authors during each meeting and interview. Mainly the interview questions were on the working of the claim database, in terms of input document, data entry, frequency, authorization, distribution and sharing of information in database, report generation, data updates and maintenance of database.

Further discussion with Production and Finance personnel enabled the understanding of product assemblies and internal claim cost analysis. The information gathered here were mainly on the flow of the claim process within the organization and personnel involved.

3.1 Proposed Theoretical Framework

Upon review of RDM literature and iterative usage of EDA on the dataset, an integration of RDM principles and EDA steps was proposed. In their application to this case study of claim data analysis towards improving robustness of processes, the principles and steps were found to complement each other. The proposed framework is illustrated in Figure 1 below.

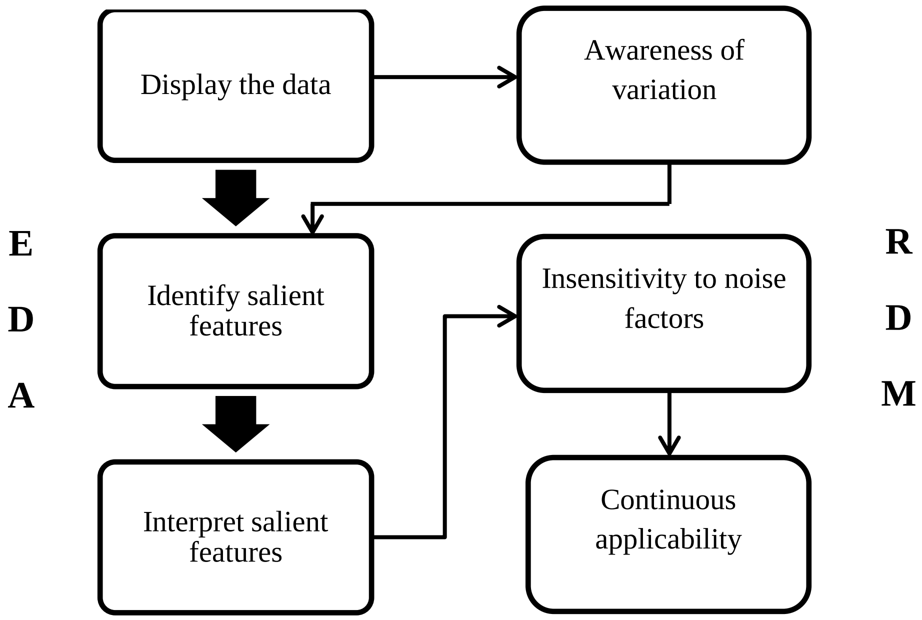

Figure 1: Theoretical Framework of EDA-RDM

3.2 Empirical Setting

The organization under study is an internationally leading supplier of equipment and systems for heavy and medium-heavy trucks and trailers. Their customers include suppliers on the global truck market, including European truck and trailer manufacturers, and also ‘body builders’ who complete building of a truck after they have left the factory. Both the body builder and trailer manufacturers are important links in the chain to reach the end customer. This business area has its own sales companies in Sweden, Germany, Denmark, Norway, Belgium, the Netherlands, the UK and France. The Multi-Function Coupling (MFC) was launched in 2008 as a new revolutionary concept for connection of truck and trailer. The new

MFC enables faster connection and disconnection, while reducing idling time and thereby also CO_2 emissions. MFC is said to have increased safety and ergonomics levels, permitting more efficient operation and reduced wear which leads to prolonged service intervals. Today, this product has been adapted to vehicles from Scania, Volvo, MAN, DAF, Mercedes and Renault (VBG, 2010).

3.3 Claim Database

This improvement project is based on the product claim database stored in MS-Access at the manufacturing facility. The database contains claim forms, list of products and parts, list of failure codes, list of customers and list of departments in the organization. The claim of products by customers, including sales offices, dealers and end customers have been stored in this database, and was made available to the authors during this project. The products claimed include MFC from 2008 onwards. The content of the database was copied onto statistical software JMP in order to analyze the distribution of the data. The method adopted for the analysis is exploratory. Exploratory Data Analysis (EDA) was applied due to its purpose of identifying potential causes. A large amount of data was available for analysis with a number of variables, and based on the fact that no previous analysis has been performed on this data set, an exploratory option seemed appropriate in order to identify salient features through display of data in graphical methods, which are especially powerful as they have the potential to lead to underlying causes of product failures or claims (de Mast and Bergman, 2006).

