Journal of the Society of Korea Industrial and Systems Engineering
Vol. 35, No. 3, pp.180－186, September 2012.

브레이크 패드 신뢰성향상을 위한 DFR프로세스 개발

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DFR Process for Brake Pad Reliability Improvement

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신제품 개발에 있어서 제품의 잠재적 고장모드를 줄이기 위한 설계 노력은 매우 중요하며 이를 위해서는 체계적이고 혁신적인 신뢰성프로그램을 적용하는 것이 반드시 필요하다. 기업에서 동시공학을 기초로 한 건전한 신뢰성프로그램에 포함된 주요활동으로는 DFR(Design for Reliability), 신뢰성검증 및 물리적 해석활동 등이 있으며, 이 중 DFR은 제품 개발을 지원하는 첫 번째 과학적 신뢰성활동이다. 본 연구는 브레이크패드의 신뢰성을 향상시키기 위하여 회사조직전체에서 여러 부서의 팀 구성원이 유기적으로 참여하는 DFR 프로세스를 조직하고 실행하는 전략과 기술에 대한 연구이다. 본 사례연구의 동기는 해당기업에서 DFR에 적용된 모든 도구와 기술을 통해 제품의 신뢰성을 향상시키고 동시에 글로벌시장의 잠재고객에 대하여 품질과 신뢰성에 대한 확신을 주는데 유용하게 활용하기 위함이다. 본 논문에서는 제품개발주기의 개념설계단계 부터 제품의 폐기까지의 DFR 개념 전개에 대하여 설명하고, 기술적 도구를 적용한 설계초기 단계에서의 분석사례를 제시하였다.

Keywords : Reliability Program, Design Process, Brake Pad, Development Cycle

1. Introduction

More challenging customer requirements, shorter time for product development, quicker shifting technology and more complex design leads to the application of the DFR process in manufacturing for many years. At the moment, higher manufacturing costs are due to over-designed, too complicated design and excessive warranty period. Furthermore, the final product must gained positive customer satisfaction in which the manufacturer needs to put extra efforts by applying various techniques and tools to highlight their product performance to compete in the current global market [2, 6]. All of these reasons have forced the manufacturers to implement DFR as soon as possible for product development and product improvement that run concurrently.

For the manufacturer to implement DFR in an organization, a team of multi disciplinary and cross functional members is required to learn and to practically utilize tools and techniques in DFR in a short period of time. There are also significant challenges, including lack of training and awareness, insufficient guidelines and the need to perform that have been faced by the manufacturer. Therefore, the manufacturer has to overcome these challenges via training and practically implementing the tools and techniques to the current system.

Some of the previous work done on DFR mainly focus on designing assessment reliability testing in electronics [3,

논문접수일 : 2012년 08월 20일　　게재확정일 : 2012년 08월 30일
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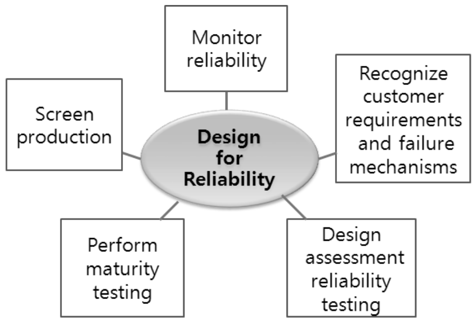
※ 본 논문은 2011년도 대구대학교 학술연구조성비 지원에 의하여 연구되었음.

11]. Pang et al. [8] have done research on designing efficient accelerated life testings to lifetime prediction models for high-power devices in hybrid cars. Hua Lu et al. [4] have published a paper on failure modes mechanisms and physics of failures in thermo-mechanical behavior of power electronics modules as part of the DFR.

On the other hand, this paper focuses on the early strategy of DFR in which recognizing customer requirements and failure mechanisms. Some publications could be found in implementing tools and techniques in identifying customers' requirements and failure mechanisms. FMEA and QFD as tools to improve mechanical robots reliability and quality are utilized by Korayem and Iravani [7] in their research. Attardi et al [1] have presented a case study regarding the reliability analysis of some automotive components based on field failure warranty data to further estimate the reliability. Volkanovski et al. [10] have utilized FTA to assess power system reliability. All of the publications are part of the DFR strategy that would be described further in the next section.