4. Results and Analysis

The organization state their most important key factors for long-term success as focus on strong customer relations and the customers' needs, among others (VBG, 2010). In an attempt to enhance their focus on customer needs, an improvement project of exploring, analyzing and understanding customer claims and their causes was initiated. It is also a part of the organization's initiative to introduce and implement robustness in the processes in order to stay aligned with the offerings of the new MFC with regards to safety and reliability.

4.1 Results

The dataset analyzed in this project contained claim data of 5 years, from 2006 until end 2010. Upon analysis of data distribution, it was realized that one customer, A5, represented a large number of claims during these years, 704 out of 2838. Here, a salient feature was identified based on the fact that this customer stood out within the distribution of customers over time with an abnormally large number of claims recorded. Further investigation clarified that this particular customer was made up of many dealers and sales offices from one country. As this particular customer base was not representative of individual claims, it was decided to exclude this customer code from the analysis in order to identify other salient features.

Based on the new distribution, histogram of customers and number of claims show customer B5 was recorded with the highest number of claims, 101 out of 2134. Once again, this number was represented by a group of customers under one sales company of another country. It was clear that further narrowing down of the data or categorization of data based on customer codes was required. Customer codes with assigned number 5 indicates customers outside of

Sweden, and codes assigned with number 1 are of customers within Sweden. In the specific analysis of claims of customers outside and within Sweden, a new set of results were obtained, as presented in Table I and II.

Table I: Number of Claims by Customers

Outside Sweden		Sweden	
Customer Code	No. of Claims	Customer Code	No. of Claims
A5	704	A1	73
B5	101	B1	43
C5	49	C1	41
D5	47	D1	41
E5	32	E1	38

Similar approach was applied in identification of failure codes from the dataset. Customers outside of Sweden recorded a high number of failure code number 8F. Further discussion showed that failure code 8F was assigned to a general failure described as non-function. Decision was made that all failure coded 8F shall be investigated further and assigned more suitable and correct codes. Therefore, distribution was re-analyzed upon excluding code 8F from dataset. Tables below show reasons of failure as claimed by customers, within and outside Sweden.

Table II: Number of Claims by Failure Codes

Outside Sweden		Sweden	
Failure Code	No. of Claims	Failure Code	No. of Claims
1F	164	2F	388
2F	163	6F	232
3F	92	4F	200
4F	50	7F	168
5F	48	1F	130

The final item to be addressed in the claim database was parts/products rejected by customers. The same categorization was made as before in division of customer bases. Tables below show the parts/products most claimed within and outside of Sweden.

Table III: Number of Claims by Products/Parts

Outside Sweden		Sweden	
Part No.	No. of Claims	Part No.	No. of Claims
P1	267	P2	420
P2	180	P5	237
P3	85	P6	215
P4	41	P7	132
P5	31	P8	107

4.2 Analysis

In the process of EDA, three steps can be discerned, as below (de Mast and Trip, 2007):

1. Display the data.
2. Identify salient features.
3. Interpret salient features.

These steps were applied in the analysis of the claim database to identify three main components of the claim process, which are customer bases and frequency of claims, highest failure reasons recorded and frequently claimed parts/products. Figure 2 shows the EDA model adapted from de Mast and Kemper (2009). The model applied to the analysis exposes idea generation through confrontation between the claim data analysis results and information on subject matter knowledge gathered through discussions and interviews. The processes in this model are explained in below sections through the three steps of EDA.