<Figure 1> DFR Framework

2. DFR Strategy

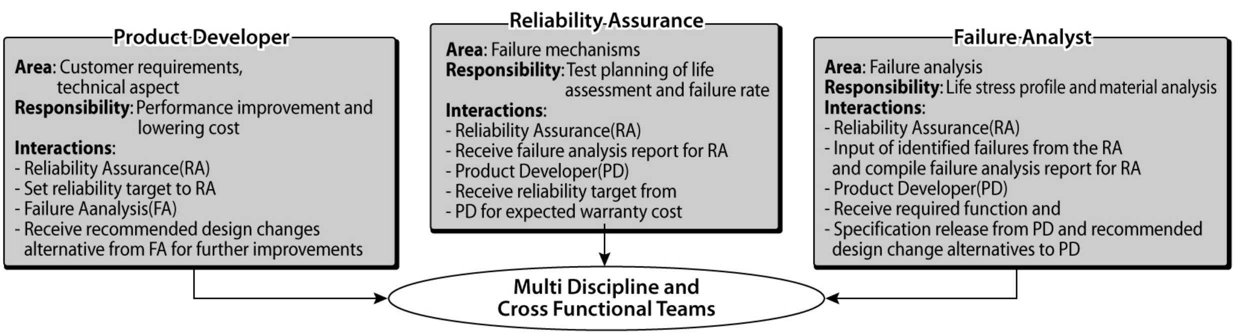
DFR strategy is based on the product, process and also the current system that have been practiced for product development. This allows the manufacturer to define and plan out the stages based on the product characteristics, customer's requirements and manufacturing processes.

From <Figure 1>, reliability tools such as QFD, FSA (Functional Structural Analysis), FMEA and FTA understand customer requirements, failure modes, failure mechanisms and the hazards that are related to product design, technical features and usage profile. Besides that, competitive benchmarking is used to further define the design requirements.

In design assessment reliability testing, mitigation of risks and reliability growth programs are involved using various techniques such as hazard analysis, ALT, HALT, HASS and analysis of field failure data. Maturity testing which help to demonstrate that the design fulfilled the customer's requirements are performed using statistically significant accelerated tests. Production screening is performed to detect infant mortality problems and to ensure that the product is robust enough. Finally, continuous product reliability improvement is required through monitoring to make sure the design will meet the target specifications.

2.1 Roles and Responsibilities

A team consisting of multi discipline and cross functional members including design, production, processing, purchasing, and marketing are required as the first step to implement DFR. Basically, three major roles support each other which are product developer, reliability assurance and failure analysis involved in the process. <Figure 2> summarizes the areas, responsibilities and interaction between the roles. Before the implementation of DFR, information is not shared and organized thus it is less productive in the outcome of the product development process. More problems and issues have not been investigated and rectified due to unclear responsibilities and areas.



<Figure 2> Multi-Discipline and Cross Functional Team Roles and Responsibility

3. DFR Product Development Process Plan

The product development process allows the manufacturer to define and plan out the phases based on the customer's requirements, product characteristics, and manufacturing processes to ensure the plan is followed, fulfilling the required standards and regulations. It is also helpful in identifying responsibility and roles for each task to be assigned based on the DFR framework in <Figure 1>.

In <Figure 3>, the product development process plan is divided into four phases with 19 stages. Some of the stages in each phase can be done

concurrently before moving up to another phase. <Table 1> lists out all the stages involved for the phases.

In the design concept requirement phase, the manufacturer can focus on the key issues and problems facing the product development process from the early phase by understanding customer requirements and failure mechanisms. Thus, corrective actions and improvement plans can be proposed to further address the issues and concerns.

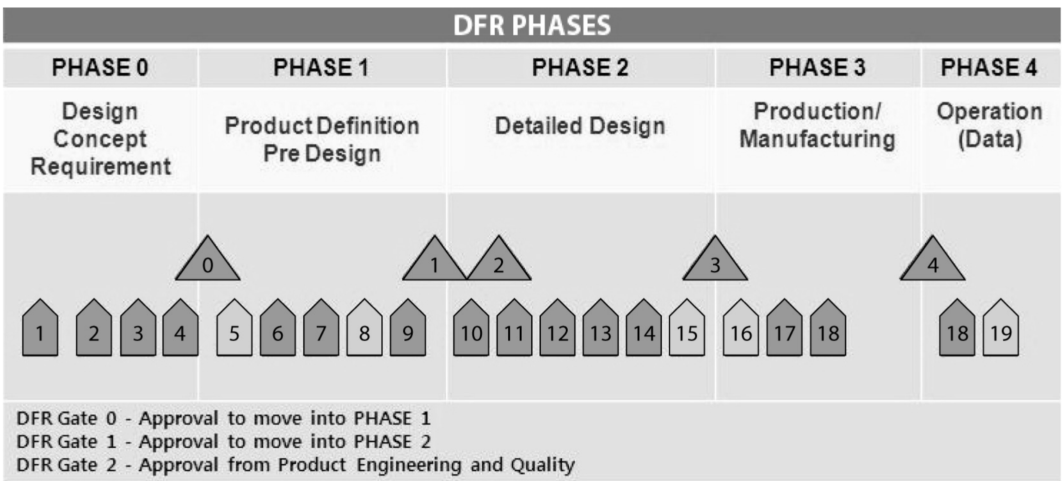
This phase is explained further, in this case a Tstudy so that various input on the product development process of the brake pads can be validated.

Based on VOC (Voice of Customer), QFD is deployed to correlate between customer requirements, engineering design elements and part characteristics of the brake pads. FSA and FMEA are performed to analyze failure mechanisms and failure modes that might occur. FTA is an analytical tool used for recognizing and categorizing hazards which resulted in calculating of the whole system reliability [9].

Furthermore, field failure data acquired during the operation is analyzed to estimate the current reliability of the product [5]. The results from techniques and tools would help the brake pad manufacturer to understand the existing level of the product reliability. After tackling and solving all the problems in this phase, the transition to the next phase must be cleared with all the team members especially in the QFD/FMEA area.

<Table 1> Description of Stages in DFR Phases

Phase	Stage	Description of Stages
Design Concept Requirement	1	Reliability Target
	2	Usage Profile, Customer requirement's
	3	Field Data Analysis
	4	Field Failure Modes
Product Definition Pre Design	5	Reliability Target Specification
	6	Major Component Reliability Requirement
	7	Reliability Prediction
	8	Reliability Growth Planning and Modeling
	9	Standard and Design Manual
Detailed Design	10	Reliability Assess : Modeling, FMEA/FTA
	11	Select Major Component
	12	Eliminate Failure Mode
	13	Reliability Test-Component
	14	Design Review
	15	Reliability Growth Monitoring
Production/ Manufacturing	16	Component and Product Test : Reliability Growth, Life, Qualification, ESS
	17	Reliability Documentation
	18	Test and Analysis in Design Change
Operation(Data)	19	Field Failure Analysis



<Figure 3> Proposed DFR Phases for Product Development

<Table 2> Issues and Problems in Implementing DFR

Issues	Problems	Actions
Customer Requirements	Not enough information collected on customer requirements. Benchmark with other competitors is not available.	QFD is deployed with the supervision of the experienced instructors. Technical specifications benchmarking of other competitors has been done.
Failure modes and mechanisms	Lack of proper documentation on interrelationship on failures modes and mechanisms. All the potential failure modes are required to be highlighted and rectified.	Functional Analysis Sturcture (FAS) has been constructed as a check list for further developing more detail FMEA. FTA also is deployed to make sure that all areas are covered.
Field Failure Data Analysis	No analysis of available field claims statistics is properly done, lack of useful information extracted from the claim database	Minitab analysis has been utilized to get information on the current reliability of the brake pads.

4. Issues, Problems and Actions

During the early phase in implementing DFR, some issues and problems have been identified. For the design concept requirement phase, customer requirements, failure modes and mechanisms and field failure data analysis have been highlighted. From <Table 2>, each problem has been dealt with and action plans have been executed. The results of the action plans are shown in sections 4.1, 4.2 and 4.3.

4.1 Customer Requirement

QFD is based on customer requirements, engineering design elements and part characteristics which help the design team to understand the customer's perspective of the product. Therefore, the most important customers' requirements are gathered and improvement of the parameters is highlighted according to these requirements. Benchmarking on the technical specifications of other competitors has been performed in order to make sure the that quality and reliability of the product is acceptable.

In this case study, <Table 3> shows the customers' requirements information that has been acquired. Comparative analyses per customer and customer satisfaction survey have been used to understand the present level of customer requirements on the brake pads. Meanwhile, <Table 4> summarizes the part characteristics that need to be further looked into from the engineer's perspective. Customers in this case study which are the car makers are focusing on prevention of noise and braking performance of the braking system as important characteristics.