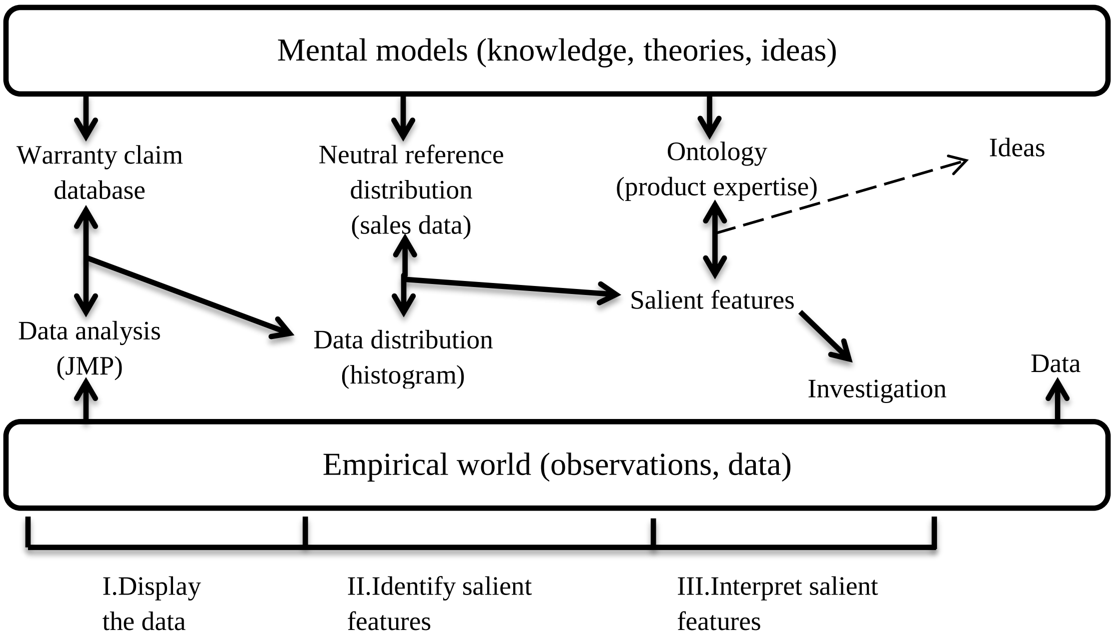

Figure 2: Mental Model of EDA

4.2.1 Display the Data

The first step in EDA is to display the data in a graphical manner in order to capture a pattern(s). Examples of techniques useful for EDA to reveal data distribution, other than histograms, are time series plots and boxplots. Histograms and time series plots were found sufficient for identification of salient features in the context of this project. Data distribution is shown in a histogram below on customers outside of Sweden and the number of claims. Noting the large difference in number of claims displayed by one customer code compared to the rest in the distribution, the customer base with the highest claim was identified.

Figure 3: Claims by Customers (Outside Sweden)

The data distribution is displayed in a histogram below shows the number of claims based on failure reasons for customers outside of Sweden. Based on the graph, the top five failure reasons were identified.

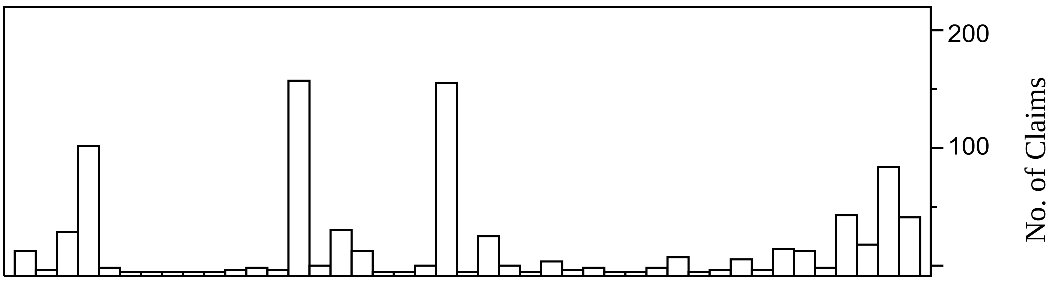

Figure 4: Failure Reasons (Outside Sweden)

The top five most frequently claimed parts/products were identified based on histogram shown in Figure 5 below.

Figure 5: Parts/Products Claimed (Outside Sweden)

4.2.2 Identify Salient Features

Upon displaying the distribution of data, salient features were looked for. According to De Mast and Kemper, salient means standing out from what was expected a priori (de Mast and Kemper, 2009). In this step of the process, a neutral reference distribution is identified. A reference distribution reflects an existing knowledge about the phenomena under study but that is neutral with respect to other features. A neutral reference distribution for the claim database would be that the number of claims received from each customer mirrors the total sales of parts/products to them. Based on the sales data, number of parts/products sold to customers in the time frame of 5 years, it was identified that P4 and P6 from claims outside of Sweden and within Sweden respectively, appear as the most claimed items.