<Table 3> Importance of Quality Characteristics for Improvement

Ranking	Quality Characteristics	Priority
1	Prevention of noise	168
2	Braking performance	126
3	Structural Strength	63
4	Durability	57
5	Appearance - good condition, no crack	53

<Table 4> Importance of Part Characteristics for Improvement

Ranking	Part Characteristics	Priority
1	Formulation of brake pad materials	900
2	Plastics Thermoforming conditions	576
3	Clamping Pressure	540
4	Annealing conditions	520
5	Appearance and dimension	453

On the other hand, the engineers' is more focused on the formulation of the materials and manufacturing process of the brake pads as important characteristics to achieve the customers' required quality level. Numerous testing standards are required by the customers to be fulfilled by the manufacturer that is shown in <Figure 2>. Action plans to revise the design and further development of the products are considered based on the results of QFD in <Figure 2>.

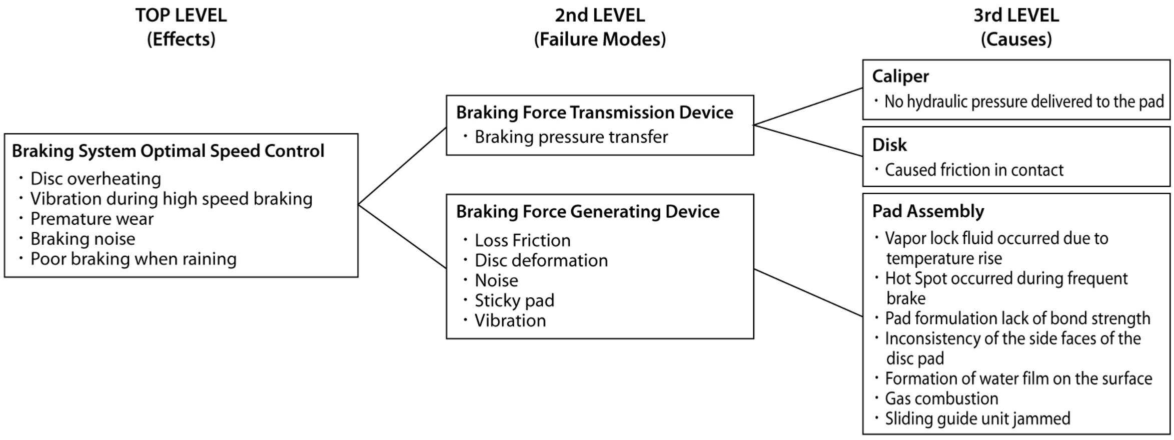
QFD facilitates investigation of critical customer requirements that later on can be associated with FMEA process. From the figure, continuous renewal of QFD through a managing process by revision and sharing documentation would help the manufacturer to update the link between QFD and FMEA by the QFD/FMEA team. Target and expectation should be revised prioritized based on the QFD process.

4.2 Functional Analysis and Failure Mechanisms

To start the process of identifying and investigating all the potential failure modes and mechanisms of the brake pad system, Functional Analysis Sturcture (FAS) is deployed. <Figure 4> shows that the investigation starts with the top level in which the effects on the system when the failures occurred, then progress to investigate the failure modes in second level. Finally in the third level, the causes are identified. All the information on the FAS is used as a checklist for the FMEA process.

FMEA mostly concentrates on component parts that only can be technically understood by engineers that have related skills to recognize and also to rectify the failure modes. During the QFD process, customers have highlighted that prevention of noise is the important characteristic but they do not know further details behind the mechanism of the braking system.