Further analysis was done in order to identify the trend of claims of P4 and P6 in terms of time, as shown in below figures. These graphs identify more detailed salient features with respect to trend of claims between 2006 and 2010. P4 shows that claims have declined over the years, while P6 shows a peak in 2008.

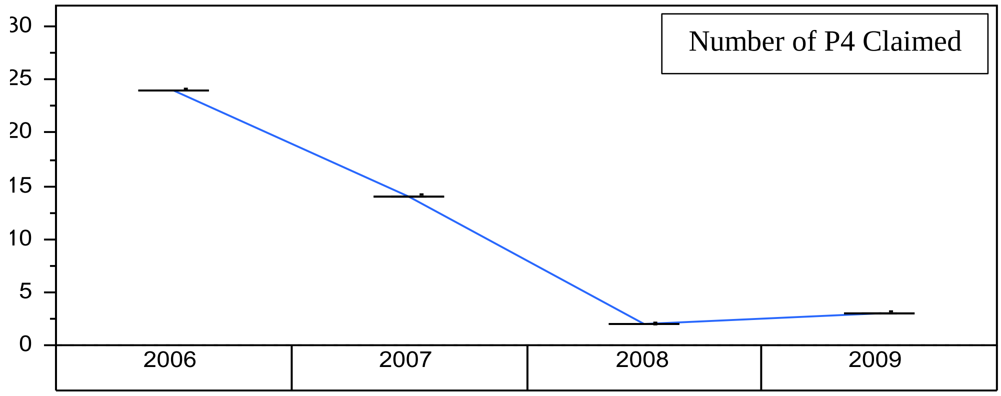

Figure 6: Time Chart for P4 Claims

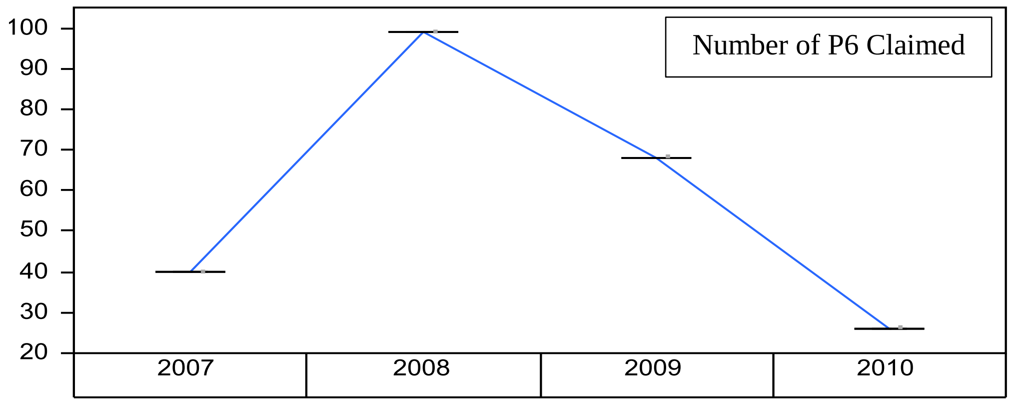

Figure 7: Time Chart for P6 Claims

4.2.3 Interpret Salient Features

The third step of the process is essentially a non-statistical one, as stated by de Mast and Kemper (2009), which is to theorize and speculate on the causes of patterns identified from earlier step. The patterns of data from the distribution were discussed with the project champion at the organization, who involved personnel from various other departments in the information gathering process. Interpretations of patterns or causes identified require expert knowledge of the subject, as stated in the fourth principles of EDA (de Mast and Kemper, 2009). Therefore, interviews with personnel from Production, Engineering, Marketing and Sales were conducted by the authors in order to fit the pieces together and gather appropriate explanation for the salient features. In the context of this paper, the most claimed items, P4 and P6, were in focus.

4.2.4 Integrated Framework

Based on the proposed framework of EDA-RDM integration, the findings of the analysis are displayed in Figure 8 below.

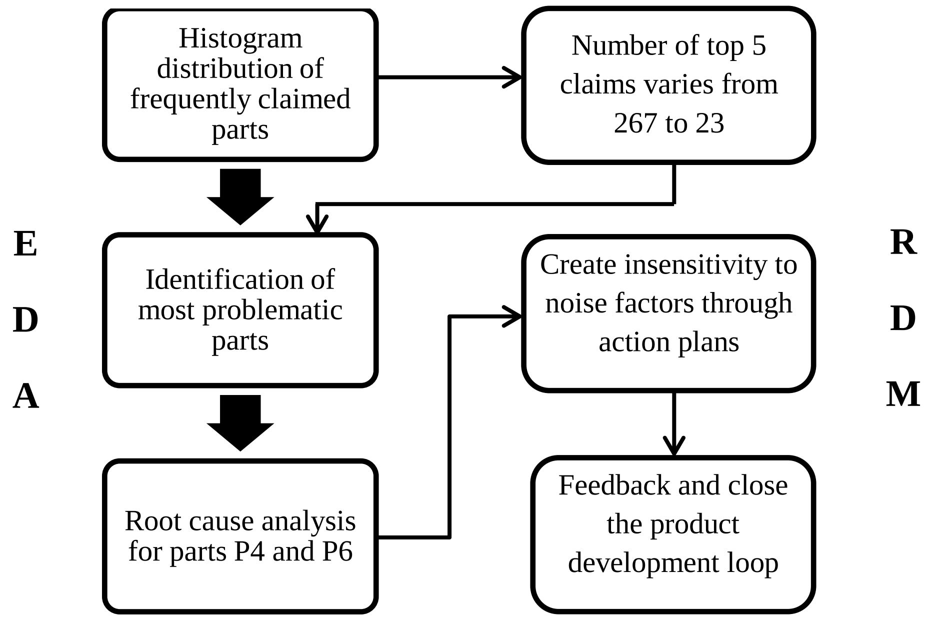

Figure 8: Integrated Framework EDA-RDM

4.2.5 Noise Factor Classification

Based on the analysis of claim database and claimed products, below figure of noise factor classification was adapted from Johansson et al (2006) to fit with the study. Products or parts claimed by customers fall into the 'In use' classification of noise factors. This classification contains two types of noise factors, external and internal, as per boxes highlighted in figure below. Products P4 and P6 identified for improvement are subjected to external and internal noise factors, which were identified upon further discussion.

a. Operating conditions includes long haulage, distribution of merchandise, logging, off-road and construction sites usage.
b. User-to-user variation includes varying handling during coupling and decoupling of product by drivers, daily maintenance and care.
c. Wear and degradation includes owner's different schedule and attitude towards major overhaul.

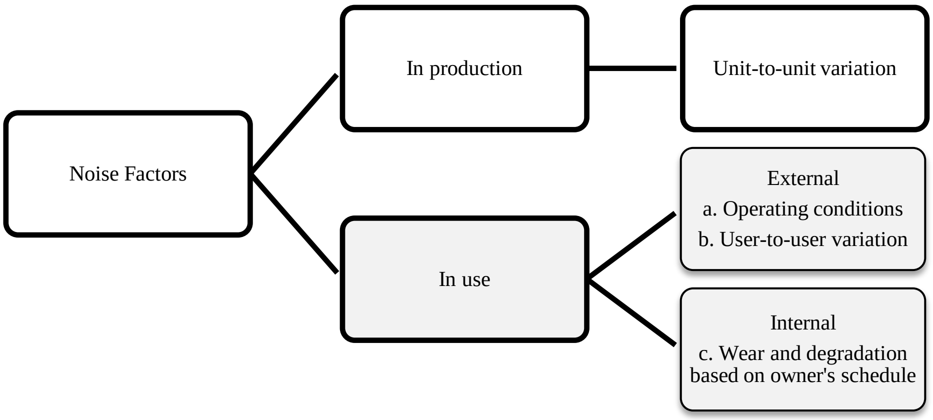

Figure 9: Noise Factor Classification

4.2.6 Feedback Loop

The product development process of the organization is shown in Figure 10 below. The integrated framework of EDA-RDM acts as a tool in analyzing the warranty claim information, directly from customers and users. Root cause analysis and identification of noise factors will serve as valuable design information in the product development process. Creating insensitivity to identified noise factors triggers robust practices, beginning at the back-end of the product and ending in the front-end. Constant flow of such information through analysis of claim products can contribute towards the basis of life cycle assessment initiative in the organization.

In Figure 10, the organization's product development process is shown. The Claim Database activity has been added as a result of this analysis.