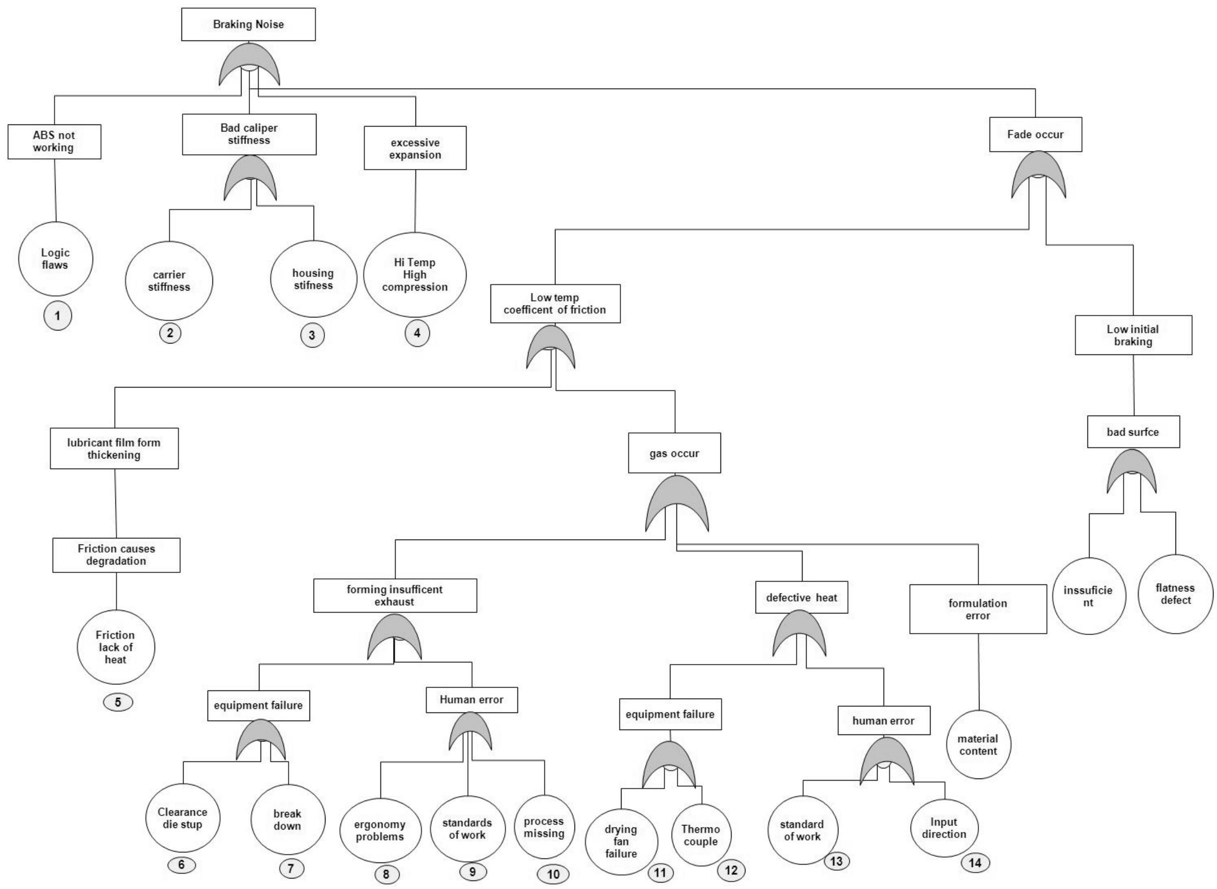
Failure modes for FMEA are arranged using Risk Priority Number (RPN) to identify the criticality. To reduce risks of the critical failure modes, corrective and action plans are proposed. Noise occurrence from the brake pads during operation is the main failure that required to be investigated further. Excessive noise due to the friction of the discs during braking, premature wear and adhesion are some of the potential failure modes that have been identified as shown in <Figure 5>. All possible failure modes that contributed to the noise occurrence during operation have been analyzed and RPNs are calculated in this case study based on the severity, occurrence and detection as shown in <Figure 5>. The highest RPN is 70 with a low occurrence factor.



<Figure 4> Functional Analysis Structure

Components feature	Potential failure modes	The potential impact of failure	Severity (SEV)	Potential causes and mechanisms of failure	Occurrence (OCC)	Current design management: Prevention	Current design management: Detection	Be detected (DET)	Risk priority (RPN)
Disk and cause friction braking exercise	Friction damage	Durability under– Due to noise complaints Work in the hill reduced Handle driving tremors, body tremors Vehicle braking under– Occurs pyeonjedong	7	Lack of strength of friction	1	Design requirements (?)	Substrate strength test (?)	5	35
				Design suitable friction	1	Design requirements (?)	Substrate strength test (?)	5	35
				Friction shape suitable set	2	No	DYNO test	5	70
	Pad and Disc stuck	From out of the vehicle Work in the hill reduced Occurs pyeonjedong Jedonggye damage Due to noise complaints	7	The pH of the upper re–design, inadequate corrosion resistance due to under–nokbalsaeng And the pore and it is increasing the oxygen flow accelerated corrosion	1	Design requirements (?)	Corrosion test MES–A–222–08	5	35
	Drag	Durability under– Due to noise complaints Vehicle braking under–	7	Compressive strain ohseoljeong – Caused by excessive compressive strain	1	Design requirements (?)	Apchukryang Meter MES–4–3–710	5	35
				Inadequate thermal design – Swelling caused by excessive friction at high temperatures	1	Design requirements (?)	Thermal test MES–A–222–08	5	35
		Fires in Brake Systems	10	Friction fire – High temperature during repeated braking, friction fire friction caused by the combustion	1		DYNO test	5	50
				Inadequate thermal design – Swelling caused by excessive friction at high temperatures	1		Thermal test MES–A–222–08	5	50
		Handle driving tremors, body tremors Occurs pyeonjedong		Compressive strain ohseoljeong – Compression deformation due to under–disk contact with the local	2		Apchukryang Meter MES–4–3–710	5	30
				Inadequate design, friction daempingseong – Daempingseong, low disk with a contagious instability	1		FRF measurement (NVH rooms)	5	15
			3	Inadequate abrasive type and size selection – Hardness of materials due to high grinding disc in contact with the local	4		DYNO test	5	60