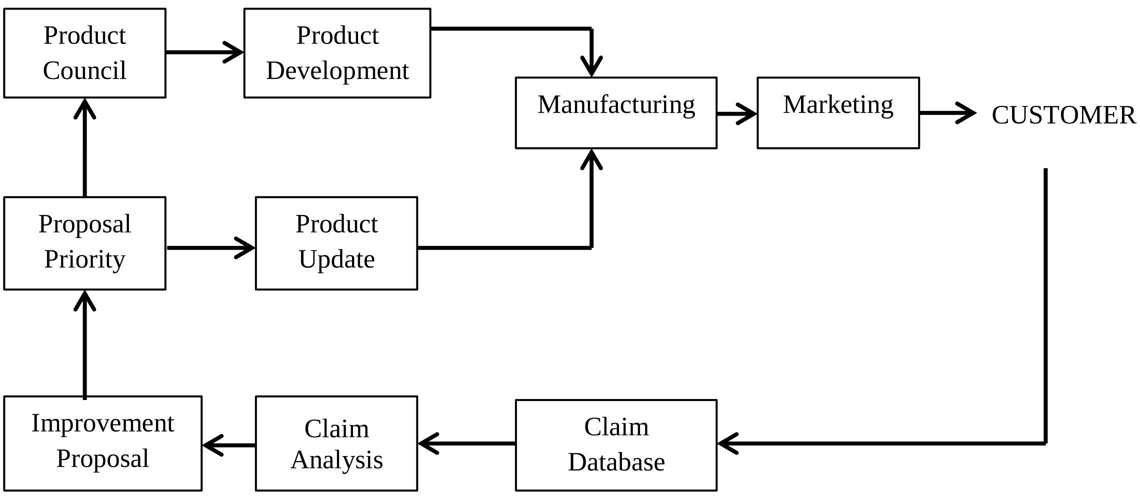

Figure 10: The Organization's Product Development Process

5. Discussions

It has to be born in mind that the claim database analysis is one of the most visible indicators of customer satisfaction of product quality, which makes the results an obvious source of information. As this information is implicit, it is more easily overlooked. Application of EDA principles has made visible salient features of the claim database. The display of data using histograms identified the most problematic products, as shown in Tables V and VI, where P1 and P2 were identified as the most claimed parts. The application of a neutral reference distribution, namely the sales data of these parts, further clarified the salient features. The most claimed parts then, in reference to the number of parts sold, were P4 and P6. Further, P4 and P6 displayed on a time chart reveals a trend in numbers claimed over five years. P4 was flushed out and replaced with new part called P3 in 2008, which explains the decreasing trend. P6, on the other hand, has been further developed and re-designed as version 3 in 2009. This is shown in the decreasing trend as well.

As EDA functions aptly as one tool in this project, the exploratory findings and outcome of the claim data analysis alone may not address the goals of increased customer focus, process robustness and production sustainability without the application of RDM principles. The integrated framework of EDA-RDM enhanced the analysis process through creating awareness of variation in customer claim trends and identification of noise factors during product use. Continuous applicability principle addresses the application of the rest of RDM principles throughout the product life cycle process, where results from the analysis are fed back into the product development process as design input. Root cause analysis process was initiated as an improvement idea resulting from the integrated framework application. This process includes key players from Production and Engineering teams. This is seen as a first step of application of robust principles and practices in the organization.

Going forward, the next step identified is an initiative towards sustainable product development cycle, where products are evaluated on the potential for re-use or recycling (Vinodh and Rathod, 2010).

6. Conclusion

The aim of this paper was to apply RDM principles at the back-end of a product development process as a way to create greater customer satisfaction and support a sustainable product development. A new framework combining EDA and RDM for data analysis has been proposed. The application of the framework has led to revelation of valuable improvement ideas for the company in the areas of practices supporting customer focus, robustness, and sustainability. In other words, this paper shows that robust design thinking at the back-end of product development process can be regarded as one way to create higher level of customer satisfaction and thus supports a sustainable development.

The research results are limited to the data recorded during the last 5 years (2006-2010). A further investigation on the interrelationships between various departments of the company with respect to the claim database will be done in the near future. Another future direction of this study includes development of indicators in an attempt to measure the continuous application of RDM principles not only at the front-end and back-end, but also during the production stage of the products.

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