<Figure 5> Part of FMEA on the Brake Pads



<Figure 6> FTA Diagram for the Braking Noise

Although RPN is not on the high risk side, all precautions have been advised thoroughly. Not many design changes are required immediately but they have to be carefully considered during the new generation product development later on by the Research and Development group. This will help the manufacturer to further improve the reliability of the new generation product in the future by taking into consideration all the suggestions for improvement from the FMEA.

Bottom-up FMEA approach (tabular analysis) and top-down FTA process (graphical analysis) are conducted concurrently to study the failure modes completely in more efficient and effective ways.

FTA identifies the weakness points that contribute to the noise issue of the brake pads via top-down approach. It is recognized as an important tool for evaluating the reliability and safety in system design, development and operation.

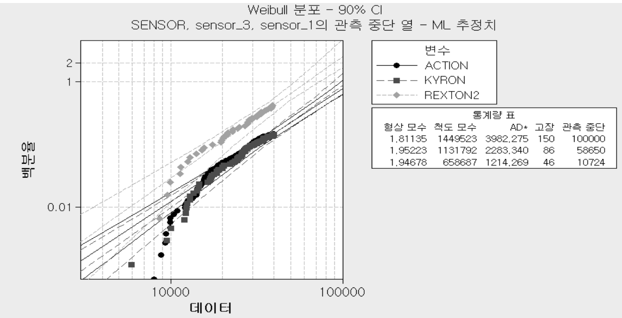
FTA is used for assessment of noise occurrence in the brake pads during operation. It starts from the undesirable event in which the noise is produced by the brake pads. All sequences of fault paths leading to the noise have been traced and the failure rate has been assigned for each fault. From <Figure 6>, fourteen low level events have been identified as the possible contributors to the noise occurrence. Based on the assumption of lowest level event failure rate is 1.0×10^{-5}, the system would produce excessive noise during braking which is considered low with an overall the failure rate of 3.6×10^{-4}.

4.3 Field Failure Data Analysis

The performance excellence of the brake pad consists of infrequent replacement and also being noise-free is the main concern of the customers that have been concluded from the QFD approach in section 4.1. In addition, over 95 percent of the customer claims recorded in the repair report at the service centers is due to noise problems. Thus, noise occurrence has been identified as most important failure to be highlighted.

Minitab is used to select the distribution function that best fits the failure data. Once the reliability modeling is set, the failure rate at any point of time over the life span can be estimated. In this reliability estimation case study, the Weibull distribution is considered to model the failure rate in time.

The assumption has been made that noise occurrence below 1,250 km due to manufacturing process quality issues is excluded. Once the noise occurred and the customer reported to the service centers, the product is considered as a failure. After analyzing the noise occurrence distribution for one of the three models of brake pads with shape parameter is 1.94 which means that higher occurrence rate, the B1 life is estimated at 62,010 km with a 90 percent confidence interval.



<Figure 7> Minitab Analysis for Three Models of Brake Pads

At warranty of 40,000 km suggested by the manufacturer, probability of noise occurrence is less than 0.01 percent. As a result, the brake pads are in very good condition and meet the target reliability that has been set earlier. <Figure 5> shows the results from Minitab analysis for three different car models of brake pads manufactured.

5. Conclusions

DFR has been customized and implemented for a brake pad manufacturer to improve and reestablish its product development plan with proper application of tools, techniques and validation process. Although the implementation of DFR is still rather new to the manufacturer, the multi discipline and cross functional team has successfully delivered the required results after proper training from qualified and experienced trainers. Positive outcomes from the implementation of DFR phase 1 have shown that the brake pad performance and reliability are adequately competitive with the other competitors in the current international market of automotive components. Therefore, it can potentially be one of the major suppliers of brake pads for the main car makers around the globe. From time to time, external and internal audits are required to ensure that the manufacturer complies with the standards in the implementation of the DFR.

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